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Atmospheric Chemistry and Physics Discussions

# *Interactive comment on* "Combustion efficiency and emission factors for US wildfires" *by* S. P. Urbanski

**Anonymous Referee #2**

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The manuscript presents an analysis from three wildfires and one prescribed fire in mixed conifer forest fuels in the northern Rocky Mountains, US. Measurements of CO2, CO, CH4, and H2O were made using CRDS techniques from an airborne platform. This proved to be a unique opportunity to measure biomass burning (BB) emissions from temperate wildfires, as the majority of BB studies in temperate fuels have been made on prescribed fires, which the author suggests may not be representative of emissions from wildfires. Emission factors for CO, CO2, and CH4 are presented along with 14 additional species that were extrapolated using EF-MCE linear relationships from the literature. EFs from this work are compared with EFs from previous field studies of temperate forest fires and from 18 prescribed fires from the literature. A relationship between fuel composition and the modified combustion efficiency (MCE) is observed from a noted decrease in average MCE with the increase in ratio of heavy



fuel consumption to total fuel consumption. This work suggests that EF variability may be strongly influenced by fuel composition. Considering that the majority of fuel consumption by wildfire occurs in the western US and these fuels often have significant accumulation of heavy fuels, low MCE fires (high CWD) and their emissions may best represent many "typical" temperate wildfire emissions. If representative of temperate wildfires, measured and estimated emission factors from this work suggest a large underestimation of wildfire emissions as reported from published BB reviews and inventories that are based on higher MCE fires. This effort is an important step towards improving the accuracy emission inventories and towards maintaining compliance with National Ambient Air Quality Standards. As the author stresses, it is critical that BB inventories and models are "supplied" with the most accurate emission factors possible. This proves difficult because wildfires are difficult to study and wildfire fuel types in the US are numerous and diverse. Devising techniques that acknowledge this and work with these limitations is imperative towards improving the accuracy of current models.

I recommend publication of this manuscript after the author addresses some minor concerns outlined below.

General Comments:

1. The author discusses the shortage of temperate wildfire measurements which are needed for wildfire emissions inventories. A valid point was made in General Comment #4 by Referee 1 and I emphasize it here: Could other literature fires be considered as part of the database on wild forest fires? For example, boreal fires are mostly wildfires and the MCE of boreal forest fires (Akagi et al., studies with an airborne data only, found in supplementary tables) often reflect greater amounts of smoldering combustion compared to temperate prescribed fires. Additionally, in the review of Akagi et al. (2011), their supplementary information provides a breakdown of temperate forest emission factors by fire type and/or fuel type (e.g. temperate wild fire, temperate prescribed fire, understory fuels, organic soils, debris, etc.). While it is true that temperate wildfire measurements are scarce, there exist several options to best estimate temper-

ate wildfire EF. I would be curious to see a comparison in Table 3 including A11 EF averages of ONLY temperate wildfires, or A11 EF airborne averages from boreal fires, with the hope that the ratios of "this study/A11" will be closer to 1.

2. Estimating the contribution of emissions from wildfires is difficult in multiple levels, as the author explores. One difficulty not mentioned in this paper is the trouble in distinguishing a wildfire from a prescribed fire (fire type). For those people who use wildfire emissions inventories, is there a standard method they use to further classify a temperate fire as wild or prescribed? I mention this because this work suggests that temperate BB EF may be the largest source of error in the management of regional air quality. Temperate EF reflecting both prescribed and wild fires may be most appropriate if our current methods of identifying fire type cannot distinguish between the two.

3. A concern I have is that the primary conclusion from the paper, that consumption of heavy fuels favors lower MCE, was not quantitatively supported from data in this work. While the data presented by the author is of great interest to BB and air quality/monitoring communities, the conclusions drawn here are quite broad and need to be limited to what was actually established. Since fuel consumption was not measured for the 4 fires in this work, conclusions should emphasize what was found from these 4 fires, rather than what was found in the 18 fires measured in the literature.

4. My last concern is the representativeness of the small sample size of three wildfires that all occurred in the same state, and in similar fuels. This point was mentioned in General Comment #1 by Referee 1, and I highlight it again here. Temperate wildfires can burn all types of vegetation, from grasses to chaparral shrubs to hardwood forest. While figure 4 shows pretty clear trends between MCEs of SE, SW, NW, and WF, it seems these trends also emphasize the inherent variability of prescribed fires from region to region (SE, SW, NW). We need to consider that the classic "temperate wildfire" MCE may also show similar variability across regions and fuel types, and at this point, it is questionable if there is enough data to say that the three wildfires measured in this work are representative of all US wildfires. While it is true that most wildfires in this



nation occur in the west, I would argue that more than three fires are needed given the large fire-to-fire variability.

Specific comments:

P36, L21: I am not familiar with the Regional Haze Rule, nor Regional Haze Regulations (P36, L14). It may be worthwhile to add a sentence or two detailing what these regulations monitor and/or aim to maintain (e.g. is it PM2.5, BC, NOx, SO2, etc.?) and if the monitored species were measured in this campaign.

P37, L25-28: It would be appropriate to mention the Akagi et al. (2013) study in this discussion. A central question in their work involved the differences in PF emissions resulting from burn history, along with additional factors such as time of year, fuel moisture, fuel composition, and atmospheric conditions, and how these may influence BB emissions. A brief discussion of key findings would strengthen and complete this section on previous work.

P69, Table 1: Consider adding a column for "Fuels" or "Vegetation Type" to give the reader an idea of what CWD (if any) may have been present. Since no measurements of fuel consumption were made and the influence of fuels on MCE is an important conclusion of this paper, any fuels data would be very beneficial here.

P44, L13: Following the format of the proceeding sentences, maybe provide 1 or 2 examples of NMOC that have been linked with both flaming and smoldering combustion (ex. C2H2)

P45, L13-P46, L2: It seems this information may be more appropriate if moved to Sect. 2.1.3 or 2.3.

P47, L16: I would like to see the South Carolina airborne prescribed fire data from Akagi et al. (2013) here. Fuels burned in their study were similar to those from B11.

P48, L8: There are many other factors in addition to time of year that affect fire behavior, as the author mentions. Is there any data on the burn history of the North Fork

Prescribed Fire plot? As noted in Akagi et al. 2013, the burn history (and frequency of burning) may also affect fire behavior. I question whether we can call this prescribed fire a wildfire just because it burned during wildfire season, since this paper aims to distinguish the differences in emissions between the two.

P49, L20: What is the effect of elevation on fires and fire emissions? Is it just used to explain the different types of vegetation?

P51, L11: I would like to see more discussion of the data presented in Table 3. It was mentioned earlier in the paper that EF are inflated by ~5% from using the CMB methodâĂŤ how do the EF from this study compare to A11 or NEI, given this adjustment? Maybe consider adding a column of "adjusted" EF?

P53, L19-20: I am confused about the linkage between fuel moisture and MCE. This work seems to support that low MCE was the result of available CWD, made available by low fuel moisture. This sentence, on the other hand, seems to suggest that MCE tends to increase with decreasing fuel moisture for a constant fuel type and fuel mass (as found by recent laboratory studies). Please clarify this in the text.

P54, L10-14: This was observed in NC and SC in B11 and Akagi et al. (2013), respectively. B11's fires took place in the early spring, and they saw generally higher MCEs for conifer prescribed fires than Akagi et al., who burned under dry conditions during wildfire season and saw relatively lower MCEs than B11. I would add a sentence or two on this to support this speculation.

Technical changes:

P34, L9: Add comma after "decade"?

P34, L9 and P37, L10: Change "has been realized" to "has been made"?

P36, L 15-16: Consider changing "quantifying the contribution of wildfires to O3 related air quality degradation is difficult" to "quantifying the contribution of wildfires to O3 formation is difficult"



P37, L4: Consider "day-time scale" instead of "day time scale"

P39, L22: Consider rephrasing "The Big Salmon Lake fire started, cause undetermined, 16 August 2011". This seems a little choppy.

P40, L10: Change "The Stud Fire which, was also caused by lightning,..." to "The Stud Fire was also caused by lightning and..."

P41, L21: Delete comma after "in-flight"

P42, L24: Delete "a" before "several km"

P43, L7: Change "of compound X, $\Delta$X, was" to "of compound X ($\Delta$X) was"

P43, L15: Change "CH4 to CO2, $\Delta$CH4/$\Delta$CO2, was" to "CH4 to CO2 ($\Delta$CH4/$\Delta$CO2) was"

P43, L17: Change "12 the molar mass" to "12 is the molar mass"

P43, L12-14: Please add a sentence or two on how the two listed Approaches compare in terms of EF (e.g. variability within X%). You may want to move P46, L9-10 here.

P44, L24: Add "Akagi et al., 2013" after "Burling et al., 2011"

P45, L13: Change to "Fire perimeters, areas of active burning, and regions of smoke…"

P45, L13-15: Awkward wording, consider removing "the Saddle Complex on 24 August"?

P45, L18: Do we know if the "pockets of burning" were mostly flaming or smoldering combustion?

P46, L20: Add comma after "previously"

P47, L3: What is meant by "muted"?

P49, L23: Change "involved" to "burned"?

P52, L27-28: Possibly delete this sentence, as this was clearly conveyed earlier in the paragraph

P53, L8: What is meant by “soundness”? I’d clarify this or suggest a different word.

P54, L4: Consider changing “fuel particles” to “fuels”.

P54, L27: Add comma after “Turtle burn”

P57, L12: Delete “and EFCO2”, as it is implied from “lower MCE”?

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Interactive comment on Atmos. Chem. Phys. Discuss., 13, 33, 2013.