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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Spatial and temporal variability in the ratio of trace gases emitted from biomass burning" *by* T. T. van Leeuwen and G. R. van der Werf

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We greatly appreciate the positive, constructive, and thorough reviews of our paper.A new version of our revisited paper is attached as supplement.
Our main changes based on the comments of reviewer 1 are summarized below:

- We shortened Section 2 by 30%.
- We expanded the discussion on the different satellite-derived products we used.
- We expanded the discussion on the different correlations we found for the whole emission factor (EF) dataset, compared to results from individual studies.

- We changed Figure 3, and quantified the amount of emissions and EF measurements in peak fire month and the shoulder of the fire season.

Please find a detailed response for reviewer 1 below.

Kind regards,

Thijs van Leeuwen

General comments

1) The manuscript is well written and fairly concise, though the introduction/section 2 could be shortened somewhat by removing the fairly detailed description of the combustion processes. Some discussion of why certain satellite-derived products may do a better job in explaining changes in EF compared to others and/or why they do well in certain regions might be a better use of the space.

This comment overlaps with comment 21 from reviewer 2. We have compressed section 2 by 30%.
Furthermore we extended the discussion on the different satellite-derived products we use in Section 4.1, lines 592-604:
"Monthly averages of coarse-resolution (regridded to 0.5°×0.5°) data were used to assess fire emissions, fraction tree cover, precipitation, temperature, NDVI, and the length of the dry season for the different EF measurement locations. The use of spatially and temporal higher resolution data is preferred over lower resolution data, but detailed information on the location and date of the measurements was often lacking. Even if detailed information was given, a large number of EF measurements were conducted in the 1980s and early 1990s, for which period global datasets are often lacking at sufficient high resolution. Also in more recent periods data availability would limit more detailed analyses: while FTC is available at 500-meter resolution, it is only available

for the year 2002. And since fires likely impact FTC a multi-year product is required for consistency, so that –for example- each EF measurement can be linked to the FTC before the fire. Here we have not included uncertainties in these environmental parameters because they have not undergone an official error assessment, with the exception of the precipitation data."

We found the highest correlations between EF variability and FTC, and added two sentences in lines 465-469 to discuss this:

"In general, the highest correlations were found for FTC, which is not surprising since and this parameter covers the range from open grasslands, through savanna and woodlands, through tropical forest. Also, within biomes, FTC could explain part of the EF variability."

2) Combustion efficiency vs. burning efficiency: are these the same thing or does CE refer to something more specific. A line of clarification would be helpful for the reader or else CE should be used throughout.

With "burning efficiency" we meant the "combustion efficiency". To not confuse the reader, we will use the term "combustion efficiency" throughout the paper. In lines 168-171 we defined the combustion efficiency:

"The amount of substances emitted from a given fire and their relative proportions are determined to a large extent by the ratio of flaming to smoldering combustion, which is related to the combustion efficiency (CE), defined as the fraction of the fuel C burned converted to CO_2."

3) The decision to exclude laboratory measurements is defendable, however there should also be some caveats given for ground- and aircraft-based measurements, too. Ground-based measurements can be biased towards the smoldering-phase combustion products while aircraft-based measurements can be biased towards the flaming-phase emissions (e.g., Yokelson 2008). These effects can be partially offset by consid-

ering the measured CE or MCE, however they do not necessarily mean the measurements represent the climatic 'norms' for different fire-influenced regions.

In section 4.3 we present several caveats for the use of ground-based and airborne measurements:

"Ground-based sampling probably oversamples the emissions which tend to be emitted during less vigorous phases of a fire and therefore remain closer to the ground, while airborne sampling may be biased towards emissions from the flaming phase that rise to higher altitudes (Andreae et al., 1996; Yokelson et al., 2008). Airborne measurements of chapparral vegetation in California (Laursen et al., 1992) were for example compared to ground-based measurements of the same vegetation type (Ward and Hardy, 1989), with overall lower EFs for CO (18%) and CH4 (60%), and higher CO2 (5%) due to the bias towards the flaming phase. Yokelson et al. (2008) performed a similar analysis for tropical forest fires, and also found lower EFs of CO and CH4 for airborne measurements." (lines 632-640).

Specific comments

4) 60 (4-5): As written, the statement "the partitioning of biomass burned into emitted....has received relatively little attention" is a little misleading, since there are at least 30 years of emission measurements available in the literature. Do the authors mean studies specific to burned area-derived products

The statement, as written, may be a little misleading indeed, and therefore we changed the sentence to emphasize that not the partitioning of biomass burned, but the spatial and temporal variability in the partitioning of biomass burned has relatively received little attention:

"The spatial and temporal variability in the partitioning of biomass burned into emitted trace gases and aerosols, however, has received relatively little attention." (lines 13-15).

4) 60 (18): "less satisfying" lower?

We changed "less satisfying" into "lower" (line 27).

6) 61 (18): suggest changing "amount of gas" to "amount of gas or particle mass" to include aerosol emissions.

We changed "amount of gas" into "amount of gas or particle mass" (lines 55-56).

7) 61 (26): Please provide a reference for SAFARI-2000.

The overview paper of Swap et al. (2002) was added as a reference for the SAFARI 2000 campaign (line 63), and we deleted the Andreae et al., 1996a reference ("Andreae et al., 1996b" now becomes "Andreae et al., 1996").

8) 63 (15-17): The final sentence of the paragraph is a little vague. Something describing factors that might affect the representativeness of the EF (i.e., are the fires representative of typical conditions?) would aid planning of future field measurements.

To make this sentence clearer, we added "of a specific vegetation type" in lines 111-112.

9) 63 (27): MCE also has some predictive use for certain aerosol species and characteristics (e.g., Christian et al., 2003; McMeeking et al., 2009; Janhall et al., 2010 and earlier work by Ward, Hardy and others)

We changed the specific sentence into:
"However, since the Modified Combustion Efficiency (MCE, defined as the amount of C released as CO_2 divided by the amount of C released as CO_2 plus CO (Yokelson et al., 1996)) has been used as an effective predictor for the emission of smoke gas composition from biomass fires (e.g., Ward et al., 1996; Sinha et al., 2003; Yokelson

et al., 2003) and for certain aerosol species and characteristics (e.g., Christian et al., 2003; McMeeking et al., 2009; Janhäll et al., 2010), our findings on CO and CO_2 EFs can be used to better understand emissions of other trace gases and aerosols as well." (lines 125-131).

10) 65 (2): start = starts, Section 2.1: Should explicitly state somewhere in this section that in most fires all of these processes occur simultaneously in different parts of the fuel bed.

We changed "starts" into "start" (line 139), and added the following sentence in lines 164-165:
"The combustion processes described above are somewhat simplified, and in most fires all of these processes occur simultaneously in different parts of the fuel bed."

11) 66 (22): vegetations' → vegetation's

Due to the shortening of section 2.2 (see comment 1) this line was deleted.

12) 69 (4): Please provide the date of the most recent result that was compiled into the annually updated of the A&M inventory.

The most recent result that was compiled into the annually update of the A&M inventory was a study of Yokelson et al., 2009. In the text we give the following reference for the updated version in lines 78-80:
"The database is updated annually (Andreae, personal communication, 2009) and we will refer to this as A&M2001-2009 in the remainder of this paper."

13) 69 (17): "specie" to "species"

We changed "specie" into "species" (line 241).

14) 69 (21): does any literature give estimates of the range of fuel C for different ecosystems? This would help constrain the uncertainties in the study. Converting from g kg DM to g kg C emitted would eliminate this source of variability

A detailed study of Susott et al. (1996) suggests a global average C fraction for biomass closer to 50%, but with a considerable range. Therefore we added the following sentence in lines 245-247:
" However, a detailed study of Susott et al. (1996) suggests a global average C fraction for biomass closer to 50%, with a considerable range, which would indicate an additional 10% uncertainty in addition to other uncertainties."

15. 70 (22-23): slightly unclear. Suggest adding "has relatively high rates of emissions of reduced gases compared to sampled regions;. . .".

Following the reviewer's suggestion we added:
"has relatively high rates of emissions of reduced gases compared to sampled regions." (lines 277-278).

16) 71 (7-13): How do these values compare to correlations observed in a couple different field studies or individual fires? This would give some idea of how tight a correlation one would expect for a relatively simple situation.

We examined our results further by comparing the correlation coefficients and slopes of the regression for different biomes with findings from other individual studies in lines 300-322:
"Although lowering the number of EF studies in general decreases the correlation coefficient, several individual studies focusing on a selected number of measurements found higher correlation coefficients than the ones reported above. Yokelson et al. (2003) found a correlation coefficient of -0.93 (EF(CH4) = -48.522 $\times$ MCE + 47.801) for 8 African savanna fires. Korontzi et al. (2003) also found higher correlations and a slightly different slope for the regression of southern African savanna measurements

- grasslands had a correlation of 0.94 (EF(CH4) = -43.63 $\times$ MCE + 42.951) and for woodlands a correlation of 0.98 (EF(CH4) = -58.214 $\times$ MCE + 56.710) was found. Both vegetation types combined gave an overall correlation of 0.94, and a trendline of EF(CH4) = -47.948 $\times$ MCE + 47.068. For the tropical forest biome, Yokelson et al. (2008) found a correlation coefficient of 0.72 for 9 fire-averaged MCEs and CH4 EFs. The slope of this regression was significantly more gentle (EF(CH4) = -47.105 $\times$ MCE + 48.555) than the slope for this biome using all measurements in the AM2001-2009 database. In older work, comparisons between the CE (which correlates well with the MCE) and CH4 EFs was presented. Ward et al. (1992) showed a correlation of 0.96 and a slope of EF(CH4) = -82.1 $\times$ CE + 78.6 for a regression of 18 deforestation fires in Brazil. We are not aware of any recent comparisons between MCE and EF CH4 for fires in the extratropical forest biome, but in older work of e.g. Ward Hardy (1991) and Hao and Ward (1993), an overall higher correlation (r>0.8) is found for extratropical forest measurements. The slope of the regression lines of these individual studies was more gentle than the slope we found for the whole dataset. Lab experiments (Christian et al., 2003; McMeeking et al., 2009; Burling et al., 2010) also show overall higher correlations between MCE and EF CH4 than our results for all data for the different vegetation biomes combined."
We then summarized these findings as follows in lines 323-333:
"Overall, higher correlation coefficients and flatter slopes for the EF CH4 and MCE relationship were found for individual studies focusing on a relatively small number of EF measurements, compared to the whole EF database of AM2001-2009. Possible explainations for these differences between the whole dataset compared to individual studies are discussed in section 4. Individual studies (e.g. Hao and Ward, 1993) have shown that the linear relationships between the MCE and EF of CH4 are quite different for individual biomes, for reasons not fully understood. This is also apparent from Figure 2; the slope and intercept of the savanna and extropical forest biome compare very well, but the regression line of CH4 EFs and their MCE derived for tropical forest biome shows a steeper slope and larger intercept. Most variation and therefore lower

overall correlation coefficient was caused by the extratropical forest measurements."

17) 72 (21): Can a quantitative example estimate be provided here? For example 20% of annual emissions. . .40%?

It is important to quantify the emissions in the shoulder of the season, and to compare this to the emissions in the peak fire month(s). We changed Figure 3 to further highlight this and make the figure easier to interpret, and now show the GFED3.1 fire emissions for the peak fire month (PFM) and the shoulder of the fire season for the savanna (Figure 3a) and tropical forest (Figure 3b) biome. The number of EF measurements for both biomes in these specific months is also shown.
In lines 347-363 we quantify the emissions in the PFM and outside the PFM for the savanna and tropical forest biome, and address the questions that are posed by the reviewer: "We explored the seasonal variation of the fire emissions for all EF data where a detailed description of the location and date of measurements was provided. To investigate whether the available measurements captured the fire seasonality we compared the number of EF measurements conducted in a specific biome with the seasonal variation in C emissions according to GFED3.1 (Figure 3). Only the $0.5^{\circ}\times0.5^{\circ}$ grid cells enclosing the locations where EF measurements were conducted for CO, CH4, and CO2 were used, and the seasonal cycle in each grid cell was normalized to its peak fire month (PFM). Figure 3a shows the seasonality of the number of EF measurements and the GFED3.1 fire emissions for all the EF measurement locations in the savanna and grassland biome for the PFM, and the months before and after the PFM. Results for the tropical forest biome are shown in Figure 3b. For EF measurement locations in the savanna biome, 46% of the total annual amount of C was emitted by fires in the PFM, and 78% when also including the month before and after the PFM. For the tropical forest biome, this was 66% and 84%, respectively. The percentage of EF measurements conducted in the PFM was 23% for both the savanna and tropical forest biome, and respectively 71% and 88% when also including the month before and after the PFM. In other words, the current body of measurements have undersampled the

peak fire month with especially the tropical forest fire measurements sampling earlier than desirable."
We added the new Figure 3 in the supplement.

18) 72 (26): "right month of the year" is contradicts the earlier statement "ideally, EFs are thus measured during both peak and shoulder of the season", making it sound like there is a "correct" period to measure fires despite the argument that measurements are also needed in the shoulder of the season. Suggest this be changed from "right" to "peak" month of the year?

This part of the text has been deleted.

19) 72 (27-30): Please provide a reference describing the extra-tropical seasonal cycle.

We added the paper of Giglio et al., 2006 in lines 364-365:
"Extratropical forest measurements were excluded from this analysis, because the fire season is much more variable from year to year compared to the tropics (Giglio et al., 2006)."

20) 79 (5-10): Yokelson et al. (ACP, 2008) performed a similar analysis for TROFFEE which may be more appropriate to refer to since they focused on tropical fires, which are more relevant to this study compared to chaparral fires.

We added the following sentence in lines 642-643:
"Yokelson et al. (2008) performed a similar analysis for tropical forest fires, and also found lower EFs of CO and CH4 for airborne measurements."

21) 80 (2): analystical? Should this be analytical or statistical?

It should be "analytical". We changed this in the text (line 652).

Tables and Figures

22) Table 2: Minor point, but acronyms in the left-most column could be replaced with full text descriptions (to avoid having to refer to the caption). Please provide units. Are the AM2001 and updated results combined? It would be interesting to see how they have changed.

We changed the acronyms with full text descriptions (see Table 2).
Units were provided in the caption (line 1130): "EFs of CO, CH4, CO2 (in g/kg DM), and MCE. . ." and in the Table itself.
The AM2001-2009 data are used here. We made this clearer by adding the following sentence in the caption (lines 1134-1135):
"Biome-averaged arithmetic means of AM2001-2009 are also shown (AM2001-2009), with standard deviations in parenthesis."
Furthermore we expanded our analysis and now also show biome-averaged EFs of CO, CH4, CO2 (in g/kg DM) and MCE, using different environmental parameters combined, in Table 2.

23) General comment on figures: The figures would be clearer/easier to interpret if the color scheme for savanna/tropical/extratropical was consistent across all of the figures. The current draft has savanna as purple in Fig. 1, green in Fig. 2, and blue in Fig. 3.

To be consistent we now use the same color scheme for all relevant figures. Savanna/Grasslands =green, Tropical Forest = red, Extratropical Forest = blue.

24) Figure 1: Please give units on the color scale in the plot as well as the caption.

We added units on the color scale in the plot as well as the caption.

25) Figure 2: Please provide the coefficients of the regressions somewhere on the plot or else at least refer to where in the text (or what table) they are provided.

In the caption of Figure 2 (lines 1160-1161), we refer to the section in the text where the regression coefficients can be found:
"Regression coefficients for the different biomes can be found in the text (Section 3.2, lines 292-299)."

26) Figure 3: Change symbols from crosses to circles and remove shadows. X-axis labeling is a little confusing. It might be more clear if the label was changed from "month" to "Time from month of maximum burning (months)"

We changed Figure 3 to make it easier to interpret, and now show the GFED3.1 fire emissions for the peak fire month (PFM) and the shoulder of the fire season for the savanna (Figure 3a) and tropical forest (Figure 3b) biome. The number of EF measurements for both biomes in these specific months is also shown.
We added the new Figure 3 in the supplement.

27) Figure 5: Black symbols are difficult to see on the red color background and the plot is too small. Might be easier to see colored symbols on grayscale. Please provide a legend describing the different symbols on one of the plots and label one of the color scales. Change 1e10 g to 10 Gg in the caption. Why not average temperature and precipitation over the same period as the fire emissions (or at least do it between 1997-2008 if 2009 data are unavailable.

Following the reviewer's suggestions, we plotted the GFED emissions in grayscale and changed the black symbols into green, red, and blue colors for EF measurement locations in the savanna, tropical forest, and the extratropical forest biome, respectively. Further we changed "1e10 g" into "Tg" in the caption (line 1178), and used an average temperature and precipitation over the same period as the fire emissions (1997-2008). We added the new Figure 5 in the supplement.

Please also note the supplement to this comment:

http://www.atmos-chem-phys-discuss.net/10/C14139/2011/acpd-10-C14139-2011-supplement.pdf

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 23559, 2010.

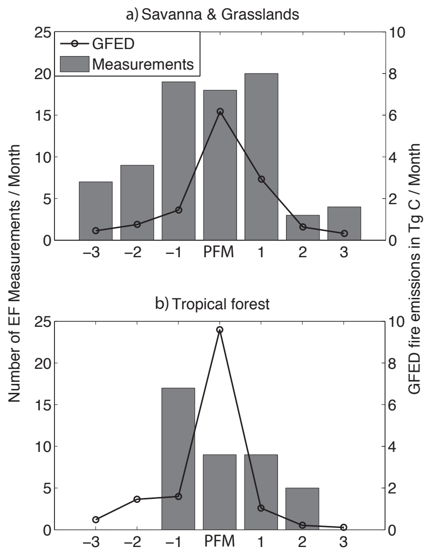

Fig. 1. Figure 3:Figure 3: Number of EF measurements (bar) and GFED3.1 fire emissions (line) in Tg C for the peak fire month (PFM), and the months before and after the PFM, for all EF measurement locations in

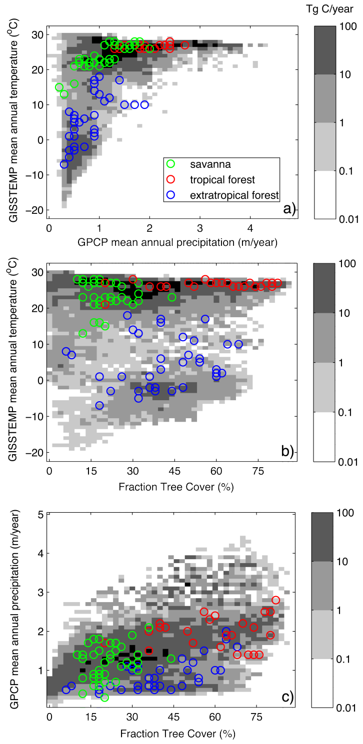

Fig. 2. Figure 5:Figure 5: GFED3.1 fire emissions in Tg C/year (mean for 1997-2008) in a temperature –precipitation (a), temperature – fraction tree cover (b), and precipitation – fraction tree cover (c) win

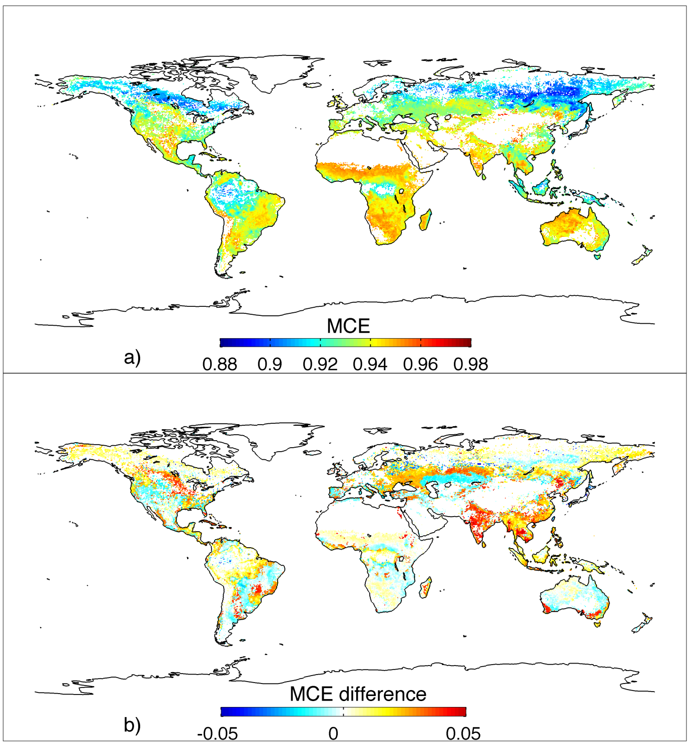

Fig. 3. Figure 6:Figure 6. a) MCE based on a multivariate regression equation that combined different environmental parameters (see Section 3.5), with a spatial resoltution of 0.5°×0.5° and weighted by the am