

***Interactive comment on “Field determination of biomass burning emission ratios and factors via open-path FTIR spectroscopy and fire radiative power assessment: headfire, backfire and residual smouldering combustion in African savannahs” by M. J. Wooster et al.***

**M. J. Wooster et al.**

martin.wooster@kcl.ac.uk

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We would like to thank Prof. Yokelson for his extremely careful review of our paper and for his +ve comments. He has highlighted many points of interest that we had not anticipated fully, and also areas where we needed to provide more clarity. We have been through each point - and adjusted items accordingly.

We have adjusted the introduction to focus on the points suggested by the Referee.

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We have changed combustion “phases” to “processes” as suggested, and make clear that the ‘stages’ we are referring to are the headfire, backfire, and RSC individual stages (which indeed may well occur separate from one another in time; unlike the phases).

We state that “Delmas et al. (1995) and Keene et al. (2006) show that CO<sub>2</sub> and CO account for a median of 99% of carbon emitted from southern African savannah fires. We cannot give a standard deviation as we don’t have this measure.

We have made it clear who is suggesting the ER of ammonia is overestimated (Sinha et al., 2003)

“EO” changed to “remotely sensed” throughout

We have reworded the abstract to make it clear that airborne FRP data was required to derive the ‘fire averaged’ ER and EF measures from the FTIR measurements.

We have updated the paper with reference to the recent emissions factor database of Akagi et al. (2011) - in both text and Tables.

GFEDv3 reference used in place of GFEDv2

Specific Points (Page and Line)

P32, L26 We are careful not to overstate the current abilities of satellite-derived fuel consumption estimates based on FRP observations. In the previous lines we say that fuel consumption is most commonly derived from burned area measures, but go onto say that FRP observations can be of use - particularly in the type of scenario listed. All are currently operating methods - rather than vague statements about future capabilities.

P33, L8-9 We make reference to the Bertschi et al (2003) study, and elsewhere we now include the suggestion that the targeting of RSC emissions is an ideal application for this system.

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P33, L11-12 - We are here referring to the maturity of burned area and FRP estimates, rather than emissions estimates.

P33, L22 - As suggested, we have included reference to studies showing the wide range of emissions factors with MCE.

P34, L2-6. As suggested we have included the application to RSC emissions and fuel consumption estimates in the abstract and introduction.

P34, L16-18 We have reduced reference to Fenandez Gomez et al (2010) as suggested

P34, L23 - we change "demonstrate" to "confirm" and reference Griffith et al. (1991) as suggested

P35, L4-5 - we make clear that we include both arid and humid savannahs in our estimate that southern African savannah burning is responsible for perhaps 25% of global fire emissions.

P35, L13-16 - we have included the statement that the carbon mass balance approach should also be used in laboratory studies due to the evaporation of fuel moisture

P35 L23-24 we have removed reference to logistics and costs

P37, L14 - we removed the word "substantial" in accordance with the suggestion

P37, L21-22 We have defined wavenumber range now

P38, L11 we have changed "stacked" to "averaged"

P39, L5-6: We now define our stages more clearly in Section 3.1. In fact we define RSC as being the period of combustion after the fire front has ceased spreading - mean

P39, L25 We now discuss the fact that the algorithm can be initialised with two layers having different temperatures for different parts of the path - in Section 3.4.4

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P40, L4-8. We have made the differences we found with HITRAN 1996 vs 2008 clearer.

P40, L9 We have made it clear that the retrieval approach used here can cope with different temperatures along the path - we discuss this in Section 3.4.4.

P40, L25-26 Phases changed to processes

P42, L22: We do not find problems with obtaining a non-contaminated background measurement of the smoke, but we don't find it necessary to calculate the emission ratios (as detailed in the paper).

P43, L10-12: We do use column amounts - so subtracting the pre-fire amount is incorrect. Nevertheless, testing indicates that the results are almost identical to when the column amounts are converted to path average mixing ratios and then the background mixing ratios subtracted

P44, L19-21 We divide the activity into headfire, backfire and RSC activity based on a combination of field observer and the airborne optical/thermal video records. We don't use the FRP data to identify flaming vs smouldering combustion - rather the "backfire" stage is classified as that where only the backfire was burning, the "headfire" stage is classified as that after headfire ignition (which burned much quicker than the backfire and thus whose emissions dominate the record when both the headfire and backfire were burning simultaneously), and "RSC" which is defined as when all flaming combustion has ceased (i.e. after the plot has been completely burned out, with no flaming activity observable). This is now made clearer in Section 3.1 P45, L16-18 We now include the fact that CH<sub>4</sub> was also included in the summation to get 99% of carbon emissions.

P45, L18-19 We have corrected the statement that "the majority of the remaining C is emitted as aerosols" and instead refer to NMHC and aerosols as suggested. We give the Akagi et al. (2011) paper as reference as suggested.

P48, L17-26: We now include comparison of our RSC results to those of RSC results

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of Bertschi et al (2003) Table 3 and Christian et al. (2007) Table 3 and Figure 2 as suggested (we do this at the end of Section 4.2). We also compare the emissions factors in the following section.

P48, L23-26 We have removed reference to a pyrolysis "phase" and to Koppman et al (2005) and instead reference Yokelson et al. 1996 and explain that the absence of large amounts of flaming combustion in the RSC stage is interpreted to have reduced pyrolysis and thus production of CH<sub>2</sub>O.

We now make reference to the extensive measurements of smoldering dung reported in Christian et al. (2007), which confirm those of Keene et al. (2006) already reported. P50, L10: "wildfires" changed to "unplanned grass fires" as suggested

P52, L1-12: This is a good point (that for our stages where EF<sub>CO</sub> matches that of Sinha et al (2003) the EF<sub>NH3</sub> is also in quite good agreement - possibly pointing towards the cause being the different elevations of the smoke sampled. We have now included this in the discussion of the EF<sub>NH3</sub> values, and also the discussion of the effect of smoldering dung on this EF.

P53 L3-5. and L53 L7-12 We have checked all Tabulated values carefully to ensure they are correct. There is a disagreement between the MCE values quoted in the text for Fire 1 and the ER<sub>CO</sub>/CO<sub>2</sub> values shown in Table 3 - because in the text we were quoting instantaneous MCE values derived from each spectral measurement via Equation (7) of the paper (the results of this calculation are also shown in Figure 6 last plate) and then averaged to give a single MCE value for a particular fire Stage, whereas the ER<sub>CO</sub>/CO<sub>2</sub> quoted in Table 3 are derived from a single linear eqn fit to scatterplots of many measurements (as shown e.g. in Figure 7). As can be seen - there are many points in the RSC stage scatterplot (Figure 7 top row) that are at the lower end of the scatterplot (i.e. low pathlength amount points), and fewer points at the high end. Such scatterplot-derived relationships can put greater weight on the individual "high end" points than would come from a simple average of the MCE values derived from

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each point (e.g. due to 'high leverage' points). If we instead derive the MCE values for each stage from the stage-specific ER<sub>CO</sub>/CO<sub>2</sub> values quoted in the table using Equation (8) - we get MCE values that vary in the way expected for Fire 1 from the corresponding ER<sub>CO</sub>/CO<sub>2</sub> values quoted in Table 3; i.e. as ER<sub>CO</sub>/CO<sub>2</sub> rises the MCE falls, and visa versa. However, conversely, for Fire 3 the MCE values agree with each other whichever way the MCE is calculated, due to there being fewer 'high leverage' points. The referee's comment remains appropriate though, that for e.g. Fire 3 - whilst ER<sub>CO</sub>/CO<sub>2</sub> changes quite a lot between the headfire and the RSC stage (by ~ 40%) the max BT and mean BT measures do not. Therefore our results seem to suggest that using remotely sensed fire temperatures to estimate MCE or ER<sub>CO</sub>/CO<sub>2</sub> maybe fraught with problems. This is now included in the text, and the conclusion/abstract.

P54, L15 - as suggested we now mention coarse woody debris in addition to organic litter and soil layers

P55, L11-12 We have altered the text to indicate both the limitations and advantages of this technique in relation to "unplanned" fires - as suggested by the referee

P55, L23-25 We have adjusted the text as suggested to summarise that we find a lower MCE than Sinha and higher EF for species associated with lower MCE - and this indicates that different smoke that tends to be probed from the two vantage points.

P56, L9 - deleted as per referee's suggestion

Table 1: Lat/Lon locations added to table (dates are in the caption)

Table 3: All values checked. Fire 1 CO/CO<sub>2</sub> ratio is somewhat unusual - and we discuss this in the main text.

Table 3: Comparison to Bertschi et al. (2003) now included.

Fig 2 Caption: It is true that at the 1km pixel scale, active combustion is occurring over an area far smaller than the pixel - probably < 1%. The MIR radiance method of FRP derivation (Wooster et al., 2003) used in the paper is not sensitive to the sub-pixel na-

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ture of the fire however, and the lowering radiance with increased pixel size therefore has no -ve impact on FRP derivation - provided the BT of the pixel is sufficiently elevated for it to be detected as an active fire pixel (and thus have its FRP assessed on the basis of its pixel signal increase above the ambient background). The fires conducted in this paper reached FRP's of many 10's of MW (see time-series of Figure 5), which would be easily detected by the spaceborne MODIS sensor since it can detect fires with FRP's of > 8 MW when imaged at nadir. Of course, the sensor would need to be passing over the area at the time of the fire. This FRP could be converted into an estimate of fuel consumption rate (not fuel consumption total), in units of kg s<sup>-1</sup> using the relationships shown in Wooster et al. (2005). [both papers are referenced in the manuscript]

Fig 5 In the main text (Section 4.1 and 4.4) we now note that the FRP and MCE data indicate that the spatial extent of the fire appears to affect FRP much more than MCE, as suggested by the referee.

Fig 8 - the convection column, such as it is, is shown in Figure 2. We now use Figure 2 to estimate the height of the main column above the plot as  $\sim 50$  m - from the shadow of the plume on the ground surface, which is far less than the plumes studied using airborne FTIR by Sinha et al. (2003) and which were reportedly sampled at  $\sim 500$  m height. The difference probably results from the relatively small 7ha size of the experimental burn plots sampled in the current experiment compared to the much larger fires whose plumes were sampled in the airborne experiment.

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