Interactive comment on “Interannual variability of global biomass burning emissions from 1997 to 2004” by G. R. van der Werf et al.

G. R. van der Werf et al.

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We thank Eric Kasischke (hereafter called “the referee”) for his thorough and useful review of our paper. The referee raises several issues which we will briefly address below. These changes will be incorporated in the final version of the paper, unless stated otherwise.

Concern 2.1.1: The referee noticed that the data used in Figure 10a is about twice as high as it should be. Actually, it is exactly twice as high as the data reported by the CIFFC due to a miscalculation on our part which has no further implications for our estimates but does have implications for the comparison. The correct data is given below (Table 1) and indicates that our burned area data matches the CIFFC reported data more closely for the pre-MODIS era.
Concern 2.1.2: The referee suggests that we miscalculated the total burned area in the two boreal regions in Table 5. However, the data reported in Table 5 (column “total area”) is the total surface area of the region, not the burned area. We will add a footnote to prevent further misunderstanding; see updated Table 5.

The referee also expresses his concern of using ATSR fire hot spots (Arino et al., 1999) because of sampling issues in high northern regions where the ATSR algorithm may not work properly. The ATSR algorithm is based on nighttime observation while in these regions there may be daylight at the time of overpass. Also, the referee mentions that the relationship between burned area and fire hot spots may vary between years (Kasischke et al., 2003).

Although we recognize the problems when using ATSR fire hot spots (we will state this more clearly in the paper), we believe that on larger spatial scales the ATSR product simulates the seasonal fire cycle reasonably well as shown in Table 2, where ATSR is compared to MODIS active fires (Giglio et al., 2003), the latter being considered the most reliable fire hot spot dataset currently available. In the period when both sensors overlap, the products identified the same month as the peak month.

With regard to IAV in fire activity, Table 2 shows that ATSR captures the same IAV as the MODIS sensor, however with a somewhat higher ratio in extreme fire years, as shown before in Kasischke et al. (2003). Although this may introduce a bias, our approach does simulate the same IAV as independent estimates in boreal North America for the period where we used ATSR to scale the MODIS burned area back in time (during 1997 – 2000, see Table 1).

Concern 2.2: Use of the term “soil organic carbon (SOC)”. We appreciate the remark that our terminology could be clearer. In the revised version we will accept the suggestions of the referee, and consistently use “organic soil layer” and “peat” instead
Concern 2.3: Estimating carbon release and emissions from the burning of surface organic layer fuels. Let us start with clarifying our approach which may answer some of the questions raised by the referee:

- We adjusted the turnover times in the CASA framework of slowly decaying soil carbon pools (passive pools, which are part of the organic soil layer which is represented in CASA by the surface and soil litter carbon pools) so that the CASA estimates of total soil and surface carbon in boreal and peat regions matched measured values from Batjes (1996). Within the CASA framework, the spatial variability of soil carbon is a function of local NPP and decomposition rates, with turnover times for different soil carbon pools scaled by monthly temperature and soil moisture. We used the Batjes (1996) database to validate the CASA values and adjust the rate constant where necessary to match observations.

- We assumed that the deeper carbon in CASA (passive pools) is only available as fuel in grid cells that were classified as wetlands which we assumed to represent peatlands (Matthews and Fung, 1987). In other (boreal) grid cells, only the carbon stored in the upper layer (represented in CASA by the surface and active soil pools) was allowed to burn.

- Maximum depth of burning was set using literature values: in the boreal the maximum depth was 10 cm (Kasischke et al., 2005, and references therein), in the tropical peat areas the depth was set to the maximum soil depth in CASA, 30 cm (but may burn even deeper according to Page et al. (2002)).

- Not all of the organic soil layer burns in a fire; usually the late season fires burn deeper than early season fires because the soil has dried out more (Kasischke et al., 2005). The moisture scalar was used to simulate this effect; only when
the soil was dry would the fires burn to the maximum depth (see above). In the tropical peat areas the fires were assumed to always burn for 50% or 15 cm to represent human induced drainage of peatlands (Page et al., 2002), and the moisture scalar determined how much of the remainder could burn.

- We assumed that the carbon density did not change with depth. Even though several field studies have shown how the carbon density increases with depth, we feel that these studies are not yet sufficiently spatially representative to be included in a global model study. To see whether our assumption was valid, we used the carbon density profile from Carrasco et al. (2006) to see what the depth of burning would be when we would combine our modeled organic soil layer consumption with the Carrasco et al. (2006) carbon density profile. The outcome is shown in Figure 3 in the paper and agrees to a large extent with measured values, burning mostly up to 10 cm into the organic soil layer with some higher values in peat areas.

We will expand the description of our approach in the paper based on the text above to make it clearer.

Referee: “In addition, I do not see how the use of a soil moisture scalar captures the complexity of variations in moisture of surface fuels in boreal regions.”

Response: Although the moisture regime in the boreal region is certainly complex, its first order controls are precipitation and evapotranspiration. We have attempted to include this using the CASA model moisture scalar which is based on precipitation and evapotranspiration. The CASA moisture scalar was used to scale the depth of burning into the organic soil layers and peat. This approach produces plausible seasonal variability in burning depth. While not representing certain underlying processes explicitly, we feel that using a moisture scalar that is dependent on data available globally (temperature, precipitation) is an improvement over assuming constant burning depth.
Improving the representation of hydrological processes is an ongoing effort within our group. We will include a statement of our neglect of permafrost-moisture interactions and strive to include these in future development of the model.

Referee: “Finally, the authors choose not to consider the fact that most of the consumption of surface organic layer fuels occurs during smoldering consumption (Kasischke et al., 2005), and use a single set of emission factors to estimate trace gas emissions during fires in boreal regions. Because of this, they probably underestimate emissions of CO and CH$_4$ in this region considerably.”

Response: We have used different emission factors for savannas, tropical forest, and boreal forests based on a review study by Andreae and Merlet (2001). These emission factors are averages from several studies, measuring all stages of a fire and, therefore, include some influence from the smoldering stage of fires. We discuss possible variability in emission factors in Section 2.5 but do not attempt to capture the seasonal dynamics of emission factors in our model yet because of a lack of parameterization data. We will include a statement in the paper that reiterates this. In the future we hope to implement more detailed representations as the model improves and more data will be available for parameterizing such representations.

Referee: “However, the approach being developed lacks any connection to numerous field-based studies of surface fuel consumption outside of Page et al. (2002).”

Response: The organic soil carbon content of our model is based on numerous field studies, compiled by Batjes (1996), and the maximum depth of burning in the boreal region is derived from Kasischke et al. (2005) who cites several field studies that examined depth of burning in various forest types. Furthermore, we have provided substantial information enabling comparisons, including figures of the depth of burning in the boreal region and a fuel consumption histogram for boreal North America.
Concern 2.4: Comparison of results with other studies. The referee mentions that comparisons against other studies are hindered by the lack of data presented. We note here that we provide all data layers used in this study to the public, so detailed comparisons for any region are possible. As mentioned in the article, anyone who would like to use our data may download gridded burned area, fuel loads, combustion completeness, emissions, etc. (available at http://www.ess.uci.edu/~jranders/). We will, however, add the suggested burned area table with the same format as Table 6 to better facilitate comparison (see new Table 7). We will also change Table 5 in the text to so that it includes fire emissions per m$^2$ burned, again facilitating comparisons (see updated Table 5). We are hesitant to add an additional significant digit to the entries in Table 6 as requested by the referee as this would suggest a higher accuracy than we can deliver.

Minor comments:

1. We will add the Hess et al. (2001) reference to the references already in place.

2. We will replace the URL with the Stocks et al. (2002) reference.

3. We have chosen to simultaneously use kg m$^{-2}$ and g m$^{-2}$ because of the large range of fuel consumption between various biomes. The prefix ‘k’ is not a different unit but a way to easier interpret larger numbers, as used in this paper.

4. We will add the French et al. (2004) reference, as well as Hoelzemann et al. (2004).

5. We will change the last sentence to clarify how these plots relate to estimation of uncertainty. Last sentence: “The histograms in Fig. 11 illustrate the modeled relationship between burned area, fuel consumption and vegetation type.”
This regionally dependent behavior of the global model is consistent with the results from regional fuel models (Amiro et al., 2001; Hély et al., 2003). As more field measurement of fuel loads become available the validity of these responses can be evaluated. We feel the histograms are meaningful in that they illustrate the modeled relationship between burned area, fuel consumption and vegetation type as we discuss in Section 3.4. The plots also show that the global model produces plausible results similar to regional models such as Amiro et al. (2001) whose model was developed and run using more local information. This gives use some confidence that our results are consistent with these regional studies that are more locally constrained (meteorology, fine spatial resolution data, calibration sites, experiential constraints).

6. We will change *JGR-Biosphere* to *JGR-Biogeosciences*.

In summary, the referee points out potential important processes that we do not explicitly treat in our model. Every model is built on assumptions and simplifications because process understanding and observational data for calibration and validation are lacking or insufficient. We will include statements in our paper that mention those processes thought to be important in boreal fires but that we do not explicitly account for. We take heart in fact that our results are comparable to other independent region specific studies and produce atmospheric signals consistent with atmospheric inversions. We will continue to develop and improve our modeling as process understanding and more data to constrain process representation become available.

**References**


Interactive comment on Atmos. Chem. Phys. Discuss., 6, 3175, 2006.
Table 1: Annual burned area as reported by CIFFC compared to burned area from Giglio et al. (2006) for the 2001–2004 period, and before 2001 using ATSR fire hot spot data (Arino et al., 1999) scaled to burned area from Giglio et al. (2006).

<table>
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<tr>
<th>Year</th>
<th>CIFFC ($\times 10^4$ km$^2$)</th>
<th>This study ($\times 10^4$ km$^2$)</th>
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</thead>
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<tr>
<td>1997</td>
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<td>0.68</td>
</tr>
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</tr>
<tr>
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<td>2.15</td>
</tr>
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<td>2004</td>
<td>3.08</td>
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Table 2: Monthly fire hot spots detected by the MODIS (Giglio et al., 2003) and ATSR (Arino et al. 1999) fire hot spot products for the fire seasons of 2002, 2003, and 2004 in Boreal North America (BONA). Note that the peak fire season occurs in the same month for both products.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>MODIS</th>
<th>ATSR</th>
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<tr>
<td>2002</td>
<td>5</td>
<td>1590</td>
<td>290</td>
</tr>
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<td>2002</td>
<td>6</td>
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<td>5</td>
<td>507</td>
<td>106</td>
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<tr>
<td>2003</td>
<td>7</td>
<td>2364</td>
<td>983</td>
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<td>8</td>
<td>5391</td>
<td>1598</td>
</tr>
<tr>
<td>2003</td>
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<td>108</td>
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</tr>
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<td>236</td>
<td>33</td>
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<td>2004</td>
<td>6</td>
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<td>7</td>
<td>10871</td>
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<td>2004</td>
<td>8</td>
<td>8590</td>
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</tr>
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<td>2004</td>
<td>9</td>
<td>12</td>
<td>151</td>
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Table 5: 1997–2004 average NPP, fuel loads, fire return times (FRT), and combustion completeness (CC) for different regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>NPP (g C m$^{-2}$ y$^{-1}$)</th>
<th>Fuel loads (g C m$^{-2}$ y$^{-1}$)</th>
<th>FRT (y)</th>
<th>CC</th>
<th>Total area$^4$ (10$^6$ km$^2$)</th>
<th>Emissions$^5$ (g C m$^{-2}$ y$^{-1}$)</th>
<th>Emissions/Total losses$^6$ (%)</th>
</tr>
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<tbody>
<tr>
<td>BONA</td>
<td>266</td>
<td>1864</td>
<td>1641</td>
<td>3505</td>
<td>473</td>
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<td>0.55</td>
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<td>941</td>
<td>2237</td>
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<td>0.48</td>
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<td>0.63</td>
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<td>206</td>
<td>638</td>
<td>843</td>
<td>241</td>
<td>0.47</td>
<td>0.73</td>
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<td>46</td>
<td>42</td>
<td>194</td>
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<td>4183</td>
<td>0.90</td>
<td>0.94</td>
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<td>10</td>
<td>0.40</td>
<td>0.63</td>
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<tr>
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<td>731</td>
<td>1299</td>
<td>13</td>
<td>0.32</td>
<td>0.56</td>
</tr>
<tr>
<td>BOAS</td>
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<td>3499</td>
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<td>0.24</td>
<td>0.56</td>
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<tr>
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<td>93</td>
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<td>341</td>
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<td>0.82</td>
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<tr>
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<td>252</td>
<td>356</td>
<td>16</td>
<td>0.57</td>
<td>0.79</td>
</tr>
</tbody>
</table>

1 Fuel loads were weighted by burned area and separated into biomass fuel (which included all live herbaceous and woody biomass available for fire) and litter fuel (aboveground litter, belowground litter in boreal regions, and belowground peat in wetland regions).
2 The fraction of woody biomass that was available for fire depended on the mortality scalar, as in van der Werf et al. (2003).
3 CC was weighted by burned area and by fuel loads and separated into biomass CC and litter CC similar to the fuel loads separation.
4 Total surface area of the region.
5 Emissions per unit area burned.
6 Total losses include emissions (both from vegetation fires and biofuel burning) and $R_h$. 

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Table 7: Area burned (× 10^4 km yr\(^{-1}\) = Mha yr\(^{-1}\)) for different regions and years.

<table>
<thead>
<tr>
<th>Region</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
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<th>Std. dev.</th>
<th>Std. dev./mean</th>
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<tr>
<td>BONA</td>
<td>1.5</td>
<td>4.8</td>
<td>2.3</td>
<td>0.7</td>
<td>0.4</td>
<td>2.6</td>
<td>2.3</td>
<td>4.0</td>
<td>2.3</td>
<td>1.5</td>
<td>0.65</td>
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<tr>
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<td>2.1</td>
<td>2.1</td>
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<td>1.7</td>
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<td>0.4</td>
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<td>17.1</td>
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