Review of "Biomass burning fuel consumption dynamics in the (sub)tropics assessed from satellite" by Andela et al.

General comments

The paper presents an approach to estimate fuel consumption by combining satellite data with field data and analyzes the derived spatial patterns of fuel consumption. Burned area data from MODIS is combined with fire radiative power (FRP) data from SEVIRI and MODIS to estimate fuel consumption. This approach requires a factor to convert fire radiative energy (FRE) to burned dry matter. The authors used a standard factor reported in the literature based on laboratory measurements (e). As an alternative, the conversion factor was estimated from field data by fitting a regression between MODIS FRE and field measurements of fuel consumption. By using the standard conversion factor, the derived conversion factor and by using MODIS or SEVIRI FRP data, the authors find similar spatial patterns of fuel consumption but large differences in absolute numbers. Relations between fuel consumption, NPP and fire return intervals remarkably differ between continents.

I very much appreciate the approach of combining these different datasets. Such estimates are certainly valuable to better understand and model vegetation-fire-carbon cycle interactions. The paper is very well written.

We would like to start thanking the reviewer for his thoughtful and constructive remarks. Please see our response to the specific comments and minor remarks below. In addition, we will upload a pdf file containing the suggested textual changes in response to both reviews (using track change) and the updated figures, references to line numbers used here refer to this document.

Specific comments

One conclusion of the authors is "Moreover, satellite-derived fuel consumption estimates could be used as a reference for biogeochemical models, while providing improved insights in the underlying processes." (p. 22, l. 16-17). Although I completely agree that satellite-derived data can help to improve process-representations in bio-geochemical models, I disagree with this conclusion. The authors present large differences in fuel consumption between the MODIS- and SEVIRI-based estimates and additional large differences in the lab-based and the field-based FRE-to-DM conversion factor. These two issues indicate large uncertainties in fuel consumption estimates.

Thus, I'm not convinced that these estimates can be used as a reference for models unless the uncertainties in fuel consumption are quantified. In my view, a major uncertainty originates from the fitted regression between MODIS FRE and field measurements of fuel consumption because only a limited set of field data is available with a limited representativeness for MODIS pixels. I think it is necessary to quantify the uncertainty of the regression (i.e. of the conversion factor) for example by bootstrapping the set of measurement point that goes into the computation of this regression. The bootstrapped distribution of conversion factors (or for example the 0.025, 0.5, and 0.975 quantiles of this distribution) can be then propagated into the computation of fuel consumption to provide spatial fields of upper and lower uncertainty estimates.

The distribution of conversion factors can be also used to test if the lab-based factor of 0.368 really differs from the derived factor or if this is a sampling issue. Such an uncertainty would make the estimate of fuel consumption much more valuable and I would accept it for benchmarking and testing biogeochemical models.

We agree that the uncertainty in the absolute fuel consumption estimates remains high. Our confidence in the spatial patterns is better because we find a reasonable comparison between the spatial patterns of SEVIRI-derived fuel consumption (observing the full diurnal cycle) and MODIS derived fuel consumption. The biggest challenge is to create accurate estimates of FRE, while SEVIRI misses much fire activity due to its large distance to Earth and subsequently large pixel size, the MODIS instruments provide only a limited number of daily observations and further suffer from increasing pixel sizes towards the swath edges. We assume that the conversion factor found by Wooster et al. (2005) is correct, and that structural differences between the uncorrected MODIS derived fuel consumption and field observations stem from errors in our FRE estimates. Following the suggestion of reviewer #2 we therefore now speak of a "FRE correction factor", rather than deriving an alternative conversion factor. Although this does not affect our fuel consumption estimates, it does provide the reader with better insight in where the largest uncertainties originate from.

We appreciate the suggestion to use bootstrapping to get an estimate of the uncertainty associated with the "FRE correction factor". We now show the 95% confidence interval of the FRE correction factor in Fig. 3a and we have also made updates to our methods, results and discussion sections accordingly. However, we expect that this may be a relative conservative estimate of the total uncertainty, for example because of the difficulties associated with the comparison of field observations with our long term mean 0.25° estimate and the fact that uncertainty may further be affected by the fire diurnal cycle, regionally. We found the "FRE correction factor" to be 1.56, indicating that MODIS derived FRE per unit area burned should be multiplied by a factor of 1.56 to get fuel consumption of the same magnitude as the corresponding field studies. We expect that the decreasing sensitivity of the MODIS instruments towards the swath edges (e.g., Freeborn et al., 2011) is responsible for most of the underestimation of MODIS-derived FRE. Using bootstrapping (n=10,000, method="bias corrected and accelerated bootstrap") we found that the 95% confidence interval of the bootstrapped distribution of the slopes is 1.30 - 1.80. This corresponds to a 16% increase, or decrease, in absolute fuel consumption estimates.

Minor remarks

p. 21, l. 31-32: I don't understand the connection of this sentence with the previous sentences. Can you please clarify it and improve the text.

We mean to say that compared to GFED we find relatively high fuel consumption in many of the more arid regions. This finding suggests that these regions may play a more important role in the inter annual variability of the land carbon sink than what would be expected based on current state of the art biogeochemical models, like GFED4. We have changed the sentence to read:
"The enhanced fuel consumption in arid and semi-arid drylands found here confirms the important role of arid and semi-arid drylands in the inter-annual variability of the global carbon cycle (Poulter et al., 2014)."

Figure 2 a, b and c: It seems that the two maps fit pretty well. I only noticed the biases after the second reading when I saw the labels of the color legend and the different axis ranges in (b). Can you please make the same color legend ranges for both maps and the same ranges for the axes in (b)?

The goal of this figure is to show the reader that the spatial patterns in fuel consumption derived from SEVIRI and MODIS are rather similar, despite the large absolute differences. We discuss the absolute differences both in the results (P11, L11-12) and in the discussion (P20, L19-22). To avoid further confusion we now specifically mention this difference in the caption of Fig. 2: "Note that on average MODIS-derived FC is about twice as large as SEVIRI-derived FC."

Figure 5 and corresponding analysis: Can you really treat fire return period as the independent variable? I assume fire return period and fuel consumption are highly inter-related. Maybe you can explain this better or you could use a different predictor variable. Additionally, it is strange that the high NPP values are at the bottom of the axis. The plot would be easier if NPP increases from bottom to top.

We have chosen NPP and fire return periods because they are often thought of as the main drivers of fuel loads and are responsible for much of the modelled variation in fuel consumption in GFED4s. In more arid areas combustion completeness is often high and fire return period can most likely be thought of as an independent explanatory variable. In more humid regions with more incomplete combustion an effect of fuel consumption on fire return periods may be expected. For example, when lower fuel loads are associated with higher flammability and thus likelihood of burning. We have now updated the text in the discussion to better acknowledge the possible interaction between fuel consumption, fuel loads and fire return periods.

P23, L19-24 "For example, the highest fuel consumption in the more humid African savannas was found in the most frequently burning grid cells, suggesting a high combustion completeness. In areas where burning is largely limited by fuel humidity, the combustion completeness may have a considerable impact on fuel consumption. The fact that both frequently burning and almost fire free areas occur under similar climatic conditions in (sub)tropical savannas suggest that fuel conditions are important, while frequent fire occurrence may enhance flammability (Shea et al., 1996; Ward et al., 1996)."

In addition, we have also reversed the y-axis of Figure 5.

Table 1: Can you add the references as additional column to improve readability?
- Done

References

Freeborn, P. H., Wooster, M. J. and Roberts, G.: Addressing the spatiotemporal sampling design of MODIS to provide estimates of the fire radiative energy emitted from Africa, Remote Sens. Environ., 115, 475–489, 2011.

Poulter, B., Frank, D., Ciais, P., Myneni, R. B., Andela, N., Bi, J., Broquet, G., Canadell, J. G., Chevallier, F., Liu, Y. Y., Running, S. W., Sitch, S. and van der Werf, G. R.: Contribution of semi-arid ecosystems to interannual variability of the global carbon cycle, Nature, 509, 600–603, 2014.

Shea, R. W., Shea, B. W., Kauffman, J. B., Ward, D. E., Haskins, C. I. and Scholes, M. C.: Fuel biomass and combustion factors associated with fires in savanna ecosystems of South Africa and Zambia, J. Geophys. Res., 101, 23551 – 23568, 1996.

Ward, D. E., Hao, W. M., Susott, R. A., Babbitt, R. E., Shea, R. W., Kauffman, J. B. and Justice, C. O.: Effect of fuel composition on combustion efficiency and emission factors for African savanna ecosystems, J. Geophys. Res., 101, 23569 – 23576, 1996.