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Interactive comment on "Varying relationships between fire intensity and fire size at global scale" *by* Pierre Laurent et al.

Pierre Laurent et al.

pierre.laurent@lsce.ipsl.fr

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Major concerns:

I) The manuscript lacks a proper discussion (and references) of potential issues that may arise when estimating fuel consumption and subsequently fire intensity from FRP. FRP observations from MODIS represent infrequent snapshots of energy release across the pixel area (at best âĹij1km2 at nadir). This results in a number of difficulties when linking FRP to fire temperatures or -intensity- of which several will likely be a function of environmental gradients. First, FRP is an estimate of energy release across an entire pixel, âĹij1 km2 at nadir for MODIS. It is very uncertain what fraction of the grid cell is actually burning (and this is likely a function of fuel loads and other aspect

of fire behavior). Yet, this is a requirement to estimate fire intensity because if 1% of the pixel produces 10 MW of energy, or 50% of the pixel produces the same amount makes a difference of 50 times the "intensity". Second, several studies suggest that vegetation structure (in particular tree cover) also have a significant effect on the relationship between fuel consumption and observed FRP (e.g. Roberts et al., 2018 RSE). Third, the sensitivity of the MODIS instruments to detect active fires (i.e. minimum FRP that can be observed) is a direct function of the scan angle and is up to a factor of 5 lower at large scan angles compared to nadir. This may be important when looking at distributions (e.g. median), because you are likely to strongly underestimate the occurrence of low FRP values. Fourth, the fire diurnal cycle (a function of fuel conditions, vegetation type, and climate) also produces a sampling error, since there are only few daily overpasses and in some ecosystems fire activity may peak already early in the morning while in others this maybe later in the afternoon. It would be important to properly discuss what "MODIS FRP" actually represents. I also disagree with the statement "This is in agreement with .. , since these quantities are two proxies of the number of ignitions." (lines 120-122). I do not see how the number of active fire detections is related to ignitions? A single fire may produce up to hundreds of active fire (FRP) detections if it becomes large enough and burns for a long period of time. Several studies have linked active fire detections (with or without FRP) to total amounts of fuel consumption (or biomass burned), which would be a function of area burned, fuel loads and other conditions. Moreover, looking at the distribution of FRP detections may become problematic here. In high fuel load temperate and boreal forested systems a large share of the active fire detections may come from smouldering rather than the active fire front (and ratios may change over the fire's lifetime), while for grasslands it may be mostly actively flaming fire fronts that are observed. In this light it would be important to much better define "fire intensity" (i.e. what do the authors want to measure exactly?), and discuss how using FRP as a proxy for this quantity may be further influenced by the above mentioned limitations.

Answer: We highly agree with the numerous comments on the use of FRP stated by the reviewer. First, using FRP as a proxy of Fire reaction intensity is not straightforward, and we agree that it should depend on the considered land cover. We decided to replace all occurrences of 'Fire Intensity' in the text with 'Fire Radiative Power' (including the title), since this is what we are really observing in the analysis. Then, we discuss our result under the hypothesis that FRP could be used as a proxy of fire reaction intensity (that we now clearly define in the text), and we discuss the limitation of such an approach. Note that we are now dividing each GFED regions into different land covers (forests/savannas/grasslands, see minor comment 9)). This separation is really helpful, because we can now separate in each GFEd regions grasslands (where FRP can be safely used as a proxy of fire intensity) from forests (where canopy could intercept part of the emitted radiation, and where smouldering could significantly contribute to the detected FRP). We added references to support the discussion.

We have also added in the discussion a paragraph (and references) about the spatial and temporal errors of MODIS instruments. We also think that keeping the separation into GFED regions allows to mitigate the sampling error : for example, if detection threshold varies with latitude, we can expect it to significantly differ between BONA and NHAF, but to vary less within each region. We then expect FRPs to be equally related to FI within a biome, whatever the FRP intensity, so the relationships with FS is conserved in our results. This uncertainty in FRP was also pointed out by reviewer 1 for which we also provide additional information and references on detection thresholds. In the following, we displays a draft of the paragraphs we would like to add to the discussion section:

"In the previous section, we hypothesised that FRP could be used as a proxy of fire reaction intensity. We now focus on the limitations of such an approach. First, the energy released by a wildfire can be decomposed in three parts : convection, conduction, and radiation. FRP only represents the radiative part of the energy emitted by a fire. Moreover, the fire reaction intensity used in Rothermel's equation does not share the same spatial extent as FRP : fire reaction intensity pertains to the flaming front of the

fire, while FRP integrates all the radiative energy emitted over a 1 km2 window. This means that radiation emitted from smouldering can also contribute to FRP, not only the flaming front. The impact should differ for different vegetation types : smouldering fires are more frequent in forested areas, whereas in grasslands most of the detected radiative power will be released by the active fire front. Another issue appears from the integration of radiative energy over the 1 km2 window : it is impossible to know if the detected FRP arises only from a fire covering the full 1 km2 area or only from a smaller fraction of the FRP pixel. However, we can expect this effect to be mitigated by the fact that our analysis does not account for very small fires, since the FRY database does not provide fire patches smaller than 107 ha for MCD64A1. Finally, a recent study (Roberts et al. 2018) used 3D radiative transfer simulations to show that the canopy structure intercepts part of the FRP emitted by surface fires. This means that the FRP measured from remote sensing for forested areas and savannas could underestimate the real FRP. We can also expect this underestimation to vary with tree species. For example, it is probable that the amount of radiation energy intercepted by the canopy differs strongly between canopy fires from highly flammable black pines from BONA (Rogers et al. 2015) and surface fires from pine needle bed in BOAS. All these considerations emphasize the importance to split the study of the relationship between fire size and FRP in different vegetation types, since the reliability of using FRP as a proxy of fire reaction intensity depends on it."

"The amount of radiative energy reaching the MODIS instruments is much smaller at large scan angles than at Nadir. This means that the MODIS instruments will be less sensitive to low values of FRP at high latitude (Giglio et al. 2003, Schröder et al. 2005). This could explain the difference of the distribution of FRP associated with fire patches in BONA (Figure 2) : the stronger asymmetry of the distribution in this region (i.e. the larger tail toward high FRP values) could arise from missing active fire data from less intense fires in this region. The temporal sampling of FRP also differs with the latitudinal coordinate : the number of satellite overpass is larger at high latitude than at the equator (from 2 observations per day until 15 at the poles, Giglio et al.

2006). This should rise the probability to recover FRP information for fire patches at high latitude, assuming that their radiative intensity is high enough to exceed the higher detection threshold at larger scan angles. Also, in some regions (such as NHAF and SHAF) fires exhibit a strong diurnal cycle (Giglio et al. 2006). The detection rate of active fires will therefore be higher if the peak of diurnal intensity is synchronized with satellite overpass. However, we can expect the sampling error rate and the variation of FRP sensitivity with latitude to be more homogeneous within each GFED regions that at global scale."

Please find our point-by-point answers to specific comments in the following.

1) Line 87. That is ok, but what do you do if you have two adjacent fire patches? Are you double counting the active fire detections?

Answer: Yes, this is what we do. However, note that we are performing the matching using Standard Deviation Ellipses (SDEs) from the fire patches, since these are the information provided by the FRY database. SDEs delimit 2/3 of the burn pixel of the fire patches, and are localized around the central area of the patch. This should limit the amount of attributing twice a active fire pixel.

2) Line 95. ".., we compute for each patch the mean FRP value of all .. ". This isn't entirely clear to me, do you first estimate the mean of each patch and then look at the median across patches? Again, it would be important to understand what the distributions look like (e.g. across land cover types) to understand the potential implications of such decisions.

Answer: Yes, this is what we do. We have added as supplementary plots :

- a map of the ratio of missed matches between fire patches and active fire pixel data.

- a histogram showing the global fire size distribution of fire patches and the distribution of fire patches without recovered active fire information.

We now discussed these plots in the discussion, they help us to discuss the limitation

of using FRP as a proxy of Fire Intensity.

3) Line 155 "In each 1x1 cells", typo.

Answer: The mistake has been corrected.

4) Lines 155 – 160, please move this to the methods section, accompanied by a short explanation on how that helps to answer your research questions.

Answer: We have moved the section to the methodology section.

5) Line 170 "Following the hypothesis from Rothermel's equation", maybe be a bit more specific here and add references. For clarity you could also repeat your own objectives here, e.g. "We aim to investigate if fire size and intensity are driven by a same set of environmental and climate conditions.." Also, I am somewhat surprised that in addition to speed, the authors don't mention fire duration as a potential driver of larger fire sizes.

Answer: We agree. This is also related to the first concern of reviewer 2. We are now giving more details about Rothermel's equation.

6) Line 174 "Tropical areas" is not a vegetation type, delete?

Answer: We meant tropical forest. We now separate each GFED regions in biomes.

7) Line 178 "experience limited fire energy" what does this mean? Do you mean to say something like "In equatorial areas with high annual rainfall, biomass burning is characterized by low spread rates are combustion completeness (cite), resulting in a more gradual release of energy from fires"?

Answer: Yes, this is what we meant. Also, if the fuel is not totally dry, part of energy release by the fire will be 'wasted' to vaporize the remaining water in the fuel.

9) Lines 198 – 214, this is an interesting discussion. However, what I miss here is a discussion on the potential influence of the spatiotemporal progression of the fire season. For example, the authors clearly find highest median FRP in more arid environments

(e.g. southern Africa or interior Australia), these regions also tend to burn later in the fire season. So in Figure 2 when focusing e.g. on Australia. The increase in "fire size : median FRP" ratio isn't that simply because we are first looking at a dominant signal from tropical northern Australia and then the signal becomes more and more dominated by interior Australia towards the end of the fire season? In that light I like the suggestion of reviewer #1 to take an approach that has a stronger focus on vegetation types, or areas that are otherwise more similar in terms of climate and vegetation compared to the GFED regions.

Answer: We agree. We are now separating each GFED regions in biomes. Note also that the separation into biomes is extremely helpful when it comes to the discussion related to your major concern for our analysis.

We put here the main answer to reviewer #1 about separating GFED regions in different land cover.

"We agree that relying only on GFED regions tends to mix together biomes with different biomass, fuel types, and with very different drought conditions. The problem with the use of drought datasets is that it is difficult to choose how to perform the separation between different levels of 'drought severity' : we could focus on the length of the drought season, or the severity of the Fire Danger Index, a combination of both, etc .... This choice would seem quite arbitrary, and would require a dedicated analysis. Instead, we propose to use MODIS Land Cover Data to separate each GFED regions in different biomes (Forested, Savannas, Grasslands/Shrublands, see Figure attached to the answer). We clearly see that the relationship varies with the biomes : the results are especially striking in Australia, where we see that the FRP/FS relationship differs a lot depending on the considered biome. Finally, since we do not directly study the relationship with biomass and drought, we removed from the abstract and the discussion the sentences where we claimed that the fire intensity is driven by these quantities."

10) Line 238 "Fire danger index has been constantly increasing during the last 50

years", I believe conclusions of that paper were a little more nuanced.

Answer: Actually, the article focused on the length of the fire season rather FDI. The author claims that the global fire season length has increase, even though fire season length can still decrease in some areas of the world. We have modified the text.

11) Figure 2: why do y-axis on the right side have no caption? Also, it's probably good to mention that "The background histograms represent the number of fire patches" in the caption. Finally, what is the size and ranges of the FRP-bins? Are you excluding bins with less than x fire patches?

Answer: We have added a caption on the y-axis, which represent the number of fire patches in each FRP bin (corresponding to the background histograms). We also modified the caption and give the ranges of FRP bins in the caption and in the text.

12) Table 1: "FI at maximum size (MW)", seems to be incorrect since you did not look at the FI for the largest fires. Something like "FI with largest associated fire patch sizes", or similar may be more appropriate.

Answer: Yes, we agree. We have modified the legend and the table. We have also found some similar occurrences in the text, and we have changed them.

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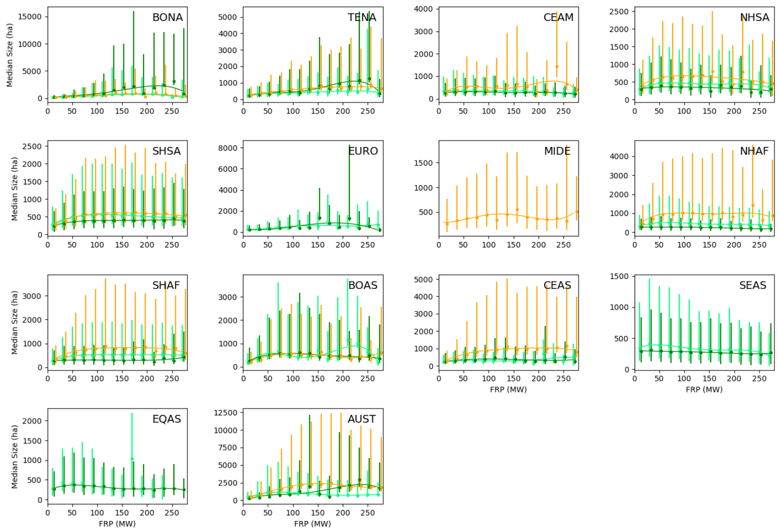

Fig. 1. FRP vs fire size for different biomes

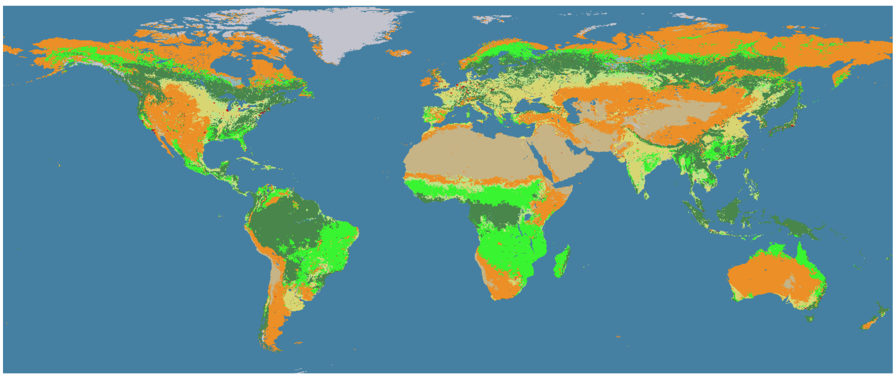

Fig. 2. Map of the land cover biomes