Overview

We greatly appreciate the constructive reviews and editor assessments of our paper. Based on the reviewers' comments we modified the text and expanded the database by including several new interesting studies. More specifically, the following main concerns of the reviewers were addressed:

- The level of scientific focus was increased by providing uncertainties (either standard deviation or range, depending on the number of studies available) throughout the text for the different FL, CC and FC values.
- Terminology like 'fuel loading' and 'ground fuels' are now more clearly defined and used more consistently throughout the paper. The same counts for the definition of the different biomes: for example, we used a fraction tree cover map now to distinguish between wooded savanna and tropical dry forest.
- Within the temperate and boreal forest biomes we expanded the discussion on differences in wildfire and prescribed fire fuel consumption. Moreover, new biome-averaged values for both biomes are presented.
- We introduced a new 'shifting cultivation' section, and removed these measurements from the pasture section.

Please find a detailed response below.

Kind regards,

Thijs van Leeuwen, on behalf of all co-authors

Response to referee #1 (R. Yokelson)

General comments:

This can be a useful database for the scientific community with a bit more work. The authors could highlight in the abstract, or elsewhere sooner in paper, that this is an updateable database that resides on the Internet.

We highlight in the Introduction Section that the database will be updated frequently and is available online, by adding the following sentence:

P6L16-17: "The database, available at http://www.globalfiredata.org/FC, will be updated when new information becomes available."

In addition, this message was repeated in the Summary Section:

P31L23-25: "When new information on fuel consumption becomes available, the field measurement database will be updated. The most up-to-date version can be retrieved from http://www.globalfiredata.org/FC."

A few methodological notes. In much of the refereed literature "fuel loading" is considered equivalent to "total biomass." In US land management agencies, and some refereed literature, "fuel" has a very different operational definition meaning the biomass expected to experience significant consumption under the current weather and fuel moisture conditions. It's not uncommon then to calculate fuel loading (FL) as e.g. "biomass less than 2.5 cm in diameter and less than one meter above ground." The authors allude to possibly using the more restrictive operational definition on page 4 line 14. It's important to distinguish because if one applies a combustion completeness (CC) calculated with respect to a restrictive pre-fire fuel loading to total biomass, the overall biomass burned or "fuel consumption" (FC) can be too high. The authors should ensure they do not fall in that trap.

It is indeed important to distinguish between these different definitions, because the calculated combustion completeness with respect to total biomass or the more restrictive fuel load will impact the fuel consumption estimates.

In the database presented we only allude to a more restrictive operational definition when authors of a refereed study did so, and in some of these studies a 'total available biomass' is not even presented. To make clear that in most of the literature consulted the 'fuel load' was actually equivalent to 'total available biomass', we changed the following text in the Introduction Section:

P4L22-29: "In general, the FL is equivalent to the total biomass available. New studies do provide estimates of standing biomass (e.g. Baccini et al., 2009; Saatchi et al., 2011). However, fires do not necessarily affect standing biomass. Especially in savannas the trees are usually protected from burning by a thick barch and in some of the literature the FL therefore has a more restrictive definition, referring to only that portion of the total available biomass that normally burns under specified fire conditions, which is often only the fine ground fuels. In both definitions the FL is typically expressed as the mass of fuel per unit area on a dry weight basis."

Moreover, we expanded the discussion in Section 3.2 by making clear that this fuel load definition issue will add uncertainty and may impact the FC:

P25L33-P26L4: "Note that for temperate and boreal forest measurements sometimes the more restrictive definition of FL (as presented in Section 1) was used, and this can have an impact on FC values as well; if one applies a CC calculated with respect to a restrictive pre-fire FL to total biomass available, the overall FC that was estimated can be too high."

Also, the temperate forest and chaparral ecosystem-average FC values seem too high *and some effort should be made to distinguish wild and prescribed fire FC at least for the temperate forest ecosystem as explained in more detail below. Section 3.7 and Table 5 of this open-access paper provides some prescribed fire FL and FC measurements the authors may want to include: http://www.atmos-chem-phys.net/13/89/2013/acp-13-89-2013.html*

As noted by the reviewer, fuel consumption of wildfires is higher than in prescribed fires according to conventional wisdom and also according to the data presented in Tables 1 of our paper. We agree that these differences between wildfires and prescribed burns are too large to neglect, and therefore we made the following changes:

* We expanded Section 2 on the measurements, by stating that –in general- obtaining FC measurements for wildfires is more challenging than for prescribed burns:
P7L12-21: "Most of the studies we found in the literature rely on the planar intersect method (PIM), where fuel measurement plots are typically divided in multiple, randomized smaller subplots. The (small-size) biomass in these subplots is oven dried and weighed both pre- and post-fire to estimate the CC and to determine the FC. The consumption of larger-size material (diameter >10cm) is often estimated based on experimental observations of randomly selected trunks and branches that were identified before the fire (Araújo et al., 1999). The PIM is mainly applied in prescribed burns, and obtaining FC measurements for large wildfires is logistically more challenging but can be based on comparing burned with adjacent unburned patches."

* Within the temperate forest biome we now distinguish between wildfires and prescribed burns:
P12L32-P13L7: "While tropical fires are largely intentionally ignited to pursue land management goals, the temperate forest is also subject to wildfires. Obtaining FC measurements for wildfires is obviously challenging, so most information is derived from prescribed fires which allow researchers to measure pre-fire conditions. However, these fires may not always be a good proxy for wildfires. For example, wildfires in western conifer forest of the US are often crown fires (while prescribed fires usually only burn surface fuels). Due to potential discrepancies with respect to FC, we distinguished between these fire types in Section 3.2."

* Several prescribed fire FL and FC measurements from the study of Yokelson et al. (2013) were included, as presented in Table 1c.

* We calculated the biome-averaged values for the temperate forest biome in a different way: instead of focusing on 'total FC' studies, we now use all measurements presented in Table 1c. Thus, studies that provide information on one specific fuel class only (e.g. ground fuels (Goodrick et al., 2010)) were also included. Due to this, the calculated biome-averaged FC for the temperate forest biome decreased from 93±79 t ha^{-1} to 58±72 t ha^{-1}, and is now closer to what we expect.

* We expanded the discussion on differences between wildfires and prescribed fires in Section 3.2, and provide the reader with FC values that may be more representative for both fire types:
P25L15-P26L4: "In the temperate forest biome FC was underestimated in GFED3 by 74% compared to the field measurement average for collocated grid cells. In our averaged field measurement estimate we included all measurements presented in Table 1c. As noticed in Section 2.3, it is likely though that studies that provided a total FC (i.e. the FC of ground, surface and/or crown fuels) are more representative for wildfires. Prescribed burns, on the other hand, tend to burn less fuel and therefore the studies that only include ground or surface fuels were probably more representative for this fire type. When focusing on studies that provide information on

one specific fuel class only, the field average for the temperate forest would be significantly lower (13±12 t ha^{-1}) as well as the discrepancy with GFED3 (+14%). This FC value of 13 t ha^{-1} may be more realistic for prescribed fires, which contribute to roughly 50% of all temperate forest fire emissions in the contiguous United States (CONUS). Still, it remains very uncertain how well FC measured for specific fuel classes is representative for prescribed fires and wildfires. This issue also counts for boreal forests, where GFED3 overestimated the field measurements by almost 80%. When only including studies that provided a total FC (i.e. the FC of ground, surface and/or crown fuels), the field average for the boreal forest would increase from 35±24 t ha^{-1} to 39±19 t ha^{-1} and the discrepancy with GFED3 would decrease (from +79 to +60%). This value of 39±19 t ha^{-1} may be more representative for boreal wildfires. Note that for temperate and boreal forest measurements sometimes the more restrictive definition of FL (as presented in Section 1) was used, and this can have an impact on FC values as well; if one applies a CC calculated with respect to a restrictive pre-fire FL to total biomass available, the overall FC that was estimated can be too high."

* We decided not to label prescribed fires and wildfires in table 1c, since it is not always clear if a study is more representative for one of these fire types. Moreover, the study in Mexico (Yokelson et al., 2007) was actually the only 'real' wildfire that was measured.

* Several chaparral measurements from Yokelson et al. (2013) were included, and lowered the biome-averaged FC from 32±19 t ha^{-1} to 27±19 t ha^{-1} and is now closer to what we expect.

The writing needs to have a sharper, higher-level scientific focus. The statement that readers must use "extreme caution with average values" doesn't meet the normal scientific criteria for expressing the situation nor does omitting the uncertainties. The way to explain it scientifically is that FC is naturally variable and hard to measure and there are few measurements for some ecosystems. Thus confidence in the average value is low and the coefficient of variation is large. It's important therefore to include uncertainties for each value in the text and let the user assess the implications for their application. In general, high uncertainty alone does not justify implementing a non-average value, but using non-average values could be justified if they were produced by a validated model that explains the observed variability in field measurements. If the authors believe such a model exists they should promote it clearly. At present, a comparison is presented towards end of paper, but no conclusion is presented after the comparison. Using a non-average value, but within the uncertainty, could also be of interest (or convenient) if it systematically improves representation of e.g. downwind concentrations. In this latter case, it would ideally be made clear by the user if altering the FC is the only reasonable solution or if a change in other uncertain parameters (e.g. burned area) cannot be ruled out.

Although it is problematic to properly quantify uncertainties, especially given the 'definition' problem for ecosystems and/or terms like 'fuel load', and limited amount of information for most biomes, we agree that more effort can be put into the scientific explanation and writing. In general, we made the following changes to have a sharper higher-level scientific focus throughout the text:

* Uncertainties for each average value were consistently added. We appended the standard deviation, or range when only two values are available.

* We added a more scientific discussion and conclusion on the use of biome-averaged values:

P26L5-20: "For most biomes, a few field measurements had a FC that was an order of magnitude larger than the other values listed in Table 1, which explains the discrepancy between the median and average FC values that was sometimes found (e.g. the 'Australia and Tasmania' region in Figure 4). By neglecting these 'outliers' the biome-averaged values may change significantly, but this could lead to erroneously low or high estimates as well. In general, FC shows a large variability between biomes, within biomes, and even within a specific fuel type. FC is often hard to measure, and since only a few measurements are available for some biomes, care should be taken when using the biome-averaged values presented in this paper. It is up to the user to assess the implication for their applications: the use of non-average values could be justified if they were produced by a validated model that explains the observed variability in field measurements. Using a non-average value that is within the uncertainty of the biome could also be of interest (or convenient) if it systematically improves representation of e.g. downwind concentrations. Note that in this latter case, the user should consider if a change of other uncertain parameters (e.g. burned area) can or cannot be ruled out."

Also, the word "rate" is used erroneously throughout the paper since "rate" implies an amount per time rather than an amount per area.
Agreed and deleted where required.

I believe the authors intent is to offer this a useful database and not a comprehensive treatise on uncertainties in calculations of biomass burned at various scales, but they could provide a slightly broader summary of uncertainty at the top of page 5 by including or recognizing some of the following points: A fire that is missed by FRP may be seen as burn scar, this is a possibility, but not a given fact because many short-lived fires also have small burn scars. In general, detection of fires as heat, fire emissions, and burn scars is far from complete. Challenges for bottom-up or top-down approaches are clouds, the cloud mask, and orbital gaps. Added challenges for bottom up approaches include fires that are too small, canopy obscuration, sites that green up before next look, and detected fires assumed to be in wrong ecotype or uncertainty in FC in general. Additional weaknesses of top-down include uncertainty in injection altitude, meteorology, secondary chemistry, poor spatial and temporal resolution, and the unknown contribution of other sources. All approaches are highly uncertain, but work should continue on all because biomass burning is a very important source.

As noticed by the reviewer, the scope of this paper is to present a useful database and not a comprehensive treatise on uncertainties in calculations of biomass burned at various scales. In our paper we discuss different properties that are used to estimate emissions, and we do provide a short summary of their uncertainty and/or we refer to papers where these uncertainties are discussed in more detail. Examples are given in:

P4L14-19: "The burned area may be estimated directly from satellite observations, with the MODerate resolution Imaging Spectroradiometer (MODIS) 500 m maps (Roy et al., 2005; Giglio et al., 2009) being currently the most commonly used products for large-scale assessments. Although small fires and fires obscured by forest canopies escape detection with this method (Randerson et al. 2012), the extent of most larger fires can be relatively well constrained in this way."

P5L3-13: "Another approach that has been developed over the past decade is the measurement of fire radiative power (FRP) (Wooster et al., 2003; Wooster et al., 2005; Kaiser et al., 2012). FRP per unit area relates directly to the fuel consumption (abbreviated as 'FC' in the remainder of the paper) rate, which again is proportional to the fire emissions. The FRP method has several advantages compared to the Seiler and Crutzen (1980) approach, such as the ability to detect smaller fires and the fact that the fire emissions estimates derived this way do not rely on FL or CC. One disadvantage is that the presence of clouds and smoke can prevent the detection of a fire, and the poor temporal resolution of polar orbiting satellites hampers the detection of fast moving or short-lived fires (which still can show a burn scar in the burned area method) and makes the conversion of FRP to fire radiative energy (FRE, time-integrated FRP) difficult."

However, to emphasize that uncertainties are substantial for the different properties, we added the following text and refer to van der Werf et al. (2010), who provide a more detailed discussion on these uncertainties:
P4L13-14: "These four properties are obtained in different ways and generally uncertainties are substantial (van der Werf et al., 2010)."

The need to assign ecosystems properly to use this data suggests a possible additional short section would be useful with recommendations on vegetation maps/layers or at least citations to commonly used options and/or any review articles on the topic.
Indeed, to use this database the different ecosystems need to be assigned properly, and therefore a clear and consistent definition throughout the paper is key. As suggested by the reviewer we redefined some biomes and provide a more clear description in the different biome sections (2.1-2.11). In general, the following changes were made:

* Within the savanna biome we now distinguish between grassland savannas and wooded savannas, and use these terms consistently throughout the paper.

* Within the tropical forest biome we distinguish between tropical evergreen forest and tropical dry forest. To distinguish between tropical dry forest and wooded savanna, we harmonized with the emission factor compilation of Akagi et al. (2011), in which 60% canopy cover was the delineation:
P12L6-10: "Different forest types may partly explain the discrepancy found, and therefore we distinguished between measurements conducted in primary tropical evergreen forest, secondary tropical evergreen forest, and tropical dry forest (Figure 3). To distinguish between tropical dry forests and wooded savannas (Section 2.1), we harmonized with the emission factor compilation of Akagi et al. (2011) in which 60% canopy cover (Hansen et al., 2003) was the delineation between both ecosystems."

* To distinguish between boreal and temperate forests, we define boreal forest as "high latitudes of about 50-70°" forested regions on P14L10. Within the temperate and boreal forest biome we now distinguish between wildfires and prescribed fires as well.

* Within the pasture biome (section 2.5) we removed the two shifting cultivation studies, which were then included into a new 'shifting cultivation' section (2.7).

Specific Comments:
P8117, L3: first use of "rate" which I suggest to eliminate
"These fuel consumption (FC) rates depend" was changed to "Fuel consumption (FC) depends".

P8118, L8: particles also
We changed "accurate trace gas emission estimates" to "accurate trace gas and particle emission estimates".

P8118, L13: change "can be obtained directly" to "may be estimated" since there are options and it's not an exact measurement.

“can be obtained directly” was changed to “may be estimated”.

P8119, L1: here “rate” is OK since power has time in the denominator.
“rate” was not deleted here.

P8119, L10 “emissions” to “consumption”
“emissions” was changed to “consumption”.

P8119, L15: append “which is updated on-line”
“The accompanying database is updated frequently and on-line.” was appended.

P8119, L17: add “also” after the first “is” since FC is fundamentally the difference between pre and post fire biomass loading. Assuming that FL X CC is as useful is strictly true if FL and CC don’t depend on each other.
The sentence was changed to:
P5L22-24: “To improve and validate fire emissions models, it is crucial to gain a better overview of available FC measurements, as well as of the FL and CC components that together govern FC.”

P8119, L20: I believe it is fire-integrated FRE (energy) divided by fire-integrated burned area that might give FC under ideal conditions. Getting FC from FRP would be like trying to measure how far a car drove by measuring its speed at one point.
We agree, and to be more specific we changed the text to:
P5L24-27: “This is obviously the case for emissions estimates based on burned area, but also FRP-estimates could benefit from this information because one way to constrain these estimates is dividing the fire-integrated FRE by the fire-integrated burned area, which in principle should equal FC.”

P8119, L23-24: I would just say that fine fuels usually have a higher CC than coarse fuels since there a general inverse relationship between FL and CC has not been demonstrated (at least not in this paper, e.g. more grass is not known to make CC decrease?).
Indeed, this inverse relationship between FL and CC has not been clearly demonstrated, and therefore the text was changed to:
P5L30-33: “Forested ecosystems in general show relatively little variability in FL over time for a given location, but CC can vary due to weather conditions. Fine fuels usually burn more complete than coarser fuels, and therefore CC in grassland savannas is often higher than in forested ecosystems.”

P8119, L24-25: In the absence of disturbances total forest biomass tends to increase at a well-behaved rate, but depending on how FL is defined it can change with the weather. The authors should choose one definition of FL and use throughout – or clarify that this problem adds uncertainty.
When discussing seasonal variations of FL within the savanna biome, it is indeed important to clearly state how the FL is defined. To make clear that in most of the literature consulted the ‘fuel load’ <u>was</u> actually equivalent to ‘total available biomass’, we changed the following text in the Introduction Section:
P4L22-29: “In general, the FL is equivalent to the total biomass available. New studies do provide estimates of standing biomass (e.g. Baccini et al., 2012). However, fires do not necessarily affect standing biomass. Especially in savannas the trees are usually protected from burning by a thick barch and in some of the literature the FL therefore has a more restrictive definition, referring to only that portion of the total available biomass that normally burns under specified fire conditions, which is often

only the fine ground fuels. In both definitions the FL is typically expressed as the mass of fuel per unit area on a dry weight basis.”

Moreover, we expanded the Discussion Section 3.2 by making clear that this fuel load definition issue will add uncertainty and may impact the FC:
P25L33-P26L4: “Note that for temperate and boreal forest measurements sometimes the more restrictive definition of FL (as presented in Section 1) was used, and this can have an impact on FC values as well; if one applies a CC calculated with respect to a restrictive pre-fire FL to total biomass available, the overall FC that was estimated can be too high.”

P8120, L9: Akagi et al listed 47 FC measurements for nine fuel types to provide examples, this paper is a first attempt at a comprehensive tabulation of refereed measurements.
We changed the text and now refer to the useful work of Akagi et al. (2011):
P6L12-15: “Building on Akagi et al. (2011), who listed 47 measurements for nine fuel types, this paper is a first attempt to establish a complete database, listing all the available FC field measurements for the different biomes that were found in the peer-reviewed literature”.

P8121, L11: “After the burn” implies a prescribed fire or slowly moving wildfire and comparisons in and out of fire perimeter are also done post fire.
Several changes were made to the description of the planar intersect method, and its acronym (PIM) is now used throughout the remainder of our manuscript:

P7L12-21: “Most of the studies we found in the literature rely on the planar intersect method (PIM), where fuel measurement plots are typically divided in multiple, randomized smaller subplots. The (small-size) biomass in these subplots is oven dried and weighed both pre- and post-fire to estimate the CC and to determine the FC. The consumption of larger-size material (diameter >10cm) is often estimated based on experimental observations of randomly selected trunks and branches that were identified before the fire (Araújo et al., 1999). The PIM is mainly applied in prescribed burns, and obtaining FC measurements for large wildfires is logistically more challenging but can be based on comparing burned with adjacent unburned patches.”

P8122, L5: is Mg ha-1 actually better? If using metric tons they are sometimes spelled “tonnes” to avoid confusion with British “ton” – either way it should be plural!
We decided to stick to the tons ha-1, and therefore changed “ton” to “tons” instead.

P8122, L16&17: Reminder, improper uses of the word “rate”
The word “rate” was removed here.

P8123, L3: using “dry savanna” before defining, fix suggested next comment
P8123, L5-7: suggest moving these two sentences after the Gill and Lana reference on previous page.
We followed the suggestion and moved the two sentences after the Gill and Allan (2008) reference.

P8123, L4-5: Note I backed up. For grass production to limit area burned maybe it needs to be explained that fuel density can affect how well a fire propagates for a given wind speed?
We added a more detailed explanation by changing the text to:

P9L8-14: "As these systems are generally fuel limited, grass production and consumption by herbivores are very important factors controlling the extent of area burned particularly in drier regions where rainfall can vary strongly between years (Menaut et al., 1991; Cheney and Sullivan, 1997; Russell-Smith et al. 2007). Grass production controls fire spread because low-biomass grasslands have less continuous fuel swards, and also because they burn at lower intensities which reduces the probability of spread".

P8123, L12-13: the lack of grasses that "restrict" nitrification causing moisture-independent low biomass in Australia. Can this be restated so it is more obvious what is meant?
We restated this sentence to:
P9L19-21: "This difference is mostly due to the fact that Australia's native grasses are limited by nitrogen availability at high rainfalls, something African grasses such as *Andropogon gayanus* overcome through various mechanisms (Rossiter-Rachor et al., 2009)".

P8123, L14: Miombo and Cerrado and "Monsoon" Forest are also commonly called "tropical dry forest," maybe more often than a savanna? This is an important "gray area" that could be pointed out. In Akagi et al 2011 they adopted a percent tree cover value as an unambiguous threshold. Here the authors appear to have adopted yet another term that is seen sometimes: "wooded savanna."
As mentioned by the reviewer, unclear definitions of these different ecosystems may confuse the reader and it is therefore important to point out this gray area. Within the savanna biome we consistently distinguish between grassland savanna and wooded savanna. We harmonized with the emission factor compilation of Akagi et al. (2011), in which 60% canopy cover (fraction tree cover (FTC)) was the delineation between wooded savanna and tropical dry forest. The FTC product was derived from the Vegetation Continuous Fields (VCF) collection which contains proportional estimates for vegetative cover types: woody vegetation, herbaceous vegetation, and bare ground (Hansen et al., 2003). This is stated in the tropical forest section (Section 2.2):
P12L6-10: "Different forest types may partly explain the discrepancy found, and therefore we distinguished between measurements conducted in primary tropical evergreen forest, secondary tropical evergreen forest, and tropical dry forest (Figure 3). To distinguish between tropical dry forests and wooded savannas (Section 2.1), we harmonized with the emission factor compilation of Akagi et al. (2011) in which 60% canopy cover (Hansen et al., 2003) was the delineation between both ecosystems."

P8123, L20: I never heard of "dense woodland" meaning "tropical dry forest" or "open forest" or "wooded savanna."
We removed "dense woodland" and replaced it with "wooded savanna".

P8123, L24: Very important to add the variability here and throughout! I suggest to append standard deviation (or range in the case of only two values) to each average value given as a matter of habit.
As explained in the 4th general comment, we added uncertainties for each average value throughout the text. In principle we append the standard deviation, but when only two values are available we use the range.

P8123, L28&29: not sure regional differences are "substantial" especially compared to uncertainties or natural variation and maybe also add "nominally" before "higher."
We deleted "substantial" and added "nominally" before "higher".

P8124, L4: the "differences" are not statistically significant. "Conclusive findings" is a different concept.
We agree that this is a different concept, and therefore we restated the sentence to:
P10L10-11: "A larger number of measurements are required to conclusively say whether these differences are statistically significant."

P8124, L14: "surface area to volume"
"area" was changed to "surface area".

P8124, L23: This or in discussion may be a good place to point out that the analysis of CC data by Akagi et al 2011 (Sect 2.4) suggests that CC increases over the course of the dry season as large diameter fuels dry out. This idea is consistent with a seasonal decrease in MCE proposed by Eck et al. (2013):
We decided to point out these temporal variations of CC (and thus FC) in the discussion (Section 3.1), where we added the following text:
P22L26-29: "In general, both FC and CC may increase over the course of the dry season as large diameter fuels dry out. This was also suggested by Akagi et al. (2011) for the savanna biome, and consistent with a seasonal decrease in MCE as proposed by Eck et al. (2013)."

P8124, L24: I think the more precise terminology is tropical "evergreen" forest? A sentence fragment or some idea on how common droughts are would be helpful since the Amazon has had quite a few droughts in the last few years.
We used the more precise terminology and replaced "Tropical rainforests" with "Tropical evergreen forests".

Moreover, to highlight the importance of droughts in tropical forests, we included some relevant references for Indonesia (Field et al., 2009) and the Amazon (Marengo et al., 2011; Tomasella et al., 2013).

P8125, L7: "tons" to "t" or "Mg." I think you need to better differentiate at the outset between 1) deforestation fires, where as much biomass as possible is cut and piled and the desire is to remove the biomass as completely as possible, often in a series of burns and 2) mostly accidental or escaped fires in selectively logged forests where conversion to agriculture is not a goal. Then discuss the factors affecting these two fire types separately.
"tons" was changed to "t".

Within the tropical forest biome we distinguish between tropical evergreen forest and tropical dry forest. For tropical evergreen forest, we tried to better differentiate between deforestation fires and accidental fires by adding the following text:
P11L1-12: "Human activities have resulted in fire activity in tropical forests, often with the goal to clear biomass and establish pasture or cropland. These deforestation fires can be small-scale (e.g. shifting cultivation, discussed in Section 2.6) or on large scale with the aid of heavy machinery. In the latter case, biomass is often piled in windrows after the first burn and subject to additional fires during the same dry season to remove the biomass more completely. In large-scale deforestation regions like the state of Mato Grosso in the Brazilian Amazon, the expansion of mechanized agriculture could result in increased fuel consumed per unit area (Cardille and Foley, 2003; Yokelson et al., 2007). All these fires, but also selective logging, may lead to more frequent accidental fires as fragmented forests are more vulnerable to fire (Nepstad et al., 1999; Siegert et al., 2001; Pivello, 2011)."

P8125, L20: This is a bit oversimplified: This paper: http://www.atmos-chem-phys.net/7/5175/2007/acp-7-5175-2007.html Sect 2.3.2 gives a more specific discussion of past work by Fearnside, Kauffman, Cochrane, Morton, etc. In general, forest slash that doesn't burn in a first fire may be subjected to additional fires during the same dry season. If conversion to pasture is the goal more residual biomass can be tolerated and it is mostly removed during pasture fires in subsequent years. If conversion to e.g. mechanized soybean production is the goal, the slash (or residual material) is often assembled in windrows (long piles) to enhance CC. Other times crop residue fires or deforestation fires accidentally escape and burn some nearby degraded forest.

We consulted the ACP paper and provided some more detail on the different processes, as presented in the previous comment.

P8126, L3-4: The authors should use more consistent definitions of various ecosystems. Here tropical dry forests are mentioned in the tropical forest section and many people might include Miombo in that. One possibility is to harmonize with the emission factor compilation of Akagi et al 2011 in which 60% canopy cover was the delineation between wooded savanna and tropical dry forest. From page 5 of that paper: "Tropical dry forest is also called "seasonal" or "monsoon" forest. Tropical dry forests (TDF) differ from "woody" savanna regions in that TDF are characterized by a significant (>60%) canopy coverage or closed canopies (Mooney et al., 1995; Friedl et al., 2002). Savanna regions are qualitatively described as grassland with an "open" canopy of trees (if any)."

As suggested by the reviewer we redefined some biomes and provided a more clear description in the different biome sections (2.1-2.11). Regarding the tropical forest biome: we now harmonized with the emission factor compilation of Akagi et al. (2011) in which canopy cover (fraction tree cover (FTC)) of at least 60% was the delineation between tropical dry forest and wooded savanna. The FTC product was derived from the Vegetation Continuous Fields (VCF) collection which contains proportional estimates for vegetative cover types: woody vegetation, herbaceous vegetation, and bare ground (Hansen et al., 2003).

P12L6-10: "Different forest types may partly explain the discrepancy found, and therefore we distinguished between measurements conducted in primary tropical evergreen forest, secondary tropical evergreen forest, and tropical dry forest (Figure 3). To distinguish between tropical dry forests and wooded savannas (Section 2.1), we harmonized with the emission factor compilation of Akagi et al. (2011) in which 60% canopy cover (Hansen et al., 2003) was the delineation between both ecosystems."

P8126, L8: reminder "FC" ok by itself does not need "rate" to follow it

"rate" was removed.

P8126, L15: The observation of size or class dependent CC goes back to at least Ward et al 1992

We have not included a citation because it is a very general observation.

P8126, L16: "surface area"

"area" was changed to "surface area".

P8126, L22: I suggest that this section be divided into prescribed and wild fires (PF and WF). Otherwise people may apply FC values of 93 t/ha for PFs where the typical value is ~5 t/ha: a huge overestimate for a fire type that applies to circa one million ha a year in US. To continue: the temperate forest FC totals and FC by class both seem way too high. E.g. 42 t/ha for duff as an average for temperate forest fires is

already almost ten times typical total FC for prescribed fires which account for a large fraction of the burning. At the least, it may be that some attempt is needed to weight the "type averages" for WF and PF in this ecosystem by their relative occurrence. In addition, as a general consideration, the authors could consider weighting individual studies by the number of measurements in the study.
As pointed out by the reviewer, the presented biome-averaged FC values for the temperate forest may be problematic for certain users. Based on the reviewers' comments, we included several changes for –specifically- the temperate forest biome:

* We expanded Section 2 on the measurements, by stating that –in general- obtaining FC measurements for wildfires is more challenging than for prescribed burns:
P7L12-21: "Most of the studies we found in the literature rely on the planar intersect method (PIM), where fuel measurement plots are typically divided in multiple, randomized smaller subplots. The (small-size) biomass in these subplots is oven dried and weighed both pre- and post-fire to estimate the CC and to determine the FC. The consumption of larger-size material (diameter >10cm) is often estimated based on experimental observations of randomly selected trunks and branches that were identified before the fire (Araújo et al., 1999). The PIM is mainly applied in prescribed burns, and obtaining FC measurements for large wildfires is logistically more challenging but can be based on comparing burned with adjacent unburned patches."

* Within the temperate forest biome we now distinguish between wildfires and prescribed burns:
P12L32-P13L7: "While tropical fires are largely intentionally ignited to pursue land management goals, the temperate forest is also subject to wildfires. Obtaining FC measurements for wildfires is obviously challenging, so most information is derived from prescribed fires which allow researchers to measure pre-fire conditions. However, these fires may not always be a good proxy for wildfires. For example, wildfires in western conifer forest of the US are often crown fires (while prescribed fires usually only burn surface fuels). Due to potential discrepancies with respect to FC, we distinguished between these fire types in Section 3.2."

* Several prescribed fire FL and FC measurements from the study of Yokelson et al. (2013) were included, as presented in Table 1c.

* We calculated the biome-averaged values for the temperate forest biome in a different way: instead of focusing on 'total FC' studies, we now use all measurements presented in Table 1c. Thus, studies that provide information on one specific fuel class only (e.g. ground fuels (Goodrick et al., 2010)) were also included. Due to this, the calculated biome-averaged FC for the temperate forest biome decreased from 93±79 t ha^{-1} to 58±72 t ha^{-1}, and is now closer to what we expect.

* We expanded the discussion on differences between wildfires and prescribed fires in Section 3.2, and provide the reader with FC values that may be more representative for both fire types:
P25L15-28: "In the temperate forest biome FC was underestimated in GFED3 by 74% compared to the field measurement average for collocated grid cells. In our averaged field measurement estimate we included all measurements presented in Table 1c. As noticed in Section 2.3, it is likely though that studies that provided a total FC (i.e. the FC of ground, surface and/or crown fuels) are more representative for wildfires. Prescribed burns, on the other hand, tend to burn less fuel and therefore the studies that only include ground or surface fuels were probably more representative for this fire type. When focusing on studies that provide information on one specific fuel class only, the field average for the temperate forest would be significantly lower (13±12 t ha^{-1}) as well as the discrepancy with GFED3 (+14%).

This FC value of 13 t ha^{-1} may be more realistic for prescribed fires, which contribute to roughly 50% of all temperate forest fire emissions in the contiguous United States (CONUS). Still, it remains very uncertain how well FC measured for specific fuel classes is representative for prescribed fires and wildfires.

* We decided not to label prescribed fires and wildfires in table 1c, since it is not always clear if a study is more representative for one of these fire types. Moreover, the study in Mexico (Yokelson et al., 2007) was actually the only 'real' wildfire that was measured.

* The high estimate for duff FC (42 t ha^{-1}) can be explained by the fact that we included measurements from the study of Hille and Stevens (2005 - Mixed conifer forest duff consumption during prescribed fires: tree crown impacts, Forest Science). We now included a few other measurements from Carter et al. (2003), and the average FC for 'organic soil' decreased to 25±31 t ha^{-1}.

* In general, we decided not to give more weight to studies reporting more measurement in a certain region to prevent biases.

P8127, L6: The Mexico study should be included in average and weighted by the relative number of measurements. FL and CC are usually secondary products from measuring FC anyway and the FL definition has not yet been clarified.
We now included the Mexico study of Yokelson et al. (2007), which slightly lowered the biome-averaged FC for temperate forest.

P8127, L25: very little woody debris on sites subject to frequent PF.
Differences between prescribed fire and wildfire FC are now discussed in more detail in Section 3.2. To provide the reader with more background information on the combustion of sound and rotten woody debris, we now refer to the review paper of Hyde et al. (2011).

P8128, L4: Much of the Asian boreal forest is disturbed by illegal/legal logging in Siberia. Vandergert, P., and Newell, J.: Illegal logging in the Russian Far East and Siberia, Int. Forest. Rev., 5, 303–6, 2003.
We included the following sentence:
P14L14-16: "However, much of the Asian boreal forests are disturbed by (il)legal logging activities (Vandergert and Newel, 2003) which can increase fire activity in more remote regions (Mollicone et al., 2006)."

P8128, L10: Most of the FC in a crown fire can be duff.
The reviewer makes a good point, which clearly stresses the uncertainty of the different fuel type FC values that we presented in Table 2c. We added some discussion on this in the last paragraph of Section 2.4, and refer to the interesting paper of Hille and Stephens (2005):
P15L32-P16L1: "Moreover, it was not always clear is which class certain fuels are consumed: e.g. organic material can be consumed on the ground but also in a crown fire (Hille and Stephens, 2005)."

P8129, L5-8: just properly describe this method near the beginning of the paper, give it acronym and use acronym. The biomass in plots is oven dried and weighed both pre and post fire or at burned and adjacent unburned sites and FC is the difference.
As suggested by the reviewer, we now properly described the method in Section 2 of the paper and used the acronym throughout the remainder of our manuscript:
P7L12-21: "Most of the studies we found in the literature rely on the planar intersect method (PIM), where fuel measurement plots are typically divided in multiple,

randomized smaller subplots. The (small-size) biomass in these subplots is oven dried and weighed both pre- and post-fire to estimate the CC and to determine the FC. The consumption of larger-size material (diameter >10cm) is often estimated based on experimental observations of randomly selected trunks and branches that were identified before the fire (Araújo et al., 1999). The PIM is mainly applied in prescribed burns, and obtaining FC measurements for large wildfires is logistically more challenging but can be based on comparing burned with adjacent unburned patches."

P8129, L12: The boreal forest FL average is lower than the temperate forest FL average, but is this only if the co-located boreal peat deposits are ignored? Currently the paper discusses boreal peat separately in Sect 2.9 and it would be useful to provide a little guidance on whether peatlands are a greater percentage of the boreal forest biome than the temperate forest biome and a few words of general guidance on how to couple the FC data for biomes that overlap geographically.

Based on the reviewer's comment, we added the following text:

P15L13-21: "Average FL for this biome is for upland forest types. However, deep peatland deposits (see section 2.10) cover about 107 M ha (Zoltai et al. 1998) or 18% of the North American boreal forest zone (Brandt, 2009) and 16% of the northern circumpolar permafrost soil area (Tarnocai et al., 2009). By contrast, peatlands only cover about 0.07 M ha in the temperate zone, which has higher FL overall. Despite low decomposition rates due to a cold, moist climate, the lower FL in the boreal forest region is primarily a result of slower tree growth rates (biomass accumulation) and frequent to infrequent fire disturbance that can remove substantial amounts of fuel."

P8130, L3-6: The direction a mountain slope faces is called "aspect" and aspect has long been known to correlate with ecosystem variability in the temperate zone as well. There should be plenty of references to that if a discussion of this is appropriate. The effect is only insignificant in the tropics where the sun angles are higher. Of course there are wet-side dry-side issues and altitude based variation in mountains worldwide, but not sure a discussion of "sub-grid" variability is appropriate.

We revised the sentence to:

P16L6-9: "Finally, slope aspect has been shown to have an effect as well, with the south facing slopes having the highest FL and FC due to warmer and drier conditions that better favour plant growth and fire intensity than shadowed north faces (Viereck et al. 1986; Turetsky et al., 2011)."

P8130, L10: "forest" to "deforestation" – it's helpful to distinguish between "deforestation" and "accidental" forest fires.

We changed "forest" to "deforestation" and distinguish between deforestation and accidental forest fires now, as explained in previous comments.

P8130, L19-21 and L25-27: Re "Note that two studies represent shifting cultivation measurements and were not included in the biome average calculation." Why are they in the "pasture" table/section then? Aren't they part of some biome and should they be included in some category such as tropical forest?

We agree that shifting cultivation does not completely fit the pasture category, and therefore we included a new 'shifting cultivation' category in Section 2.6.

P8131, L5-7: The ignition pattern seems like an un-needed detail, especially since it is not given for other fires. More importantly probably, the fuel geometry varies globally from short-lived burning of loose residue in the field to long-lasting smoldering combustion of small hand-piles of residue, both hard to detect from space.

We agree that the description of the ignition pattern can be removed, especially since it is not given for other fires.

In addition, we stress the importance of fuel geometry by adding the following text: P17L27-30: "Moreover, the fuel geometry varies globally from short-lived burning of loose residue in the field to long-lasting smoldering combustion of small hand-piles of residue, and both are hard to detect from space."

P8131, L15: Excellent place to cite the classic work of Yevich and Logan!
We decided to cite the work of Yevich and Logan, which is a classic paper indeed.

P8131, L17: Another good paper on fuel consumption in rice straw burning is Oanh et al., Characterization of particulate matter emission from open burning of rice straw, Atmos. Environ., 45, 493-502, 2011.
Although a clear estimate of fuel consumption is not provided by Oanh et al. (2011), we now included their fuel load measurements of rice straw in our database (available online).

P8131, L18-19: probably doesn't add much to give years of measurements in the text throughout.
We agree, and therefore "Measurements conducted in the crop residue biome were taken between the 1980's and 2010 (Table 1f)" was deleted here.

P8131, L20-22: 88% should be expressed as a fraction to be consistent. Also, isn't 0.88 CC too high for pre-harvest burning, which I understand is the most common type of burning at least globally? It would imply that a) the sugar cane field is almost 90% weeds since pre-harvest burning is to remove undesired plants prior to harvesting the cane, or b) the 0.88 is only for post-harvest burning. Re-examining the study of Lara et al, without providing methodology or references, they simply state that FC for Brazilian sugar cane fields was "about" 20 t/ha. It may be that more reliable info is now available.
We decided to stick to percentages throughout the paper.

The CC for pre- and post-harvest sugarcane in McCarty (2011) is 65%. The 88% CC for all crops (including pre-harvest sugarcane) is taken from the U.S. EPA Greenhouse Gas Inventory Methodology (EPA GHG 2008). We have fixed this citation.

P8131, L22-23 and P8132 L2: 0.88 is expressed as a fraction, but attributed to EPA source on P8132 L2. Whereas earlier the same CC is attributed to both McCarty et al and French et al. It actually doesn't agree that "good" with 0.65 value given on P17, L27. In general it's better to avoid words like "good" and just give percent differences so the reader builds up a quantitative knowledge of well things agree. Also clarify sources if possible.
We appreciate that the reviewer has pointed out this inefficient wording. This line has now been changed to:
P18L4-12: "FC values for different US crop types (McCarty et al., 2011) were used to derive crop-specific FL data (French et al., 2013) and CC values were taken from expert knowledge from agriculture extension agents in Arkansas, Louisiana, Florida, Kansas, and Washington during field campaigns in 2004, 2005, and 2006, as well as from the scientific literature (Dennis et al., 2002; Johnston and Golob, 2004). CC variables ranged from 65% for cotton and sugarcane and 85% for wheat and bluegrass, which are lower but within the range of the CC value (-23 to -3% less than

CC of 88%) used by the Environmental Protection Agency (EPA) of 88% (EPA 2008 GHG)."

P8132, L3: eliminate "wildly." This variability is exactly what you expect for growing different monocultures.
"wildly" was deleted.

P8132, L5-8: Is this a good guess or a documented fact with references? And not sure the FC from the study of Lara et al bears inclusion.
The reviewer makes a good point, and we have revised this text:
P18L13-18: "FC values varied between different crop types, as shown in Figure 6. For US crops the highest FC was found for seedgrass (10 t ha^{-1}) and rice (8.8 t ha^{-1}), while values for soybeans (0.5 t ha^{-1}) and corn (1.0 t ha^{-1}) were lower. In general, US crop values are assumed in the analysis to be approximately representative of other developed agricultural areas like Brazil and Russia (McCarty et al., 2012), but uncertainty increases for less industrialized agricultural areas in Africa and Asia."

P8132, L24: The FC for chaparral of 31.5 t/ha based indirectly on two studies is higher than the total FL in 3 of 4 studies listed in Akagi et al., 2011 Table 2 and higher than the one study by Hardy et al that actually reports FC in the authors work. Having been to several chaparral fires where only the foliage burned and the charred woody biomass remained. I think this number may be too high, but suggest the authors attempt to consult with experts at CalFire or USFS. Alternately, the Cofer et al FC value may just be unreferenced, recycled "conventional wisdom" whereas the Hardy et al measurement is definitely from a detailed, dedicated FC study. If this is the case, the Hardy et al value may deserve much higher weighting.
The study of Hardy et al. (1996) already deserves a higher weighting since it consists of 3 unique measurement locations, while the study of Cofer III et al. (1988) only provides information for one specific location. Therefore, we decided to not weigh the study of Hardy et al. (1996) even more.
However, for the chaparral biome we added a study of Yokelson et al. (2013), and including their measurements lowered the average FC from 32 t ha^{-1} to 27 t ha^{-1}.

P8132, L23-24: Stick to fractions or percentages for CC. Also, the authors seem to be saying they took the Cofer et al FC and multiplied by (1/.78) to get derived Cofer et al FL and then averaged with Hardy et al FL to get ecosystem average FL. If so, be more explicit.
We decided to stick to percentages throughout the paper.

To be more explicit, we rewrote the sentence to:
P19L2-6: "Since Cofer III et al. (1988) only provided a FC for chaparral burning, we used a CC of 76% (average CC from studies of Hardy et al. (1996) and Yokelson et al., 2013) to derive a FL estimate for the Cofer et al. (1988) study. We then used the FL values of all 3 studies to estimate the biome average FL of 40±23 t ha^{-1}."

P8132, L24-26: The last sentence on this page doesn't make any sense to me. Why would a young and old stand essentially reflect no growth and what is "of and the same counts of FC rates"
To prevent the reader from any further confusion we decided to remove this last sentence.

P8133: L3-4: "Southeast Asia"
"South East Asia" was changed to "Southeast Asia" here and also throughout the

remainder of the paper.

P8133, L5: "but only the peat above the water table can burn."
We changed "surface layer can burn as long as it is not waterlogged" to "peat layer above the water table can burn."

P8133, L7: nice pun
Indeed

P8133, L 10-11: What is meant by "(although more variable)"? Also, two more references with tropical peat carbon content, Christian et al., 2003 (JGR) and Stockwell et al 2014 (ACPD) bring total range of peat %C to 53.83 to 59.71.
Since we already provided a range it is obvious that the C content of (tropical) peat varies, and therefore "although more variable" was removed.

We consulted the study of Stockwell et al. (2014) and now refer to their C content range (54 – 60%) for tropical peat.

P8133, L15: It is widely reported that the reason to drain the peatlands was a failed attempt at conversion to rice production and commercial logging doesn't require draining swamps per se. However, some commercial logging also occurred after the fact. You might say "Commercial logging in drained peat swamps has increased their susceptibility to fire."
We changed the text to:
P19L22-23: "Commercial logging in drained peat swamps has increased their susceptibility to fire, especially during droughts (such as during and ENSO event)."

P8133, L18: "four studies provided FC measurements in tropical peatlands . . . " (skip the years throughout).
As suggested by the reviewer, ", conducted between 1997 and 2006" was deleted.

P8133, L19-22: I don't recall seeing pre-fire measurements in most of these peatland studies. In some anyway, I think the FC was estimated simply from post-fire observations of burn depth with prefire conditions reconstructed from adjacent unburned areas.
We agree, and changed the sentence to:
P19L25-26: "In general, post-fire observations of the average burn depth were combined with pre-fire conditions reconstructed from adjacent unburned patches to determine the FC."

P8133, L23: "fire regime" refers to patterns of fire occurrence and not an ecosystem and is misused here and several other places. Suggest "tropical peatland had highest FC ... including overstory"
We deleted "The tropical peat fire regime" and replaced it with "Tropical peatland (including peat soils and overstory)".

P8133, L25-27: Delete "was found to be representative" since there is only one data point! Evidently 314/0.27 was used to calculate 1056 t/ha as the ecosystem average FL? In general for the peatland biome you should make clear when you are considering the peat only and when you are considering the peat plus the rest of the biomass in the ecosystem and also that some peatland fires consume overstory forest fuels, but much of the overstory has already been removed in some peatlands.
Since there is only one data point we deleted "was found to be representative".

Indeed, as stated in P19L27-32, we used an average FL of 314 t ha^{-1} and CC of 27% to estimate an average FC of 1056 t ha^{-1}.

In Table 1i we report in the 'notes'-column which fuel types are considered. We make clear in Section 2.9 that for calculating the biome-averaged values both peat soils and overstory are considered:
P19L27-28: "Tropical peatland (including peat soils and overstory) had the highest FC of all biomes, with an average of 314±196 t ha^{-1}."

P8134, L13-14: In "susceptibility of peat fires to fire during different moisture conditions" delete "fires"?
"peat fires to fire" was changed to "peatlands to fire".

P8134, L16: how will paleoecological studies improve knowledge of FC?
Since an improvement of knowledge of FC from paleoecological studies is not that obvious, we changed the text to:
P20L16-17: "This makes modeling peat fires very difficult and stresses the importance of more field measurements."

P8134, L18-19: This text doesn't make sense as written: "the peat depth was sampled to determine the peat density" L19: is bulk density the same as density? Define "bulk density."
We changed the text to:
P20L19-21: "On each burn site, multiple plots were established and information on the peat density (which is assumed to increase nonlinearly with depth) was used in combination with the burn depth to determine the FC."

P8134, L21: As written this could imply that the two studies had the same average FC value to three significant figures. I think you mean the "average of the two studies." This is a case where the standard deviation of the mean with one study at 42 and the other at 43 very likely underestimates the real uncertainty in the biome average since site to site variability within the studies is much larger than that. Suggest using average uncertainty in this case.
We agree that this can imply that the two studies had the same average FC value to three significant figures, and we indeed mean the "average of the two studies". As suggested, we will present an 'average' uncertainty in this case since the SD presented is likely to underestimate the real uncertainty in this biome. We replaced the text with:
P20L21-24: "No data on FL and CC were provided, but the average FC of the two studies is 43 [42-43] t ha^{-1}. A standard deviation of 25 t ha^{-1} (Turetsky and Wieder, 2001) can be used as the average uncertainty for the boreal peat biome."

P8134, L22-25: Interesting, one might expect the permafrost to prevent deep burning and the hummocks to be better drained and more susceptible to fire?
Interesting finding indeed.

P8135, L5: delete "storage"
"storage" was deleted.

P8135, L10-11: So is there evidence fires are increasing or not?
The reviewer makes a good point, and to emphasize that there is actually an evidence we added a reference and changed the text to:
P21L6-8: "However, the evidence of increasing fire frequency and larger extent of the

fires in the arctic (Hu et al., 2010) may represent a positive feedback effect of global warming, so in the future more fires may occur in this biome (Higuera et al. 2011)."

P8135, L27: change "good" to "sufficient" or somehow indicate the problem is quantity and not quality.
"good" was changed to "sufficient".

P8136, L8: Shouldn't "fire occurrence" be "fuels"? In general, there is more to this than geographic coverage. More complex systems require a larger number of samples to have confidence in the mean and/or trends. The authors may want to consider whether these final sections really prove geographic trends or add new insights beyond what has already been presented and delete them if not.
Indeed, "fuels" could be "fire occurrence" as well, and we changed in it in the text.

Although we agree that there is more to it than geographic coverage, we want to provide the reader some insight on the usefulness of these biome-averaged values, given the amount of field measurements that are currently available. In the end of the Section we summarize:
P23L11-18: "Coming back to the question posed in the beginning of this section, we think care should be taken with using biome-average values. They provide a guideline but the path forward is to continue developing models or remote sensing options that aim to account for variability within biomes, and use the database accompanying this paper to constrain these models, rather than to simply use biome-average values (further discussed in Section 3.2). Use of FC for specific vegetation types within broader biomes (like the different crop types as presented in Figure 6) or fuel categories offers an interesting alternative, and is further discussed in Section 3.4."

P8136, L18: change "in not now" to "is not now"?
We replaced the sentence with:
P22L12-15: "As mentioned for the 'Tundra', where fire may become increasingly important as the region warms, the one set of field samples included in this review may not be a representative of past and future fire."

P8137, L3-5: in general CC can increase as the dry season is prolonged as argued elsewhere for savanna fires (Akagi et al., 2011).
As discussed in a previous comment, we added the following text:
P22L26-29: "In general, both FC and CC may increase over the course of the dry season as large diameter fuels dry out. This was also suggested by Akagi et al. (2011) for the savanna biome, and consistent with a seasonal decrease in MCE as proposed by Eck et al. (2013)."

P8137, L13-14: The forestry literature has dozens of tropical forest biomass measurements for forests of specific ages. They tend to show a nice increasing trend. Here the authors note that "primary tropical evergreen forest, tropical evergreen second-growth forest, and tropical dry forest" have different FC values. I suggest that these categories (or numerical stand age if available) be indicated in the table for models with access to that sort of detailed vegetation information.
We indicated this partly in the 'note' column of the different tables, but since some studies include more than one forest 'age' it was rather difficult to fit. Therefore, we refer the reader/modeler/user to the excel-database that is available online at www.globalfiredata.org/FC, where more detailed information can be found.

P8137, L16-19: Re "Clearly, the definition of a certain biome is not always

straightforward, and the regional discrepancies found within the different biomes should be taken into account when averaged values are interpreted and used by the modeling communities" So here the authors seem to claim that geographic differences in the measurements within the same nominal "biome" are statistically significant, but I don't think that has been proven?
We agree that this may confuse the reader, and therefore we rewrote the sentence so it is not obvious that these geographical differences are statistically significant:
P23L7-10: "Clearly, the definition of a certain biome is not always straightforward, and uncertainty regarding regional discrepancies within the different biomes should be taken into account when averaged values are interpreted and used by the modeling communities."

P8137, L22: delete "more" since todays models need values to use now.
The sentence was changed to:
P23L12-16: "They provide a guideline but the path forward is to continue developing models or remote sensing options that aim to account for variability within biomes, and use the database accompanying this paper to constrain these models, rather than to simply use biome-average values (further discussed in Section 3.2)."

P8137, L20-26: These could be good ideas if they work, but then give some citations to some of these models and at least a summary of how well validated they are. Or a hint that such a discussion is in next section?
We added "further discussed in Section 3.2".

P8138, L10: define "grid cell"
We replaced "grid cell" with "modeling grid cell". To prevent confusion, we deleted "pixel" and replaced it with "grid cell" throughout the text.

P8138, L12: define "pixel"
To be consistent, we deleted "pixel" and replaced it with "grid cell".

P8138, L13: define "fractionation" and explain how this calculation was done in clear terms
We included a more clear explanation on how GFED3 FC values are calculated:
P23L28-P24L2: "To calculate FC we divided the GFED3 total biome-specific emissions estimates (g Dry Matter) in every modeling grid cell by the total burned area observed for every grid cell. Since one grid cell may consist of multiple biomes we followed the GFED3 fractionation of emissions estimates, which represents the contribution of a certain biome to total emissions within one grid cell. Biome-specific information on the area burned within one grid cell was not available, and therefore we assumed that burned area followed the same fractionation as the GFED3 emissions estimates."

P8138, L13-14: define "regions" and "time period" explain why and how seriously does this over/under estimate biome average and is it expected to be biased?
In general, it's a better test of the model to compare GFED values spatially and temporally as closely as possible to the published measurements, because the ability to accurately portray trends or geographic variability (or lack there-of) is the main justification for the extra complexity of using the model. It's not clear at the beginning of the discussion that this apparently is the objective as revealed finally at L17.
To provide the reader with a more clear explanation, we added the following text:
P24L2-8: "This assumption may over- or underestimate biome-averaged GFED3 FC values: For example, in a deforestation grid cell that consists of savannas and tropical

evergreen forests, the contribution of savanna fire emissions to total emissions can be small, even when the contribution of savanna burned area to total burned area observed in a grid cell is actually quite large. In this specific case - when assuming that burned area followed the same fractionation as the emissions- the estimated FC of savannas would be overestimated."

Indeed, it is a better test of the model to compare GFED3 values spatially and temporally as closely as possible to the published measurements. Therefore we decided to only present a comparison of field measurements with co-located GFED3 grid cells, and the comparison with biome-averaged FC values of GFED3 was removed. Although the latter type of comparison may give some useful insight on how well the different biomes are represented by the GFED3 modeling framework, we think that it is outside the scope of our paper to discuss these findings.

P8138, L21: add "co-located" before "GFED3"
"co-located" was added before "GFED3".

P8138, L27-28: To be objective, another possibility that should be mentioned is that GFED underestimates the fire return interval.
We agree, and we now provide more detail on possible causes for the discrepancies:
P24L21-29: "A possible cause for these discrepancies is that field campaigns tend to focus on frequently burning areas, so fuels do not have the time to build up and increase their FL (van der Werf et al., 2010). Because of the relatively coarse 0.5° resolution of GFED3, the fire frequency in GFED is the average of more and less frequently burning patches, and thus potentially longer than in field sampling sites. On the other hand, only a very small portion of the land's surface burns annually (van der Werf et al., 2013). Improved resolution for the models may help to alleviate this problem and bring model values closer to the field measurements, although it is very unlikely this is the only reason for the noted discrepancy."

P8139, L3 "difficulty" to "uncertainty"
This whole sentence was removed, for reasons explained above.

P8139, L4-6: Improving models will not make the field measurements more representative. As far as improving the models, a simple statement that it will happen seems like unsupported, vague speculation. If some specific model advance is planned this could a good place to describe it in concrete terms. Otherwise change "will" to "may"
We changed "will" to "may"

Moreover, we modified the text:
P24L27-29: "Improved resolution for the models may help to alleviate this problem and bring model values closer to the field measurements, although it is very unlikely this is the only reason for the noted discrepancy."

P8139, L10: The statement about "repeated fires" doesn't make any sense yet. Do you mean you increased the fuel consumption for some burned areas to account for follow- on attempts within the same dry season to burn residual material that failed to burn in the first fire of that dry season? All ecosystems have repeated fires at some time scale – especially the savanna so this needs to be clarified. In general, the paper needs to be written so that people who did not do these calculations know exactly what you did.
We acknowledge that the statement needs to be clarified, and therefore we changed the text to:

P24L32-P25L5: "This discrepancy may be partly explained by the fact that repeated fires in the tropical forest domain (when forest slash that did not burn in a first fire is subject to additional fires during the same dry season) are not always included in the field measurements. Within GFED3, on the other hand, these repeated fires were modeled by the number of active fires observed in the same grid cell (fire persistence), which yields information on the fuel load and type of burning (Morton et al., 2008; van der Werf et al., 2010)."

P8139, L18: Another reason to think about providing a column with rough or actual forest age and maybe even fitting a FC vs forest age relationship.
As discussed previously, we indicated this partly in the 'note' column of the different tables, but since some studies include more than one forest 'age' it was rather difficult to fit. Therefore, we refer the reader/modeler/user to the excel-database that is available online at www.globalfiredata.org/FC, where more detailed information can be found.

P8139, L19-28: Wildfire fuel consumption is higher than prescribed fire fuel consumption according to conventional wisdom, common sense, and the data in Table 1 (I think, it would help to label each fire as PF or WF).
We refer the reviewer to his third general comment, where we explain which modifications were made throughout the paper to better distinguish between wildfire and prescribed fire FC.

P8139, L21: "focused" or "included only" or "9 out 10" please be specific.
"focused on" was changed to "included".

P8139, L23: what do you mean by "ground fuels" litter plus duff, duff plus roots, dead and downed wood included? Define terms near beginning of paper and then use as consistently as possible.
Differences in US and Canadian definitions in fuel categories are minor; sometimes, definitions are not exactly the same between scientists in the same country. As long as the definitions are clearly explained (as currently done on P7L23-24 and P7L31-P8L4) we believe that all scientists will understand. To clarify, we did include some changes. All references to "duff" were removed from the text as this is a general forester's term, and we replaced it with "organic soil".

P8139, L25: prescribed fires tend to burn less fuels and the studies that do not include canopy fuels were probably for prescribed fires. While it is easy to imagine the CASA model generating grass and litter and then GFED using a CC assumption to burn some of that grass and litter, I have no clue how FC is calculated in GFED for a complex forest environment and a paragraph summarizing that would be useful. Without that, this section and important comparisons will be enigmatic.
To make this section less enigmatic, we decided to remove the comparison with GFED3 FC for the whole biome. Although this comparison may give some useful insight on how well the different biomes are represented by the GFED3 modeling framework, we think that it is outside the scope of our paper to discuss these findings. We decided to only present a comparison of field measurements with co-located GFED3 grid cells.

Moreover, we now included a more clear explanation on how GFED3 FC values are calculated. A more detailed description can be found in Van der Werf et al., 2010:
P23L25-P24L8: "GFED3 fire emissions estimates (monthly 0.5°×0.5° fields) are based on estimates of burned area (Giglio et al., 2010) and the satellite-driven

Carnegie-Ames-Stanford Approach (CASA) biogeochemical model (van der Werf et al., 2010). To calculate FC we divided the GFED3 total biome-specific emissions estimates (g Dry Matter) in every modeling grid cell by the total burned area observed for every grid cell. Since one grid cell may consist of multiple biomes we followed the GFED3 fractionation of emissions estimates, which represents the contribution of a certain biome to total emissions within one grid cell. Biome-specific information on the area burned within one grid cell was not available, and therefore we assumed that burned area followed the same fractionation as the GFED3 emissions estimates. This assumption may over- or underestimate biome-averaged GFED3 FC values: For example, in a deforestation grid cell that consists of savannas and tropical evergreen forests, the contribution of savanna fire emissions to total emissions can be small, even when the contribution of savanna burned area to total burned area observed in a grid cell is actually quite large. In this specific case - when assuming that burned area followed the same fractionation as the emissions- the estimated FC of savannas would be overestimated."

We expanded the discussion on the differences between prescribed fires and wildfires in both temperate and boreal forest biome:
P25L15-P26L4: "In the temperate forest biome FC was underestimated in GFED3 by 74% compared to the field measurement average for collocated grid cells. In our averaged field measurement estimate we included all measurements presented in Table 1c. As noticed in Section 2.3, it is likely though that studies that provided a total FC (i.e. the FC of ground, surface and/or crown fuels) are more representative for wildfires. Prescribed burns, on the other hand, tend to burn less fuel and therefore the studies that only include ground or surface fuels were probably more representative for this fire type. When focusing on studies that provide information on one specific fuel class only, the field average for the temperate forest would be significantly lower (13±12 t ha^{-1}) as well as the discrepancy with GFED3 (+14%). This FC value of 13 t ha^{-1} may be more realistic for prescribed fires, which contribute to roughly 50% of all temperate forest fire emissions in the contiguous United States (CONUS). Still, it remains very uncertain how well FC measured for specific fuel classes is representative for prescribed fires and wildfires. This issue also counts for boreal forests, where GFED3 overestimated the field measurements by almost 80%. When only including studies that provided a total FC (i.e. the FC of ground, surface and/or crown fuels), the field average for the boreal forest would increase from 35±24 t ha^{-1} to 39±19 t ha^{-1} and the discrepancy with GFED3 would decrease (from +79 to +60%). This value of 39±19 t ha^{-1} may be more representative for boreal wildfires. Note that for temperate and boreal forest measurements sometimes the more restrictive definition of FL (as presented in Section 1) was used, and this can have an impact on FC values as well; if one applies a CC calculated with respect to a restrictive pre-fire FL to total biomass available, the overall FC that was estimated can be too high."

P8140, L11: 1.6 t/ha (also in Table 3) seems like it has to be a misprint as that number is not physically realistic. If not, how can GFED be more than 50 times lower than the measurement average?
That is a very interesting question, which needs further investigation. We removed the comparison with GFED3 FC for the whole biome, for reasons explained in the previous comment.

P8140, L12, It may not be that all the measurement locations were "wrong," but that the overall sample is skewed. It may also be the mix of fire types that might be non-representative. Or the model could be wrong. Change "indicates that the" to

"suggests that the mix of" and add "and fire types" before "shown." It's nice to consider all the data, but a review article may justify having to reject some data.
This part of the text was removed for reasons explained in the previous comments.

P8140, L13: "counts" to "holds"
This part of the text was removed for reasons explained in the previous comments.

P8140, L14: The authors may find that the USDA Cropland by crop type: database is helpful to fine-tune their comparisons http://www.nass.usda.gov/research/Cropland/SARS1a.htm
We used this CDL database in the creation of the French et al. (2013) fuel load map of the contiguous United States (CONUS) to improve the cropland fuel types classification, spatial distribution, and calculation of fuel load in CONUS.

P8140, L17: "measurement" (no "s").
This part of the text was removed for reasons explained in the previous comments.

P8140, L20: change first "on" to "of" and delete "studies on"
This last paragraph was completely removed, since it did not go well together with the rest of Section 3.3.

P8140, L21: Many FL measurements exist also for different aged tropical forests in neotropics.
Interesting, and hopefully we can include these measurements in our database in the near future.

P8140, L22: make it clear if the spreadsheet at the link includes the values in the paper and additional values not in the paper both. Instead of saying "it may change the average" say how it does change the average if included, but also why that was not considered appropriate for the paper.
This last paragraph was completely removed, since it did not go well together with the rest of Section 3.3.

P8141, L1-29: Few things could be improved. First, the FRP/FC relationship is given to three significant figures with no uncertainty three times, which is unrealistic. 0.316 +/- 0.05 seems more reasonable. Plus that's only when there is no obscuration at all. FRP is at best sensitive to the momentary rate of fuel consumption, but not the total FC for the whole fire. FRP could be indirectly related to FC if all of some fire product was detected and that products emission factor was known and highly constrained. But emission factors are variable. And when viewing from space in practice, if a cloud/cloudmask covers the smoke, but not the hotspot, the emission/FRP is essentially zero. When the cloud/cloudmask covers the hotspot, but not the smoke, the emission/FRP is infinite. Thus, the relationship is likely to be fairly uncertain. FRP has to be integrated over the life of the fire to get FRE to estimate FC more directly. Geostationary data (with fifteen minute time resolution) would be better than MODIS for this, but many tropical fires are small and only live 15-30 minutes. In general observed, emitted energy is going to be less than actual energy, but there may be an over-/undercorrection to produce final estimate. The second paragraph says that FC measurements by FRP are "anecdotal" but the third paragraph gives a FC from FRP with no uncertainty attached and seems to indicate that the approach works almost perfectly. Maybe what is missing is whether the "FRP-based" calculation of FC was tuned to match available measurements or if there was fortuitous cancellation of errors, etc. Also be clear if it "worked" at an *ideal point or on a broad landscape scale.*

Based on the reviewer's comments we modified Section 3.3: we now included uncertainty estimates, and provided more detail on the (uncertainty of the) FRE-FC relationship for different fire types:

P25L33-P26L4: "Besides a comparison with GFED3 data, we performed a comparison of field measurement averages with fire radiative energy (FRE, time-integrated FRP) derived estimates as well. The basis of the FRE approach for estimating FC is that the heat content of vegetation is more or less constant, and that the FRE released and observed through a sensor can be converted to FC by the use of a constant factor, which was found to be 0.368±0.015 kg MJ^{-1} across of a range of fuels burned under laboratory conditions (Wooster et al., 2005). More recent field experiments, however, indicated that the conversion factor might be slightly lower for grasslands in North America (Kumar et al., 2011; Schroeder et al., 2014). Smith et al. (2013) investigated the relationship between FC and FRE for pine needles with different fuel moisture contents, and found that FRE released per kilogram biomass consumed decreased with fuel moisture content due to the energy required to evaporate and desorb the water contained in the fuel. Thus, corrections for FRE based FC assessments may be needed for fuels that burn at higher fuel moisture contents (such as peat). Differences in heat content of fuel may introduce additional variation: For example, a clear relationship between FRE and FC has not yet been demonstrated for fires with a significant consumption of smoldering prone fuels, like e.g. organic soils in boreal forests or large woody debris and trunks in tropical deforestation regions. Another potential source of uncertainty in the relation between satellite-derived FRE and FC is the correction for atmospheric disturbances, which may significantly alter FRP retrievals and hence estimates of FC (Schroeder et al., 2014). Note that, currently, atmospheric correction is not performed for the standard fire products derived from MODIS. Moreover, Schroeder et al. (2014) also indicate that cloud masking in the MODIS FRP product may lead to FRP underestimates as hotspots under thick smoke may be erroneously masked out.

Despite all these uncertainties, there is a number of studies that relate FRE to FC on regional (Roberts et al., 2011; Freeborn et al., 2011) to global scales (Vermote et al., 2009; Ellicott et al., 2009), and Kaiser et al. (2012) used FRE to represent biomass burning in an operational chemical weather forecast framework. However, since such estimates can be derived independently of burned area, only a limited number of studies allow a straightforward comparison to the FC values given in mass units per area burned from the field experiments used in this study. Hence, evidence of performance of FRE-based methods against field experiments is more of an anecdotal nature.

A common finding of FRE-based estimates is that FC is generally lower than GFED estimates, as shown by Roberts et al. (2011) who estimated FC for Africa through an integration of MODIS burned area and Meteosat Spinning Enhanced Visible and Infrared Imager (SEVIRI) derived FRP and found values that were about 35% lower than GFED. For the savanna biome a median FC of ~4 t ha^{-1} was found for grassland and shrubland. The 75th percentile was about ~7 t ha^{-1} for grassland, and 8 t ha^{-1} for shrubland, while the 25th percentile was about 2 t ha^{-1} for both grassland and shrubland classes. The median for wooded savanna was ~5 t ha^{-1} (75^{th} percentile: ~9 kg ha^{-1}, 25^{th} percentile 2 t ha^{-1}). These values correspond relatively well with the mean of 4.3±2.2 t ha^{-1} and 5.1±2.2 t ha^{-1} found in grassland savanna and wooded savanna field studies, respectively. Boschetti and Roy (2009) explored temporal integration and spatial extrapolation strategies for fusing MODIS FRP and MODIS burned area data over a single large fire in a grassland dominated area with sparse eucalypt trees in northern Australia. They estimated a FC range of 3.97 to 4.13 t ha^{-1}, which is well within the range found in the Australian FC studies summarized in

Table 1. Kumar et al. (2011) exploited properties of the power law distribution to estimate FC from FRP for an Australian savanna and a study area in the Brazilian Amazon. While their FC estimate of 4.6 t ha^{-1} of the Australian site is similar to the temporal integration results of Boschetti and Roy (2009), the estimate for the Brazilian site is above 250 t ha^{-1} and thus substantially higher than the biome-averaged value for Brazilian tropical forest (117±56 t ha^{-1}). This large discrepancy may suggest that FRE approaches have difficulty with estimating FC in regions of tropical deforestation.
In general, realistic values are often obtained for well-observed fires, but unrealistically low or high values can often occur especially for smaller fires due to the sparseness of FRP observations and inaccuracies in the temporal interpolation and the burned area estimates. While FRE seems to provide realistic estimates under a range of conditions, issues of undersampling of FRE and -maybe less important - the conversion of FRE to FC still remain to be addressed more completely in order to derive spatially explicit FC estimates using the FRP approach."

P8142, L5-6: Most of the burning in Brazilian Amazon is pasture fires or crop residue fires so 250 t/ha is really high unless the study site was small enough to only include slashed and burned tropical forest.
The FC estimate of 250 t ha^{-1} from Boschetti and Roy (2009) is indeed very high for a region where a substantial part of the burning is coming from pasture fires, crop residue burning and shifting cultivation. However, GFED FC for the co-located grid cells estimated a FC of 215 t ha^{-1}, which is relatively close to the Boschetti and Roy (2009) estimate. Since a clear relationship between FRE and FC has not yet been demonstrated for fires with a significant consumption of smoldering prone fuels, like e.g. trunks in tropical deforestation regions, we now point out that the FRE derived FC for tropical forest regions is highly uncertain:
P28L9-14: "While their FC estimate of 4.6 t ha^{-1} of the Australian site is similar to the temporal integration results of Boschetti and Roy (2009), the estimate for the Brazilian site is above 250 t ha^{-1} and thus substantially higher than the biome-averaged value for Brazilian tropical forest (117±56 t ha^{-1}). This large discrepancy may suggest that FRE approaches have difficulty with estimating FC in regions of tropical deforestation."

P8144, L1: "reasonable" to "reasonably" and add "co-located" before "measured" Somewhere in conclusions the fact that measured/GFED3 FC for temperate forest is 93/1.6 unless this is rectified during the revisions.
As suggested by the reviewer, we changed "reasonable" to "reasonably" and added "co-located" before "measured"

The comparison with GFED3 FC for the whole biome was removed, and therefore the temperate forest discrepancy was not mentioned in the Summary Section.

Table 2b: "logs" versus "large woody debris" same thing or different?
To prevent confusion, and given the fact that both fuel types are sometimes overlapping, we now merged them into the new category 'Woody debris (>20.5cm), Trunks'

Table 2c: the FL of the litter alone is greater than the total FL in Table 5 of Yokelson et al 2013. As a former wildland firefighter, prescribed fire lighter, etc I think 60% CC for duff and 96% CC for dead downed logs is only applicable to extreme fire conditions. These fuels quite often experience only surface charring. I would say more typical is 10% CC for each of these fuel components during wildfire season.

Measurements from the study of Yokelson et al. (2013) were now included in our database, and their total FL was indeed lower than the FL for litter as presented in Table 2c. Our estimates are based on all peer-reviewed studies that provided specific information on FL, CC, and FC for different fuel classes. FL of litter was found to be high, and the same holds for the CC of dead woody debris. However, these findings are based on a few studies only, and therefore we emphasize in Section 3.4 that "more field measurements are needed to decrease the uncertainty and better understand the variations found".

Fig. 2: Use "Wooded Savanna" instead of "Woodland" which is easier to confuse with forest?
We replaced 'woodland' with 'wooded savanna' in Figure 2. Moreover, "grassland" was changed to "grassland savanna".

Fig 6: make clear all US (McCarty) except Lara is Sugarcane Brazil.
The figure caption was changed to: "Fuel consumption (FC) rates for different US crop types as reported by McCarty et al. (2011), except for Brazilian sugarcane (Lara et al., 2005)."