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Interactive comment on "Global top-down smoke aerosol emissions estimation using satellite fire radiative power measurements" by C. Ichoku and L. Ellison

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Detailed Responses to the comments of Anonymous Referee #2:

This paper builds on the previous work of Ichoku & Kaufman (2005), seeking to improve the approach and reduce uncertainty by applying new data (e.g. MODIS C5) and methodologies. For example, attention to the revising the algorithmic approach to estimating fire AOT is noteworthy and welcome. The authors are commended for addressing uncertainty in their data and algorithm as well as attempting to fill gaps in the data. Comparison with other inventory sources of emissions (e.g. GFEDv3) is helpful, but as the authors suggest, is not yet a matter of validation. Nevertheless, the paper offers the approach and resources (e.g. their website) to continue to improve biomass burning emission estimate using satellite data.

Authors: Thank you very much. We truly appreciate the time and effort the Referee has invested in reviewing this manuscript and providing objective comments, which have resulted in a much improved revised version of the manuscript.

Page 27330, Line 21: Andres et al., 2012 citation not in the reference section.

Authors: Reference has been added.

Page 27336, Line 20-21: Spatial and, especially, temporal resolution seems like it would introduce error. Winds, especially local fire-affected and generated weather can change rapidly. I realize data limitations may not allow a finer detail of understanding, but comparison with local weather station data (when available), perhaps conducting some analysis within the U.S., could reveal the potential and real bias introduced by using this course resolution dataset.

Authors: We acknowledge the risk of the spatial and temporal limitations of the wind data in our analysis. However, we have endeavored to use one of the most optimal global wind data available. MERRA reanalysis wind data and other meteorological variables are global and very widely used by the research community, and we considered it appropriate to use these data in our research. We consider specific validation of the MERRA wind data using measurements from local weather stations to be outside the scope of our work, as such verification activities must have been done to some extent by the large and

competent team that produces the MERRA data. Besides, any weather stations we may find, may not be located close enough to a fire to resolve the finer details of the wind patterns around the fire environment, and may be so few and far between to enable us to generate a global Ce product as we have done. In future versions, we plan to always continue to find and use the most optimal global wind data available.

Page 27339, Lines 16-17: "except that for the..." – Awkward statement, rephrase.

Authors: The statement has been clarified to: "However, when an individual τ_{a550}^{f} value is negative, it is set to zero."

Page 27338, Line 18 and 27376, Figure 1: this appears to be an ideal case. What happens when wind speed and direction make quadrant selection ambiguous? In addition, and perhaps more importantly, how can you/do you differentiate smoke sources when fires occur across the landscape? I am thinking of savanna regions such as Africa or Australia where widespread fire activity will result in you 3x3 window being "contaminated" with additional fires and thus sources of smoke.

Authors: The calculation for quadrant selection is very specific (using the fire-local wind direction in relation to the satellite track direction), so that one quadrant must be selected for each fire. As mentioned in the manuscript, the wind quadrant is correct about 80% of the time. Cases where the wind speed is very small, as well as other potentially sub-optimal situations, are identified and filtered out before calculating Ce to reduce ambiguity, as described in detail in section 4.3, using the thresholds defined and listed in Tables 2 and 3. We have also provided further detail on our algorithm for handling background smoke contamination in section 4.2.

Page 27340, Lines 13-18: Derivation of L – clarity/better description is needed. Assuming the length is based on the dimensions of the downward pixels would seem to be, at times, a gross overestimate of the plume length.

Authors: In cases where plumes are short, L can be grossly overestimated, leading directly to a similar overestimation in deriving the time, T. However, we have now elaborated this aspect of the work by plotting the probability density functions (PDFs) for T at different threshold settings in a new figure and corresponding description in a new paragraph in section 4.2. Although our method of using thresholds for quality assurance measures did improve the distribution of T significantly, we have now acknowledged in the manuscript that future versions of FEER Ce will need to deal more regimentally with this issue.

Page 27341, Line 24: Why rationale for 6 points as the minimum. Why not more/less (though the latter seems trivial)?

Authors: We considered 6 to be "the number of data points that seems minimally reasonable for linear regression fitting" and have added this quoted clause in the text.

Page 27342, Lines 4-5: Applying Ce from regional averages to individual pixels, let alone near-real time, sounds like ripe with potential bias. Hopefully this is discussed later, but a caveat should be mentioned...e.g. "even in near real time, while addressing/ accounting for/keeping in mind the inherent biases..."

Authors: You are right. The following clause has been appended ", bearing in mind the possibility of large biases due to the inherent differences in individual fire characteristics even within the same fire regime."

Page 27343, Lines 10-11: How is the improvement in AOT methodology better than Ichoku & Kaufman (2005)? Refer to later analysis in the paper to support this statement.

Authors: We have appended the following to the affected sentence: "…, which resulted in C_e values that were found to be overestimated (Sofiev et al., 2009; Kaiser et al., 2012), as discussed in Section 4.6".

Page 27345, Line 12: Define "semi-randomly". How do you choose these sites? This last question is addressed, broadly in the figure caption (i.e. fire type, biome, etc...) but should be in the text as well with greater specifics for, presumably, how this is "semi-random".

Authors: We have inserted the following explanation into the text: "The selections were made by examining random grid cells spread out throughout the entire globe and manually ensuring that the final selection maintained diversity in location, fire type, biome, number of data points, and expected goodness-of-fit of linear regression."

Page 27347 Line 12 and Figure 3: Describe the meaning of the color-coding. Although it seems rather intuitive, it is good practice to define color-coded schemes such as this.

Authors: A short description of the color scheme has been added to the table caption.

Page 27348, Line 12: I would suggest using a different word than "clean" as this implies the data is without impurity...as you go on to discuss it is not and even underlying errors in FRP and AOT estimation might are included in "clean" data.

Authors: "… creating clean …" has been substituted with "… retaining the relatively higher quality …"

Page 27349, Line 23 & Figure 5: The difference seems rather negligible, with the greatest differences occurring near the low-end of Ce. It might add value to suggest what the resulting difference is in terms of emission load.

Authors: We have looked at the resulting Ce product map (in Figure 7) when the outlier algorithm removal was not applied, and admittedly at that scale the two products look similar. However, we recognize that for many of the 30% of the grid cells that have outliers removed by our algorithm, the difference is significant for those specific instances. We anticipate that a large majority of users will need the Ce product not just

globally but also regionally – down to even using only one grid cell's Ce value in some cases. We have already done so ourselves in another recently published paper about our collaboration with an experimental burn in California a few years ago (Schroeder et al. (2014) *Remote Sens. Environ.*, 140 (2014) 719–730). That is why we deem it important to apply whatever correction schemes we found appropriate to improve our Ce product.

Page 27350, Lines 9-10: Justify why filtering and outlier processing were primarily driven by Aqua-MODIS data. Why was Terra-MODIS not given equal footing?

Authors: Terra-MODIS and Aqua-MODIS for the most part produced similar results, as explained in Page 27350 lines 2–3. However, given that only samples (rather than the entire datasets) are used in developing the filtering and outlier-removal algorithms, decisions had to be made regarding which samples would serve the required purpose(s) most optimally, while also avoiding spending too much time analyzing more data that would ultimately not increase the value of the results. Aqua-MODIS, which is on the afternoon overpass orbit, invariably has more data related to biomass burning than Terra-MODIS (by about a factor of two). Therefore, given that the two datasets are not too different, we decided to draw samples from Aqua-MODIS, which would be more representative of the full combined dataset.

Page 27352, Lines 10-12: Awkward sentence; considering rewording.

Authors: Sentence has been reworded.

Page 27352, Lines 10-19: This process of gap filling based on a 15x15 grid cell window would seem difficult to achieve if the requirement is to find identical fire-prone land cover type. Traveling that far from the center, candidate cell would almost certainly incur differences in land cover, land use, and fire regimes for many areas around the globe.

Authors: Please accept our apologies for the confusing way we described this. The confusion was in our explanation of QAmin selection, which was first done using the 15x15 window, and then the sampling starts at 3x3 and goes outward. We have reworded the paragraph so that it is clear that we begin with a 3x3 window, and expand out to 15x15 *only* as necessary.

Page 27352, Line 22-29 and Figure 7: It is worth pointing out that most of the gap-fill resulted in low Ce values, even for areas, which presumably have higher real Ce (e.g. portions of northern North America and Asia, and SE Asia – Indonesia/Malaysia). In addition, the figures 7b and 7c seem to reflect fire counts (high confidence, r2) and areas of persistent cloud cover (low r2)

Authors: It is pertinent to recall that three other levels of QA were introduced to what is shown in Figure 6 before interpolated gap-filling was done. However, these gap-filled locations are found in areas that burn very little, such that the fill values are derived from the few Ce values that are available. The forest in Indonesia is likewise filled with the already low values computed in Figure 6, except for Java, which is composed of mostly

cropland and savanna fires. In China, we do see large gap-filled values in the eastern reaches of the fire domain that is dominated by cropland and grassland. Therefore, it seems that the gap-filled values of Ce are not always low, but do follow the land-cover type fairly closely.

Concerning the QA and r^2 maps reflecting fire counts and areas of persistent cloud cover, this might be coincidental, indeed, because of different factors associated with fire occurrence, cloud cover, and satellite observation. However, Equation 15 deals with the introduction of lower-QA data into the data product because of the fact that we use r^2 as a parameter that must be improved. Thus, the resemblance of the QA map to a fire count map may be due to the fact that many grid cells are completely missing in the highest-QA Ce map, but may exist at lower QA that when introduced reflects the low fire occurrence. Also, at the suggestion of Reviewer-1, we have introduced a new Table that shows the counts of grid cells with the QA values relative to different r^2 ranges.

Page 27358, Lines 17-24 & Figure 9: The GFASv1.0 FRE is a very rough summation of FRP and can hardly be considered FRE. Though it may be an available data source of "FRE", I would strongly encourage you to clearly describe the limitation of this estimate of FRE and corresponding emission especially when comparing with other (i.e. bottom-up) inventories of emissions. You should also point out in the Figure 9 caption that you not just using monthly average FRP, but a monthly "FRE" value generated by multiplying the average by number of days per month.

Authors: We have inserted the following statement in the text, highlighting the likelihood of large uncertainty in the GFAS.v1 FRE, and providing justification for why we used the data: "Such derivation of monthly average FRE based on only four or less MODIS fire observations a day (from Terra and Aqua satellites) cannot capture the fire diurnal cycle, thereby resulting in high uncertainty. However, that is currently the only feasible way to obtain FRE globally. Higher frequency (sub-hourly) observations from a few available geostationary satellite sensors that measure FRP have different characteristics and produce an average of 17%–38% underestimation relative to MODIS (Roberts et al., 2005; Xu et al., 2010). Moreover, a combination of these geostationary FRP data still does not provide global coverage, as some large biomass-burning regions, including Siberia, Central Asia, and India, are left uncovered (Zhang et al., 2012). Since the GFASv1.0-based FRE data are global, publically available, and being used in the European Union's Monitoring atmospheric composition & climate (MACC) project (http://www.gmes-atmosphere.eu/about/project_structure/input_data/d_fire/), they were considered appropriate for use in deriving emissions using the FEER.v1 C_e product to enable comparison with existing emissions inventories, as described below."

Figure 9 caption has been further elaborated as recommended.

Page 27359, Lines 27-29: "Globally,.." Reword this sentence, specifically the "constitute only about 55% of it". "It" is confusing and vague.

Authors: The sentence has been reworded to remove ambiguity.