Response to anonymous reviewer’s #2 comments.

The authors thank the reviewer for their insightful and constructive comments. Our responses to anonymous reviewer's #2 comments are detailed below. Reviewer’s comments are in italics and our responses in standard font.

General Comments:

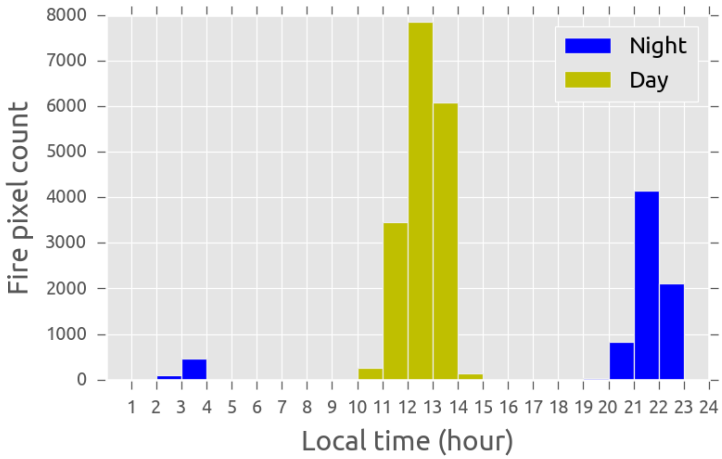
Your atmospheric simulation of smoke transport explicitly retains all smoke in the boundary layer. Wind shear in the vertical column, and other transport differences, will be a source of error in your estimates of smoke from many active fires that release smoke above the boundary layer (around 20% according to Val Martin ACP 2013 and Peterson 2014 JGR, but both of these estimates are based on satellite data with 1030am local overpass time, and thus likely conservative relative to overall fire behaviour). Is there any way these effects can be estimated with the data you have corralled for this study?

Indeed, restricting injection heights to the top of the planetary boundary layer is a limitation to the method. While the quantification of error and bias introduced by this limitation was not achieved, the authors expect that this effect is small when compared to other sources of uncertainty, both accounted and unaccounted for in the manuscript. Energetic burning episodes when smoke is injected directly into the free-troposphere can be expected to have significantly different transport pattern when compared to our within-PBL transport model output. And as a result, many of such cases should have been filtered out by the MODIS AOT and modelled plume extent matching step in the analysis. Consequently, this limitation should be primarily manifested as a selection bias in the results, excluding the most energetic events from the sample.

The difference between boreal and temperate fires’ day-night behaviour is an interesting sidelight to this work. However, there is a good chance it is an artifact, and you must explore this before you finalize the paper. The basic idea is this: Terra and Aqua MODIS have nominal equatorial overpass times of 1030 and 1330 local solar time (LST, this can be calculated as UTC+[longitude/15.], where longitude is from -180 to 180), with the opposite orbital nodes crossing at 2230 and 0130 respectively. At higher latitudes, the wide MODIS swath covers a larger range of LST. Thus, a portion of the 2230 Terra swath will have LST<2100, and that portion will increase with latitude. So, if you define “daytime fires” as fires detected from 0900-2100LST, this will include all fires from the 1030 Terra overpass, all fires from the 1330 Aqua overpass, and depending on latitude, some fires from the 2230 Terra overpass. In order to avoid this, you should run the calculation using daytime=0600-1800LST, and see if the boreal-vs-temperate difference you observed holds up. I have attached a figure to illustrate this point, based on the MOD14 MODIS fire product.

The authors want thank the reviewer for this detailed comment. The problem here was that we did not state clearly how the daytime to night-time fire pixel counts were derived. The 0900-2100LST periods were used to emit particles, not to determine if an observation represents daytime of night-time burning. The authors were aware of the large spread of LST values for northern latitudes and therefore all fire detections from Terra overpasses with equatorial crossing time 2230 were considered to be night-time observations.

Please see the figure bellow, which shows counts of fire detections per local hour and day - night classification for all fire events analysed in the manuscript.



We have added a clarification on how fire detections were classified as daytime or night-time fires into section 2.33

“Emission source number and locations for daytime periods were determined from the highest number of fire detections observed during a single either Terra of Aqua daytime overpass with 10.30 and 13.30 equatorial crossing time. Similarly, emitted particle source number for the night periods were determined by the largest burning extent observed during one of the night-time overpasses with 22.30 and 1.30 equatorial crossing times. Notably, the Terra overpass at 22.30 in high latitudes makes observations of regions where local time is earlier than 21:00. In this study, however, all fires detected during this overpass were classed as night-time observations.”

*page 4 Section 2.5 AOT attribution. This is the first of several very complicated steps, it is worth the effort to express very carefully how this was done. You have these ingredients: 1) modelled plume extent: this is a point cloud with the locations of all the smoke particle endpoints at solar noon on each day 2) MODIS AOT: you have the centroid location and retrieved AOT of each valid AOT retrieval on the day 3) background MODIS AOT: you have MODIS AOT and centroids for valid retrievals from two days prior to construct the background estimate As I understand it, you take these steps: 1) you interpolate modeled plume extent to 25km equal area grid, taking every grid cell that contains a portion of the plume and including it in the sample; 2) you interpolate MODIS AOD to the same 25km equal area grid; 3) you determine whether the number of valid same-day MODIS AOT data is at least (plume area /100km2)*0.8 (“80% coverage of plume area”)*

If #3:
4) You calculate the background AOT using the 2-days-prior AOT 5) you calculate the smoke AOT increment for each grid cell by subtracting background AOT from same-day AOT If the median AOT increment is > 0: 6) you set negative AOT increments equal to zero 7) steps 1-6 are repeated for smoke transport times of up to 3 days, in increments of 12 hours. 8) If multiple days / multiple fires contribute to a grid cell AOT increment, you apportion the grid cell AOT increment to fire events and emission periods according to the number of smoke particles from the HYSPLIT simulation in each grid cell Note that the cutoff in Step 3 will systematically eliminate coverage from scenes covered by the MODIS swath edge, because the smoke retrievals will be too few to cover the area based on the assumed 100km2 retrieval footprint.

Thank you for the detailed suggestions and advice on how to describe the method. This section is conveying very complex processing steps and we perhaps didn’t achieve sufficient clarity. The section has been rewritten following the above advice and clarifying what was not stated properly. It

is our belief that the method description now reads better and it is much more clear what was done in order to obtain our estimates:

“Elevated MODIS AOT observations were attributed to a specific fire event and emission period by comparing above background MODIS AOT retrievals to plume extent modelled by HYSPLIT (Fig. 1). The attribution required to determine three pieces of information; (i) event-specific background AOT value, (ii) modelled plume extent at local solar noon for each day of burning and (iii) coinciding MODIS AOT observations. First of all, background AOT value was estimated for each of the selected burning events. It was determined by the median value of the AOT retrievals within 150 km radios from the fire event centroid observed two days prior to ignition. For each day of fire activity, modelled plume extent (Fig. 1 (D–F)) was determined from the locations of all HYSPLIT particle endpoints at solar noon, and AOT observations (Fig. 1 (A–C)) from either Terra or Aqua platform with the highest spacial coverage for the day and plume area were selected.

After the required information was obtained, the following steps were performed for each day of burning attempting to estimate fire-emitted AOT. First, plume regions bounding the particles released during the previous three daytime and night-time emission periods were identified. Estimation of emission was attempted individually for each of the regions representing plume areas emitted during a specific time interval. This allowed the estimation of emitted AOT for up to three previous days from a single day of MODIS imagery. Importantly, such approach allows the estimation for some emission periods even if full MODIS plume overview is not available. Emitted AOT attribution was performed for the plume regions which satisfied two conditions. The region had (i) at least 80 % of MODIS AOT areal coverage assuming that a single AOT pixel represents 100 km 2 area, and (ii) with-region AOT median value was higher than the estimated background value for the fire event.

MODIS AOTs for the selected plume regions were interpolated to a 25 km resolution equal area grid (Fig. 1 (G--I)) by employing radial basis function interpolation with a~linear kernel. Fire-emitted AOT were estimated by subtracting the background value from the within-plume AOT. The estimated fire-emitted AOT in every within-plume grid cell was apportioned to different emission periods and different sources based on information on release time and source of the HYSPLIT particles contained within the cell. If all particles found within a grid cell were released during the same emission period and originated from a single source, the cell's AOT was simply attributed to that emission period and source. If a mixture of particles were found within a cell, indicating that multiple fires and multiple emission periods contributed towards the grid cell AOT, the attribution was performed by apportioning a~grid cell's fire-emitted AOT in proportion to the numbers of modelled particles released during the emission periods and with origin found within the grid cell. For example, if a grid cell had AOT value of 1, and 100 HYSPLIT particles were located within the cell during the satellite overpass, 80 of which were emitted two diurnal cycles ago, and 20 during the previous diurnal cycle, the grid cell AOT was split accordingly between the emission periods. Panels K and L in figure 1 illustrate partitioning of total plume AOT to two different emission periods. Similarly, if there were any particles emitted from different fire events, grid cell AOT was divided both between different emission periods and different fire events.”

page 2 Line 55: “Consumed biomass estimates inherit errors of fire location”. The papers cited here cover a lot of ground, but I don’t think they really cover errors associated with fire location. That source of uncertainty is described by Hyer and Reid (GRL, 2007).

Thank you for this suggestion, the reference has been added to support the relevant statement.

page 3 line 11 “larger than 100km2 and with duration longer than 7 days” Please elaborate slightly on the data and calculations used for these determinations, especially the 7 days.

The paragraph has been updated detailing what was meant by “larger than 100km2” and “duration longer than 7 days”. Fire event size was determined by the size of the bounding box containing all fire detections for the event. Event duration was determined by the time span between the first and the last MODIS fire detection for the event. Burning episode was considered continuous if there were no 24h or longer gaps between the consecutive observations.

page 3 line 15 the Stocks and Kasischke papers relate to fire size distribution in the boreal forest. While the dominance of large fires has been documented for certain parts of temperate north America (see Strauss, Bednar, and Mees, Forest Science, 1989), it does not hold for all areas and in any event is not covered by those citations.

Thank you for noting this. The paragraph was changed clarifying: “Burning episodes larger than 100km^2 are not numerous, but account for more than 80% of total burned area in boreal North America (Stocks 2002, Kasischke 2002)” and “are a dominant mode of burning in parts of temperate regions as well (Strauss et al., 1989)

Page 3 line 25 “particles were continuously injected” HYSPLIT in your configuration simulates transport of discrete particles, please specify the interval at which particles were released in HYSPLIT Page 3 line 25 “vertically distributed” please specify the discrete intervals at which
particles were released in HYSPLIT page 3 line 25 “within the planetary boundary layer” as diagnosed by GDAS? Please specify.

This section has been rewritten as requested by other reviewer, addressing all issues raised here as well. The specific points are clarified bellow.

“particles were continuously injected” has been changed to “20 particles released per hour per each active fire pixel within the fire event”.
“vertically distributed” was changed to “uniformly distributed between the surface and the top of the boundary layer as given in the GDAS archive”

page 4 line 6 “is about twice the size at swath edges.” Actually, the single MODIS pixels increase roughly 8x in size from nadir to swath edge, and the 20x20 pixel footprints used by MxD04_L2 increase proportionally. However, there is significant overlap between MxD04_L2 footprints at swath edge, see Sayer et al. (http://www.atmos-meastech.net/8/5277/2015/). You may not need to quantitatively account for this for this study, but you should be aware of this.

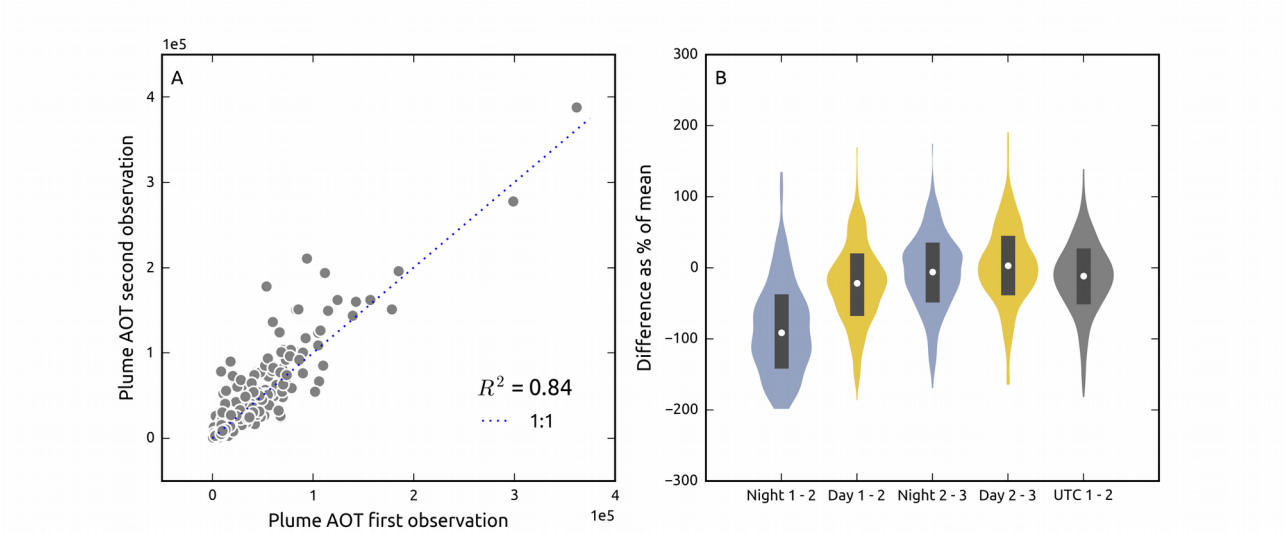
Thank you for noting this discrepancy. MODIS pixel size is indeed ~9 times larger at the edge of the swath as demonstrated in the suggested study (Sayer et al., 2015). The relevant paragraph has been updated stating “...10 x 10 spatial resolution at nadir. MODIS pixel size increases with view angle, and pixels at the edge of the swath are approximately 9 times larger.

Page 4 Section 2.4 how were AOT data selected from MxD04_L2 (quality flags, cloud fraction, etc.)?

The selection criteria were added to the text “all retrievals with quality assurance confidence > 0 were selected. To maximise coverage, no cloud fraction filtering was applied.”

Page 7 line 21: “the agreement between two or more estimates for the same emission period is reasonably static across the plume age categories.” I do not see where this is shown in figures or tables. If it is there somewhere, please direct the reader to it when you make this statement. One simple change would be to add a second panel to Figure 5 showing the agreement between Day 1 and Day 3 AOT for the same event/time pairs.

Indeed this statement was not supported by any of the figures. As suggested, we have now included panel B to Figure 5 showing difference between two estimates obtained at different stages of plume development. The statement now refers to the new figure.



Minor corrections and typos

Thank you for taking time to find these mistakes. The authors apologise for leaving them in. All of these now have been corrected.