Biogeosciences Open Access

Discussions

Interactive comment on "Global analysis of radiative forcing from fire-induced shortwave albedo change" *by* G. López-Salda na et al.

G. López-Salda na et al.

gerardolopez@isa.utl.pt

We would like to thank anonymous referee #2 for the valuable contributions to the manuscript specially when pointing out the impact of dealing with datasets with different spatial resolution.

Anonymous referee #2 Response: As the referee points out, this is the first attempt to study a large area, in this case the whole Earth's land surface and quantify the impact of fires on the energy balance system.

General comments In general I found that it would be much easier for the audience to absorb the main findings if the results and discussions were better organized. for example, one paragraph for spatial distribution (e.g., a global map of 11 year long term

C6006

mean would be very valuable), one for interannual variation and extreme fire impacts, one for land cover differences, and etc.

The results section will be modified to show findings in a top down approach, going from the global to the regional results. We will add the following paragraph and plot at the beginning of the results section:

Figure 1 illustrates the global spatial distribution of mean radiative forcing caused by "instantaneous" shortwave albedo changes on areas affected by fires. Most fires occur in the tropical and sub-tropical environments. High values of radiative forcing, e.g., greater that 5 Wm-2 in those areas, shown in dark red tones, might suggest frequent intense fire occurrence like in South Sudan, Angola and Northern Australia, whereas low forcing in dark blue tones, like the big cluster in Ukraine and the South West corner of the Russian Federation are related to frequent non intense fires.

A subsections to address the interannual variability and land cover affected will be included in the results section as follows:

Interannual variability and land cover affected

The main discrepancies between area burned and radiative forcing occur in the period of 2005–2007, where intermediate-high area burned is associated with the lowest values of radiative forcing in 2005 and 2007, and a high abrupt peak in 2006. The greatest drop in mean shortwave albedo change occurs in 2002, which corresponds to the highest total area burnt (3.78Mha) observed in the same year and produces the highest mean radiative forcing (4.5Wm-2) (Fig. 2). The lowest short-wave albedo change values in 2005 and 2007 are not associated to low area burned and similarly the lowest and very abrupt drop of area burnt in 2009 does not produce the lowest albedo change and radiative forcing (Fig. 2).

Most fires occur in the Sahel (Fig. 5) and the Australian savanas (Fig. 6) corresponding to an average up to 89 % of the total global area burnt, whereas the highest radiative

C6007

forcing per unit area is located in forests of Australia in 2003 and 2006, Europe in 2010 and Asia in 2003, with mean continental values of 15.435Wm-2, 15.26 Wm-2, 13.98 Wm-2 and 8.55 Wm-2 respectively (Fig. 3).

In croplands, Asia shows the greatest oscillations with a minimum of 2.11 W m$-$2 in 2004 and maximum of 6.1 W m$-$2 in 2008 (Fig. 3). The rest of the continents show a low variability in cropland areas, with the exception of Australia in 2003 showing a steep peak of 6.54 W m$-$2. In non-forests, the highest radiative forcing is in North America in 2004, in Europe in 2010 and in Asia in 2003 and 2010. High oscillations are also observed in Australia with an abrupt drop in 2010, contrasting with very stable inter-annual cycle of Africa.

The extreme events will be addressed in the "Discussion and conclusions" section as a subsection which includes a modified figure 3:

Extreme events

Continental Europe includes Russian territories and, has as eastern borders the Ural mountains, the Ural river and the Caucasus mountains, as well as the water line of Caspian lake. Therefore, the anomalous fire events in July 2010 around Moscow are included in European continent. On an annual basis, in Russia, 90–95 % of burnt areas are located in the Asian part of Russia with the majority (59.3 %) being forests, with the exception of the extreme event of 2010 (Shvidenko et al., 2011). The abrupt peak in 2010 in Fig. 3e corresponds to that event exactly with mean annual value for forests in continental Europe of 13.98 Wm-2. The mean continental value is more realistic when compared to the massive maximum number of 167 Wm-2 for the same event including aerosols in smoky conditions found in the literature (Chubarova et al., 2012). Similar extreme events can be observed in Fig. 2f in 2003 and 2006 in Australia, depicting the Eastern Victorian alpine fires, which burnt 1.3Mha in 2003, and the Grampians in Victoria in 2006 that burned 184 000 ha. A plausible explanation is that a weak to moderate El NinÌČo event had a very strong impact in Australia causing the major

C6008

2002–2003 drought had rainfall deficiencies over the period March 2002 to January 2003 (Australian Government, 2014). Fires affected eastern New South Wales (NSW), Canberra, and the mountains areas of southeast NSW and forested areas in eastern Victoria as show in Fig. 6 upper-left panel. A radiative forcing above 15 Wm-2 over northeast Victoria and the Great Dividing Range Mountains in the Kosciuszko National Park in southern NSW mainly to a large shortwave albedo decrease due to forest fires is shown in Fig. 6. Broadly, forest has a low shortwave albedo âĹij0.3 that varies with the viewing and illumination conditions (Liang, 2000). Given the extraordinary circumstances during the 2002–2003 drought in Australia, the forest fires dramatically altered the albedo, up to a 60 % relative change in some areas, during the Austral summer (pick of incoming radiation), nevertheless changes due to seasonality, e.g., vegetation senescence that affects surface reflectivity were not taking into account and a contribution of the decrease in albedo in the Australian summer might be due to these non-fire related changes. In Fig. 2b, the highest value of radiative forcing occurs in 2003 when the massive boreal fires in western Siberia burning over 20 Mha and being one of the largest forest fires on record (Sheng et al., 2004). Croplands and non-forests are following the west Siberian event of 2003, showing the highest mean radiative forcing value of all cropland areas (Fig. 2b).

Comment: My main concern is the potential implication of the much different spatial resolution of MODIS BRDF/albedo (0.05 deg) and burned area (500m) that were used in this study.

We fully understand the concern about the difference in spatial resolutions. The 500m MODIS BRDF/Albedo, which indeed will produce the most accurate results was not used mainly due to the amount of data required to perform the analysis. Additionally, the main goal of this study is to quantify the impact of fires on the Earth's balance energy system. When using a spatial resolution of 0.05° at global scale we are still capable to observe the main burned area patterns, for instance, a common spatial resolution for burned area long term data records is 0.25° for the Global Fire Emissions

C6009

Database (GFED4).

Comment: Secondly, and most importantly, when aggregating the MODIS 500m burned area to the CMG 0.05 deg grid, did the authors apply any threshold to identify the CMG grids, burned or not burned? For example, if only 10% of 500m pixels within each CMG âĹij5km grid were burned, but the albedo change was calculated at âĹij5km resolution, which would include many unburned 500m pixels, and thus would lead to low bias of albedo change and forcing estimates. It wasn't clear whether and how this fractional burned area at the CMG resolution was considered.

In the first version of the analysis we used a nearest neighbour method when aggregating the MODIS 500m burned area to the 0.05Deg grid. The assumption was that we would keep only the core burned pixels that, at global scale contribute the most to the Albedo changes due to fire. Nevertheless using this assumption we were consistently, 1) overestimating the burn area, since we assumed that the whole pixel was affected by fire and 2) underestimating burned area, where coarse resolution pixels not mapped as burned due to the resampling technique applied, were not taken into account at all. The description of the resampling applied to address this issue will be added to the section 2.2 Burned area identification as follows: It was necessary to perform a spatial aggregation on the monthly datasets to 0.05Deg to match the CMG spatial resolution. The proportion of the CMG pixel that was affected by fire was calculated, thus giving a fractional burn area estimate. When more than one date was found inside a CMG pixel the mode of the day of burn was selected.

Using this new fractional burned area dataset the albedo change was calculated as discussed in section 3.1, subtracting the pre-fire from the post-fire albedo and then multiplying by the fraction of the area affected in each pixel. The associated radiative forcing was computed as before, however, when calculating spatial statistics, at global and continental scale in different land cover types, a weighted mean was computed using the fractional burned area as weights. The updated results did not change the trends or temporal behaviour, what changed was the magnitude of the albedo changes

C6010

and the radiative forcing. The updated abstract reflects the new numbers as follows: The analysis reveals a mean decrease in shortwave albedo of -0.0143 ($1\sigma = 0.017$) causing a mean positive radiative forcing of 3.99 Wm-2 ($1\sigma = 4.89$) over the 2002 - 2012 time period in areas affected by fire. The greatest drop in mean shortwave albedo change occurs in 2002, which corresponds to the highest total area burnt (3.78Mha) observed in the same year and produces the highest mean radiative forcing (4.5 Wm-2). Africa is the main contributor in terms of burned area but forests globally yield the highest radiative forcing per unit area, resulting in detectable shortwave albedo changes. The global mean radiative forcing for the whole analysis period ~ 0.0275Wm-2 shows that the contribution of fires into the Earth system is significant.

As a remark, the burned area extent is the same as before since no resampling was applied at all to calculate it. The original 500m was used to compute the global and regional extent.

Other specific comments

1. In both the title and "Abstract", please make it clear the albedo change and forcing presented in this paper were indeed "instantaneous". This is critical for understanding the numbers, as both quantities change significant as vegetation recovers after fire. This paragraph in the abstract was modified: The main goal of this study therefore, is to quantify the changes in instantaneous shortwave albedo produced by biomass burning activities and their associated radiative forcing.

2. In the "Introduction", page 7777, Line 11, "The radiative forcing caused by CO2" , did you mean by CO2 change?

The sentence was modified as follows: The global mean concentration of CO_2 in 2005 was 379 ppm, leading to a radiative forcing of +1.66 Wm-2 ($1\sigma = 0.17$).

3. In page 7777, Line 18-24, again, when referring to other studies, please clearly state the time periods of the albedo change and forcing, e.g., did Govaerts et al. and Jin and

C6011

Roy report the "instantaneous" change? Since this manuscript was for global analysis, please also cite some studies in other regions, such as in boreal regions.

Paragraph will be modified as follows: Earlier studies aimed to quantify the impact of fires on the land surface albedo. Govaerts et al. (2002) analysed a Meteosat albedo time series for 1996 in Northern Hemisphere Africa and using fire-induced albedo perturbation probabilities, estimated that fires are responsible for a relative albedo decrease as large as 25 %. Jin and Roy (2005) used MODIS data to estimate a mean 2003 instantaneous shortwave albedo change of −0.024 over all the burned areas in the Australian tropical savana, which exerted a shortwave surface radiative forcing of 6.23 Wm-2. Several studies have been carried out in the boreal area, Jin et al. (2012a) analysed the sensitivity of spring albedo to the MODIS-derived difference Normalized Burn Ratio (dNBR) while Jin et al. (2012b) found a fire-induced surface shortwave forcing (SSF) integrated over an annual cycle of -4.1 Wm-2 between southern and northern boreal regions.

Citations to add: Jin, Y., Randerson, J. T., Goetz, S. J., Beck, P. S. a., Loranty, M. M. and Goulden, M. L.: The influence of burn severity on postfire vegetation recovery and albedo change during early succession in North American boreal forests, J. Geophys. Res., 117(G1), G01036, doi:10.1029/2011JG001886, 2012.

Jin, Y., Randerson, J. T., Goulden, M. L. and Goetz, S. J.: Post-fire changes in net shortwave radiation along a latitudinal gradient in boreal North America, Geophys. Res. Lett., 39(13), doi:10.1029/2012GL051790, 2012.

4. In Page 7777, Lines 26 to 27, state clearly the uniqueness of "the main goal", e.g., continental and global estimate. Also I didn't get that it is for instantaneous estimate instead of longer term impact until I read the method and results?

The paragraph will be rephrase it as follows: No earlier studies have attempted to quantify the impact of fire on shortwave albedo at global scale; therefore, the main goal of this study is to quantify the "instantaneous" shortwave albedo change in areas

affected by fire and the corresponding radiative forcing at the surface.

5. In Page 7779, Lines 6-13, with regards to linear temporal interpolation, any special considerations for the abrupt albedo change after fire, both for adjacent pre-fire and post-fire periods ? It makes sense to include only snow-free albedo after knowing that this study was to look at the instantaneous change after fire.

No considerations were taking into account to perform the linear interpolation related to the fire occurrence. Since only the best pixels were kept for processing, the gaps in the time series for some pixels indicates that those pixels were masked due to their quality flag value:

2. mixed, 75% or less full inversions and 25% or less fill values 3 all magnitude inversions or 50% or less fill values 4 50% or more fill values

Instead of using low quality pixels that could lead to spurious changes in the shortwave albedo, we considered that applying a linear interpolation between pixels with high quality data was the most adequate option to have a gapless time series. The interpolation was applied only to fill single 8-day gaps.

6. In Page 7779, Lines 20-22, when aggregating MCD64A1 500m burned area to CMG 0.05 degree resolution, did you record and keep track of the fraction of burned area? See the main comment on this. When the estimate was presented over the area burned, did you mean only over the areas burned identified by the 500m burned area product, or over the areas burned at the 0.05 deg resolution?

This issue was addressed in the general comments.

7. In Page 7781, Line 16: change near-infra-red to near-infrared Will be change as follows: . . . which generally are very reflective in the near-infrared and. . .

8. In Page 7783, Line 25-29, it would be interesting to present numbers for global LAND area only. Quantities in radiative forcing are different due to an introduction of burned area fraction requested in the general comments. The numbers for global LAND area

only will be presented as follows:

In order to quantify the global or regional impact, it is necessary to normalize the forcing by the proportion of the total area burned to the total surface. Given r = 6 371 007.181 m as the radius of the idealized sphere representing the Earth; the total global surface is âĹij510.07 Mkm2. Assuming a proportion of land in the planet of 30%, given the mean radiative forcing in areas where fire occurred during 2002–2012 is 3.99Wm-2, the global mean forcing only in land is 1.197 Wm-2

9. Page 7784, Line 10: change from "In here, we . . ." to "We here . . ."

Sentence will be change as follows: We here used the radiative forcing as measure. . .

10. For "Results" and "Discussions", see general comments on the organizations.

"Results" and "Discussion and conclusions" sections were modified. Please see response to general comments.

11. Table 1, not necessary, a reference is good enough. Table 1 will be removed.

12. In "Results", Page 7782, Line 19-23, are all linear trends presented significant (Figure 2)? For the statement of "The mean albedo changes, considering the change between post-fire shortwave albedo minus the pre-fire value, have the opposite trend of the total annual area burnt.", is the magnitude of post-fire albedo reduction also decreasing, consistent with the trends of burned area and forcing?

The Mann-Kendall test for monotonic trend was applied to all annual global mean time series shown in figure 2. Only the burned area has a significant trend. Neither the albedo change nor the associated radiative forcing has a significant trend, therefore the finding will be rephrased as follows:

Overall, the trend in burned area for the whole studied period is negative, however the albedo change and the radiative forcing show no significant trend (Fig 2). The mean albedo changes, considering the change between post-fire shortwave albedo minus

the pre-fire value, have a slightly annual increase opposite trend of the total annual area burned. Fundamentally, a fire event will decrease the shortwave albedo, resulting a positive radiative forcing in return (Figs. 5 and 6). Nevertheless the consistent decrease in burned area did not produce a significant decrease in albedo changes, that could be explain due to changes in fire intensity.

13. In Figure 4, it would be easier to compare if all y-axis were in the same range; In Figure 5: please label image panels A to D; and refer each in the legend.

Figure 4 (figure 3 in the response) was modified to have the same scale in all y-axis as follows:

14. It would be more interesting to show a global map of mean albedo change and forcing averaged over the 11 years.

A map of the 11-year global mean radiative forcing will be shown as stated in the general comments.

Please consider reading the PDF provided as a supplement that facilitates the response reading since provides colours and text formatting.

http://editor.copernicus.org/index.php?_mdl=msover_md&_jrl=11&_lcm=oc110lcm111e&_ac

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/11/C6006/2014/bgd-11-C6006-2014-supplement.pdf

—————————————————

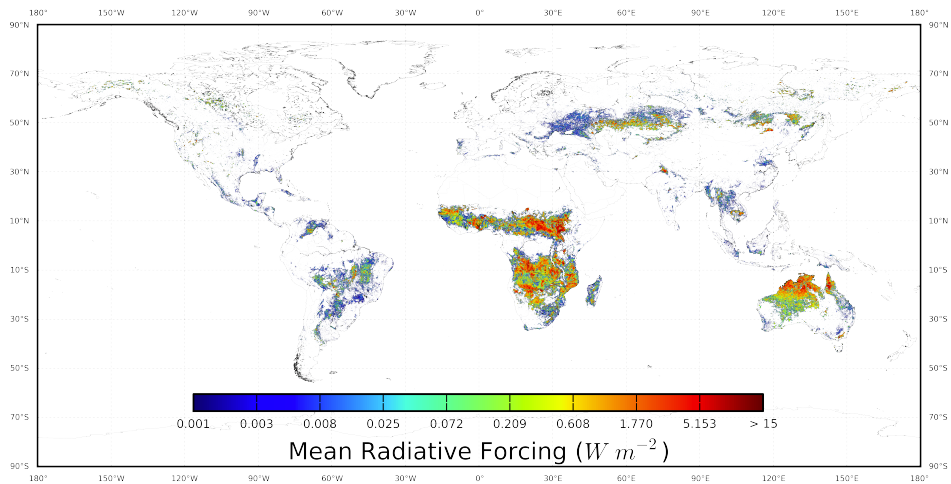Interactive comment on Biogeosciences Discuss., 11, 7775, 2014.

Fig. 1. Figure 1. Global mean radiative forcing caused by "instantaneous" shortwave albedo changes on areas affected by fires. The values were normalized using a logarithmic scale.
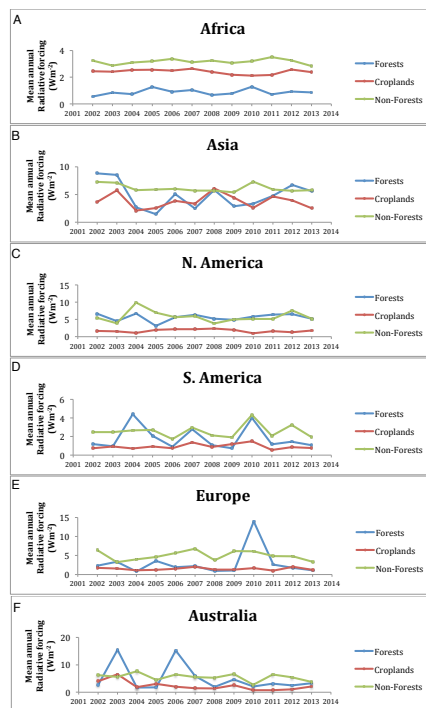
C6016

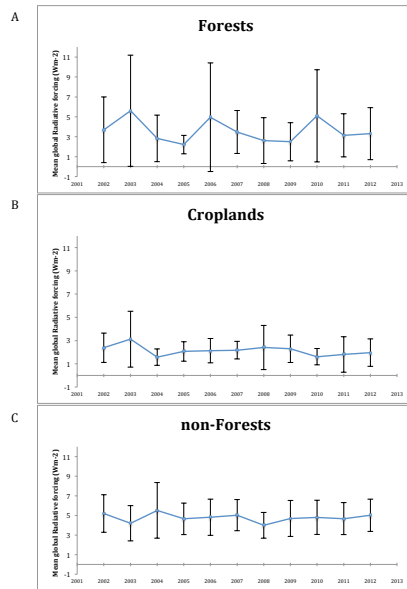**Fig. 2.** Figure 2. The mean annual radiative forcing per land cover and continent (A–F).

Fig. 3. Figure 3. The mean annual radiative forcing per land cover (A–C) in W m−2 .

C6018