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Interactive comment on "Local sources of global climate forcing from different categories of land use activities" *by* D. S. Ward and N. M. Mahowald

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Responses to the review of ANONYMOUS REVIEWER #1

Thank you for your comments and suggested edits which we address with revisions to the manuscript and also in our responses listed below. We list the reviewer comments and precede our responses with "RESPONSE". A copy of the revised manuscript with changes highlighted is given as a supplement.

REVIEWER: I have two major comments on the paper. First, I do not find the rationale for the two additional scenarios TEC and Trop-BAU. These two scenarios are highly unrealistic in the sense that they try to project as if things are really bad in tropical countries. This is based on the assumption that things can never get better in tropi-

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cal countries which will be stuck in poverty forever and economies there would never transition from agriculture.

RESPONSE: We would argue that the RCPs are unrealisticly optimistic, and so in order to bound what is likely to happen, we need to include more pessimistic scenarios. We do make assumptions about the future of LULCC in tropical countries, and globally, as is done for the RCPs. And we agree that the business-as-usual scenario is somewhat pessimistic. The reason that we introduce such a scenario is to increase the range of possible outcomes for the coming century with regard to LULCC. A range increase is justified because the RCPs all include reductions in deforestation rates relative to the present day census estimates from the FAO. In other words, all four RCPs (including 8.5) are optimistic with regard to deforestation in the 21st century. There are reasons to believe that deforestation rates could decrease this century – crop yield increases, national conservation policies, international policies like REDD, etc. However, we found in Ward et al. (2014) that deforestation rates in all RCPs were already too low in the tropics compared to 2000-2010 estimates from the FAO and only half the rates estimated from satellite over a similar period (e.g. Hansen et al., 2013). These points are illustrated in figure 5 from Ward et al. (2014) which we include in our responses (Fig. R1). In summary, it is good to be optimistic about the future for developing countries but it is also important to understand what will happen to global climate if present day activities are simply continued. In addition to further justification and text given in response to some following comments, we add text to explain the two non-RCP scenarios up front in the introduction:

Pg 1753, Line 8: “The two additional scenarios are added to bound the likely land use in the future because the RCPs scenarios tend to be very optimistic in their estimates of current and future land use conversion compared to current census and satellite based estimates (see Fig. 5 in Ward et al., 2014; FAO, 2010; Hansen et al., 2013; Kim et al., 2015).”

REVIEWER: This attempt at selective conclusion can be identified in the introduction:

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"Results for the year 2010 show substantial positive forcings from the direct modifications and agriculture sectors, particularly from India, China, and southeast Asia, and a smaller magnitude negative forcing response from wildfires." I suggest this sentence be removed in revision.

RESPONSE: We replaced "India, China and SE Asia" in the abstract with just "south and southeast Asia" as we agree that it is more appropriate for the abstract to describe regions instead of specific countries. We do, however, respectfully disagree that this is a case of selective conclusion. The major question this study asks is "where does the radiative forcing from anthropogenic land use and land cover change come from at present?" We think it is important to give the reader a brief mention of this basic result in the abstract.

REVIEWER: The emphasis on deforestation and specifically tropical deforestation is surprising because deforestation fluxes have gone down in the recent decades and RCP scenarios do have smaller LULCC forcings (Table 1) compared to fossil fuels (FF). The RF from tropical deforestation is artificially inflated in Fig. 5 which shows only RCP4.5 forcing from FF in all 6 panels (b-g). Why the FF forcing from corresponding scenarios are not shown? This figure should show RF from respective scenarios in corresponding panels.

RESPONSE: This is a good question. As we argue above, the RCPs are not capturing the tropical deforestation very accurately in the current time period, and assuming it will stay lower than current rates for the next century, which is a large assumption. The comparison to the FF from RCP4.5 is a good point. We derive the RCP4.5 non-LULCC (mostly fossil fuel burning) RFs from the difference between the total anthropogenic RF between 1850 and 2010 (or 2100) and the LULCC RF for the same period. Since we use RCP4.5 background anthropogenic emissions to determine all forcings and in this way truly isolate the LULCC contribution, we can only compute the non-LULCC RF for this RCP. To do the same computations for the other RCPs would require running all simulations again for each scenario and this is outside the scope of our study which is

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focused on LULCC-only. We have added text to the manuscript to clarify these points:

Pg 1756, Line 10: "Future RFs were computed against a background of non-LULCC anthropogenic emissions following RCP4.5 (Wise et al., 2009)."

Pg 1768, Line 4: "We are only able to compare the LULCC RFs against non-LULCC RFs from RCP4.5 for which fossil fuel burning emissions were used to compute background constituent concentrations in Ward et al. (2014). Note that the contribution of non-LULCC activities to global RF would be larger if RCP6.0 or RCP8.5 was shown."

The latitudinal band RFs for all scenarios have not been artificially inflated or modified in any way but are the actual values that we computed according to the methods and assumptions laid out in the manuscript.

REVIEWER: My suggestion is that this paper should just focus on only the 4 RCP scenarios and remove all discussions relating to the 2 unrealistic future scenarios with excessive and unrealistic tropical deforestation.

RESPONSE: We understand the reviewer's concerns since we did not give a substantial amount of justification for including the Trop-BAU scenario. We did consider the reviewer's suggestion to remove these two scenarios (the Trop-BAU and TEC) from the study and decided that they are too important to the main purpose of the study, defining costs of land use activities in terms of RF, so that we kept them in but understand the need to include better explanation for why the Trop-BAU scenario in particular is important to keep. We added the following text to the manuscript to communicate these points:

Pg 1759, Line 24: "Forest area projections for all four RCP scenarios assume reductions in the rate of global deforestation during the 21st century (Lawrence et al., 2012). It is also important to understand the impacts of LULCC and the sources of these impacts under a scenario in which current land use practices are continued. To address this knowledge gap we introduce a sixth projection in which tropical forest area

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changes for years 2010 to 2100 follow the year 2000 to 2010 rates published by the FAO (2010). Together with the RCPs, this creates a more comprehensive range in possible outcomes for the 21st century."

Pg 1760, Line 8 (last phrase added): "Recent studies suggest that deforestation rates are higher than reported in census data (Hansen et al., 2013, Margono et al., 2014), especially in the tropics (Kim et al., 2015)."

Expanding the set of future scenarios also augments our ability to define the climate costs of LULCC in RF terms by increasing the number of valid points for the statistical regression shown in Figure 9. These results would be substantially less robust if we only included the four RCP scenarios – not only because there would be fewer points but also because the range in future LULCC captured by the RCPs is so narrow.

REVIEWER: Second, the paper has too long a section on methods. It has 9 pages now. I suggest the authors briefly discuss the methods in 1-2 pages and move the elaborate details to supplemental online material. This should greatly improve the readability of the paper. Otherwise, the presentation is sound. I recommend publication only after my 2 major and the following specific comments are addressed.

RESPONSE: We agree that the methods section reads as too long. We moved the description of the RF computations to an appendix since this is mainly a summary of previous work and might not be of interest to some readers. This reduces the length of the methods section by about 30%. We did consider the reviewer's suggestion to only include 1-2 pages of methods but decided that the text describing the methods of attributing the RF to different sectors and locations should remain in the main text. Our justification for this is that although we believe our attribution methodology to be robust (see sensitivity tests in Ward and Mahowald, 2014 ERL), describing the several approximations that we make in the main text is important to help the reader understand the sources of uncertainty in our results. We also considered moving the explanation of the Trop-BAU scenario development to an appendix but again, there are several

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approximations in this process that we felt are better to explain up front. Also, this way we can more easily include some of the additional text in response to comment #1 in the main text.

REVIEWER: Specific comments:âĂĺ1. In the abstract it would be clearer if the following message is explicitly mentioned: Both in 2010 and in the future scenarios, the agriculture component of LULCC provides a positive RF and wildfires provide a negative RF. Direct modification provides the major contribution to positive RF.

RESPONSE: This is indeed a major point of the paper and we feel that this is better communicated in the revised sentences in the abstract: "Results for the year 2010 show substantial positive forcings from the direct modifications and agriculture sectors, particularly from south and southeast Asia, and a smaller magnitude negative forcing response from wildfires. The spatial distribution of future sources of LULCC RF is highly scenario-dependent, but we show that. . ."

REVIEWER: 2. In the abstract you have mentioned 3 regions: India, China and Southeast Asia as substantial contributors to positive RF due to direct modifications and agriculture. This point is not made clear in any part of the results section. I suggest removing this sentence.

RESPONSE: As noted above, we replaced "India, China and SE Asia" in the abstract with just "south and southeast Asia" as this may be more appropriate for the abstract to describe regions instead of specific countries. In the results section we do note that the US, India and China together contribute 70-80% of the RF in 2010 as well as in two of the future scenarios (Pg 1767, Line 18). We mention the US here because we are describing the continuity in RF contributions from present day to 2100 for major agricultural centers. In the abstract we are simply stating which regions the most RF is coming from which is clearly south and southeast Asia (see Fig. 5), so we do not mention the US here.

REVIEWER: 3. The methods section is lengthy. See my major comment. I suggest

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authors to prepare a flow chart for methods section in the main paper.

RESPONSE: With the summary of forcing calculations from Ward et al. (2014) now moved to the appendix, we believe the methods section becomes much more readable. To improve the organization of this section from a reader's standpoint, and in lieu of a flow chart figure, we have added a paragraph of introduction to the beginning of Sect. 2 that outlines the sub-sections: "The methodology employed in this study is explained in this section in four steps. First, a brief summary is given of the computation of global RFs due to LULCC from Ward et al. (2014) that are used in this study (Sect 2.1). This is followed by a description of the future LULCC scenarios used by Ward et al. (2014) and in this study, and also the development of an additional scenario (Sect. 2.2). In Sect. 2.3 the methods for attributing the global LULCC RFs for each scenario to three major sectors of land use activities are explained for the individual forcing agents. Finally, our approach for ascribing the sector and agent-specific RFs to individual source locations is described in Sect. 2.4."

REVIEWER: 4. Page 1754 para 15: what do you mean by direct modification? Please define explicitly.

RESPONSE: We have added in parentheses: "e.g. deforestation, reforestation, wood harvesting"

REVIEWER: 5. Page 1756, lines 2-5: "Forcing from changes . . ..." I believe the definition of adjusted forcing takes care of these changes.

RESPONSE: The adjusted RF takes into account stratospheric temperature adjustment but, in its purest form, is computed without changes in sensible heat flux or clouds, i.e. with zero climate response. The recently coined "effective" RF does include some quick response effects especially those associated with cloud feedbacks. Ward et al. (2014) use the effective RF for aerosol forcings but do not compute adjusted RFs for the agents listed in this sentence, thus we retain the original text.

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REVIEWER: 6. Page 1756, line 9: “reduce” should be “increase”?

RESPONSE: Since nitrate aerosols are effective scatterers of incoming solar radiation, increases in their concentration, for example due to increased agricultural activities, will actually lead to a more negative (stronger cooling) radiative forcing. Often it is more clear to use the phrase “more negative” instead of “reduce” as we use here. However, in the context of this sentence in which we state that increases in nitrate aerosol would likely reduce an overall positive forcing from agriculture, we think this phrasing makes the most sense and decided to keep the original text with an additional explanatory phrase: “. . .by increasing scattering of solar radiation.”

REVIEWER: 7. Page 1757, lines 1-3: Can you briefly explain why the flux was adjusted downward?

RESPONSE: We have added the following text at this location in the manuscript (now in Appendix A): “The double-counting occurs in transient-CO2 simulations when no LULCC is included but atmospheric CO2 concentrations reflect the impact of LULCC, thereby artificially increasing CO2 fertilization of vegetation.”

The entire explanation reads as follows: “The LULCC flux was adjusted downward to account for the CO2 fertilization feedback (Strassmann et al., 2008), which leads to double-counting of CO2 emissions in uncoupled terrestrial model simulations (Pongratz et al., 2014; Arora and Boer, 2010). The double-counting occurs in transient-CO2 simulations when no LULCC is included but atmospheric CO2 concentrations reflect the impact of LULCC, thereby artificially increasing CO2 fertilization of vegetation.”

REVIEWER: 8. Page 1762, line 17: change “compare the” to “compared with”?

RESPONSE: We have made this correction.

REVIEWER: 9. Page 1764: line 2: “this method”? Which method?

RESPONSE: We have re-written this sentence so that the method is explicitly described: “Ward and Mahowald (2014) show that ascribing RF from short-lived forcing

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agents to individual locations based on proportional emissions is reasonable for comparing the climate impacts of developed countries, as a group, to developing countries."

REVIEWER: 10. Page 1765, line 5: "-0.20" should be "-0.17" to be consistent with the table.

RESPONSE: Thank you for the attention to detail here. In fact, the numbers are different because there is a small positive forcing (+0.03 W/m2) that is a result of the climate change impacts o the carbon cycle from this sector's emissions. This carbon cycle response is also included in the RF reported for CO2 but in this sentence we were only referring to the forcing from N-deposition enhancing carbon uptake. The fact that we combine these two forcings into the CO2 is mentioned only briefly in the methods and now even this is in the appendix. So to make this point more clear we modified the text at this same point to read: "...(part of the CO2 RF from the agriculture sector in Table 1, along with a +0.03 Wm-2 RF from the carbon cycle response to the forcing from this sector)."

REVIEWER: 11. Figures 5 and 6: Delete the bottom 2 panels since they represent unrealistic deforestation scenarios.

RESPONSE: In light of our response to the reviewer's major comments we retain these figure panels.

REVIEWER: 12. Figures 7 and 8: What is the purpose of these figures? You have not shown the absolute values of total RF (Fossil fuels plus LULCC). By showing only the ratio of deforestation to FF fluxes, these figures have the potential to negatively portray tropical counties though their total emissions have been smaller so far. These figures again attempt to unrealistically show that things are bad in tropical countries. I suggest removing these figures or also show the total RF along with the ratios.

RESPONSE: We modified text in the manuscript explaining that these figures are included to show that in many countries LULCC is the main source of global RF and that

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this is true especially for many tropical countries.

Pg 1768, Line 8: “We plot the ratios of LULCC RF to total anthropogenic RF to illustrate that on an individual country level there is a substantial range in the proportion of total anthropogenic RF that can be ascribed to LULCC activities (Figs. 7, 8).”

There have been several assessments of country-level anthropogenic climate change contributions that show the differences the reviewer cites between developed and developing countries (e.g. Hohne et al., 2010; Matthews et al., 2014) including one using the same model setup described here (Ward and Mahowald, 2014). Rather than repeat the results of these studies and take away from the point being made here (not about the magnitude of forcing but about the composition) we instead twice reference the results of Ward and Mahowald (2014) in section 3.3 (3rd paragraph) to note which countries are important for total global anthropogenic RF and which are not.

It is important also to show the second panel in both figure 7 and 8 which includes greenhouse gases only. The impact of anthropogenic aerosols is to reduce the contribution to anthropogenic global RF from their source and since these are emitted in the greatest quantities from fossil fuel burning, aerosols reduce the proportional contribution to global RF from fossil fuels and highlights LULCC. Since major climate metrics, such as CO2-equivalents, usually only include greenhouse gases, we need to show the fossil fuel/LULCC comparison without aerosols to better inform policy debates. We add the following text to support this point:

Pg 1768, Line 18: “Standard climate change metrics, such as CO2-equivalents, often do not incorporate short-lived climate forcers (Ward and Mahowald, 2014).”

REVIEWER: 13. Page 1768, lines 10-15: Fossil fuel emission globally is now about 9 PgC/yr but LULCC emission is only about 1 PgC/yr. How do you justify that LULCC contribute more RF than fossil fuel emission? Please explain in detail.

RESPONSE: We added text to clarify this point (see below). It is true that fossil fuel

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burning contributes many more times the amount of CO2 that is emitted from LULCC each year (in the present day) and that CO2 is the largest single anthropogenic climate forcer. However, as shown by Ward et al. (2014), LULCC activities are the major contributors to non-CO2 greenhouse gas forcing, such as from CH4 and N2O, and do not lead to a large negative forcing from aerosols. Non-LULCC activities do lead to a large negative aerosol forcing and, therefore, Ward et al. (2014) estimate that LULCC accounts for 40% of total anthropogenic RF in 2010. When this global number is broken down into a country-level analysis it might be easier to see how countries could have a greater LULCC contribution. We added the following text that summarizes this finding from Ward et al. (2014) and addresses the reviewer's comment:

Pg 1756, Line 2: "They compute uncertainties for the RF from each forcing agent and find that LULCC account for 40% +/- 16% of year 2010 anthropogenic RF by a combination of substantial positive forcing from non-CO2 greenhouse gases and the absence of major negative forcing from aerosols. The forcings calculated by Ward et al. (2014) are within the uncertainty ranges in estimates of the total anthropogenic RF published in major assessments (e.g. Myhre et al., 2013; van Vuuren et al., 2011), suggesting that different approaches would likely achieve similar results."

Also, it is important to remember that the global forcing from LULCC and non-LULCC CO2 from Ward et al. (2014) that we use in this study contains the history of anthropogenic CO2 emissions since 1850, some fraction of which is still in the atmosphere today. So the CO2 RF alone does not only depend on present day emissions but also on the history of emissions. We made further note of this in the text:

Pg 1757, Line 7 (now in Appendix A): "In this way, the history of CO2 emissions from different sectors of LULCC is accounted for in these calculations."

REVIEWER: 14. Page 1770, line 15: expand VOC, it is not defined before.

RESPONSE: This was a good catch; we replaced the acronym with the full phrase and a new acronym (BVOC).

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REVIEWER: 15. In Figure 1, the direct modifications need to be defined more clearly (you have used land cover change which does not give a clear picture of what is to be conveyed)

RESPONSE: We add a definition for land cover change to the text at the point where figure 1 is first referenced and the direct modifications group is being defined:

Pg 1760, Line 15: “We define land cover changes as the replacement of a biome, such as grassland or forests, with a different biome by anthropogenic activity.”

REVIEWER: 16. In all figures, the font size of the labels should be increased for better readability.

RESPONSE: We have increased the font size on all labels in all figures by between 2 to 4 points.

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Figure R1: Comparison of projected annual rates of forest area change. Colored lines and shading represent the change in global forest area between 2010 and 2100 for the

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Representative Concentration Pathways (red) and the theoretical extreme case (light blue). The grey shaded region is bounded by the annual rate of forest area change required to completely reforest to the estimated prehistoric forest area (Pongratz et al., 2008), or remove all forests by year 2100. Reported and projected forest area change from Meyfroidt and Lambin (2011) (purple) and FAO (2010) and Hansen et al. (2013) (green) are depicted as constant rates through year 2100 to show the result if these rates were sustained.

Please also note the supplement to this comment:
http://www.earth-syst-dynam-discuss.net/5/C784/2015/esdd-5-C784-2015-supplement.pdf

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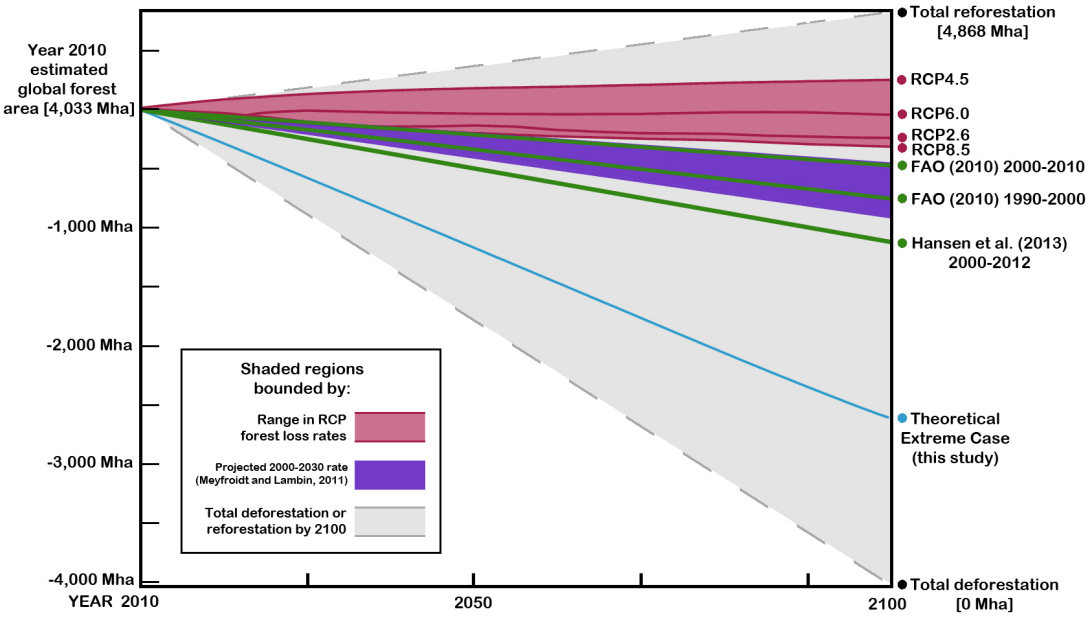

Fig. 1.

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