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Interactive comment on "From land use to land cover: restoring the afforestation signal in a coupled integrated assessment – earth system model and the implications for CMIP5 RCP simulations" *by* A. V. Di Vittorio et al.

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Response to Anonymous Referee #1, bgd-11-C2671-2014

Title: "From land use to land cover: restoring the afforestation signal in a coupled integrated assessment - earth system model and the implications for CMIP5 RCP simulations" by Di Vittorio et al.

We appreciate your thorough and thoughtful review and suggestions. We agree that there is a simple message, but the issue is much more complicated than the simple

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message implies. The complications contribute to the very existence of the reported inconsistencies and the effects on the global modeling. The following responses to your comments show how the manuscript will be improved.

Major comments

We disagree that this manuscript relies "quite a bit" on the in-review GMD paper by Bond-Lamberty et al. and an in-prep paper by Collins et al. We cite these papers to refer to additional technical details that do not need to be presented here in order to understand this paper on land coupling between ESMs and IAMs. In fact, the Bond-Lamberty et al. paper focuses on the climate feedback part of the loop that does not contribute to the reported inconsistencies, and the Collins et al. paper focuses on technical development of the model and its code. We can definitely remove these references without affecting this paper, but then we would be omitting two very relevant references. We can certainly clarify the relationship of these references to the current paper.

The use of emissions in our simulations can easily be clarified. As you note, we do specify that our simulations use emissions and the RCP4.5 scenario. The CMIP5 land use/cover data we present were used for both emissions and concentration driven CESM simulations, although we think only the concentration driven outputs are available from the CMIP5 archive. This does not matter for this paper because we only look at the land use/cover trajectory data from CMIP5. All other data are from emissions-driven simulations.

The effects of restoring afforestation on atmospheric CO2 can also be easily clarified. The vegetation carbon and atmospheric CO2 gain changes (19 Pg C, -8 ppm, respectively) are model outputs. So the 8ppm is the net reduction in atmospheric CO2 gain with a fully coupled carbon cycle operating, by 2040. And this is actually a big deal because this is over only the first 25 years of 2/3 of prescribed afforestation. There are 60 more years until 2100, during which additional afforesting occurs and the previ-

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ously afforested area continues to grow. We do explicitly state that the other numbers are linear extrapolations to make the point that the full afforestation over the entire century would likely have a very different atmospheric CO2 concentration (∼40 ppm difference). Unfortunately, our simulations cover only until 2040 because they were performed during a developmental phase. These simulations are very expensive to run, and we needed to reserve computational time for our final production simulations, which do run to 2100. The simulations presented in this paper do cover the most rapid period of afforestation from 2015-2020 and the subsequent 20 years.

We agree that regional biophysical effects of land use/cover change are very important, and in many cases more significant that global impacts on the carbon cycle, but the focus of this paper is on overall consistency of the land surface, which is required in order to adequately evaluate regional effects. We do discuss the regional impacts in the introduction, and can mention them in the discussion as well.

The land cover in CLM can be changed by only one component at a time: either the dynamic vegetation module or the land use change module. Here we use the land use change module and thus do not account for potential biogeographic vegetation shifts due to changing climate. While this is a shortcoming of the model, we are not concerned about this limitation because most current studies show that the biogeographical effects of climate change on vegetation distribution are small compared to the effects of land use change on vegetation distribution, both in recent history and in 21st century projections.

We do, however, discuss how non-crop vegetation changes when cropland and pasture change. The constraint of 'potential vegetation' is presented in section 2.3.1 (page 7161,line 17) but we should explain what it means (land cover as it would be today if no land use change had ever occurred). The algorithms for land cover change are presented in figures 3 and 4. We further discuss how this constraint (page 7167) limits afforestation in the OLDLUT and in CMIP5. We remove this constraint to increase afforestation, and if the conditions are not right where forest is added, then the forest should not grow well in CLM, which would have a negative feedback on afforestation. We further discuss this issue on page 7168 where we explain that the prescribed afforestation assumes that silvicultural inputs are available (water, fertilizer, etc.) while CLM does not include such inputs. So to meet the RCP4.5 scenario, afforestation needs to occur in CLM, but it might not produce the biomass that the integrated assessment model expected. This is one of the inconsistencies that we point out in this paper.

Minor comments

We can definitely clean up the abstract so that is presents a more clear message.

page 7155 lines 5-9: The mention of C4MIP may not be necessary, and we can remove it, but it is not "totally unrelevant." It draws a relationship between uncertainty in atmospheric variables and uncertainty in carbon uptake due to land use/cover change.

Yes, there are several "land" terms throughout the paper. We will make every effort to consolidate, clarify, and explain our "land" terms. We do define "land use harmonization" on page 7155, and use it consistently throughout the paper.

page 7157 lines 6-7: Yes, this does refer to land carbon uptake, and goes along with the next sentence and corresponding citation.

page 7157 lines 15-17: Yes, we are sure that the radiative forcing targets do not include the direct effects of land use/cover change. See http://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=welcome# for this description: "The RCPs are named according to their 2100 radiative forcing level as reported by the individual modeling teams. The radiative forcing estimates are based on the forcing of greenhouse gases and other forcing agents - but does not include direct impacts of land use (albedo) or the forcing of mineral dust." The document you refer to appears to show calculations for many radiative forcing components, but not all of them (e.g. land use) were included in the CMIP5 RCP targets.

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page 7157, lines 21-26: We disagree that this sentence is irrelevant. The radiative effects of GHGs and some aerosols are included in the RCP targets, so these forcings are included in the shared socioeconomic pathways that try to meet the RCP targets. The biogeophysical forcing effects of land use/cover, however, are not included in the target calculations. So while the atmospheric constituents change to meet the target, there is no biogeophysical forcing constraint on changes in land use/cover, which changes the total forcing from the target (see the Jones et al., 2013a reference). The only land constraint is on how much emissions are released from land use/cover change.

page 7158 line 6: We can clarify that the time varying vegetation productivity in CESM is used by GCAM at 5-year intervals.

page 7158: "lost afforestation signal": We can certainly provide more context here, or even where we introduce the RCPs on page 7156. Rcp4.5 is indeed an afforestation scenario. IAM land projection is driven primarily by human needs and economics, with some assumptions about vegetation productivity. The IAMs use a relatively simple global climate model to determine the effects of emissions at an aggregate global level, and generally do not include the effects of globally aggregated climate on their systems. To our knowledge, no global IAM uses a dynamic vegetation model to estimate biogeography.

page 7158 lines 24-25: We can take out this reference to the second stage.

page 7159 line 17: Yes, this isn't entirely clear. GCAM projects a single year of land use/cover distribution, once every five years.

page 7159: "ingesting": We can replace 'ingesting' with another word. In this case we can use 'using.'

page 7160: Yes, thank you for the suggestion, "land use run" needs to be changed.

page 7160: "GCAM initial conditions": We will clarify that the initial GCAM state is initialized to real world statistics. This state includes production amounts, costs, prices, land areas, etc.

page 7161 lines 19-21: GLM's harvest comes from 5 categories within the main categories of 'primary' and 'secondary' land. However, CLM harvest is from forest only. So the GLM harvest area is normalized by the total area available for harvest (primary + secondary), and then this fraction of harvestable area is used as the fraction of forest area harvested in CLM.

page 7161-7162 lines 22-5: This paragraph is quite dense, especially sentences 3 and 5. We will clarify this. Basically, climate effects on vegetation in CLM are used by GCAM to update land use/cover projections at 5-year intervals.

page 7162 line 8: We will put this into context, as mentioned in response to your previous comment. CESM is supposed to simulate the land use of the RCP4.5. This includes the afforestation of RCP4.5. CESM with land use change does not use a dynamic vegetation module, and even if it did, CESM should still simulate the scenario-induced changes in forest area.

page 7162 lines 13-15: Yes, the spatial allocation of cropland and pasture. GLM maintains its own map of potential forest land. New ag land preferentially replaces forest, and when ag land is lost, it is removed preferentially from area that is considered potential forest land.

page 7162 lines 23-26: The more explicit explanation follows in steps a-c on page 7163. We can rephrase this sentence to be more descriptive or to refer to steps a-c.

page 7164 section 2.3.4 title: This should explicitly refer to "land use harmonization," which is specifically introduced and defined on page 7155.

page 7164 section 3.1 title: We will make this more specific to refer to land cover area inconsistencies. However, the global land area is not exactly the same in each model, which is another inconsistency in the overall coupling.

page 7164 lines 17-18: We use "RCP4.5" in this way to distinguish these CMIP5 GCAM outputs from the GCAM outputs in our iESM simulations, which also simulate the RCP4.5 scenario. We will consider replacing "RCP4.5" with a different label here.

page 7165 line 21: We will clarify this as suggested (area covered by herbaceous PFTs).

page 7165: We will introduce figs 6 and 7 more clearly as the changes and absolute values, respectively, of the same results.

page 7165 lines 22-24: This needs to be clarified. The meaning is that the cropland area in CLM is more representative with NEWLUT than with OLDLUT. And the "normalization" here is a bug fix that makes this improved representation. It is literally a normalization of GLM cropland area to a CLM reference area.

page 7166 line 1: We mean discrepancies between scenario-prescribed land use/cover and the corresponding simulated PFT areas.

page 7166 line 9: Yes, we mean that the ESMs need to simulate the energy/climate scenarios as generated by IAMs.

page 7166 lines 13-15: This needs clarification. The sharing is between the source of land cover info and the ESMs. There are two sources relevant to this discussion: historical data and the IAMs.

page 7166 line 1 to 7167 line 4: We will make these details clear in the methods section.

page 7167 line 27: The difference plot is a cleaner and easier way to see the difference in NEE between the two simulations. We certainly can provide a plot of both simulations. It is unclear whether the reviewer is concerned about the term "significant," of which we do not have a statistical test for here, or if the reviewer prefers to see the separate plots. We might be able to calculate a t-test comparison between the simulations for each of two time periods to find out if they are statistically significantly different: 2005-2020 and 2020-2040. But even though the NEE during the two time periods might not be statistically different based on this test, land carbon uptake does increase with NEWLUT and has considerable effects on vegetation carbon and atmospheric co2 concentration, as reported on page 7168.

page 7168 lines 6-7: We can include the atmospheric co2 plot.

page 7168 line 9: Based on our current simulations, we are seeing very linear responses in both vegetation carbon and atmospheric co2 between 2005 and ∼2070. Also, we are extrapolating the difference in gain, which means that any nonlinearities introduced into both simulations by climate or fossil fuel emissions should be somewhat accounted for. So here we use linear extrapolation as a simple estimate, and to mitigate the effects of rapid change starting in 2015, we start our extrapolation at 2005. ∼70 of total prescribed afforestation occurs by 2040, but it does not start until 2015. Forest expansion in CLM reduces forest leaf area index to accommodate the new forest, which initially reduces carbon assimilation on a per area basis. As the new forests age they gain leaf area index and carbon assimilation capacity, up to a point dictated by environmental conditions. Throughout the century both forces are acting to maintain forest carbon uptake: new forest area and increasing forest leaf area index. So this linear extrapolation gives a reasonable estimate.

page 7169 lines 13-14: We mean that the ESM land use/cover distribution must match the scenario-prescribed land use/cover distribution to ensure that the ESM is actually simulating the prescribed scenario.

page 7169 lines 25-26: We will rephrase this statement to indicate that the CESM simulation does not use appropriate changes in PFT area.

page 7170 lines 9-10: We do not say that all additional carbon went into vegetation. We do correctly state, as quoted, "..afforestation has a significant impact on iESM's global carbon cycle through increased vegetation carbon and decreased atmospheric CO2 concentration." It turns out that the difference in soil carbon gain between the two simulations is only about 1.5 PgC from 2005-2040, with the NEWLUT gaining soil carbon at a slightly lower rate than the OLDLUT. This decrease in soil carbon gain is small compared to the 19 PgC increase in vegetation carbon gain. The atmospheric co2 concentration is calculated from all fluxes, and the primary change in land carbon is in additional vegetation carbon.

page 7170 line 23: Yes, the RCP4.5 scenario for CMIP5 was simulated by GCAM.

page 7172 line 9: Actually, we mean a spatially explicit land area data set. Currently, each model has its own estimate of global land area and where that land area is located (e.g. different islands may be absent/present in different land area data sets). And technically, global land area is not constant, although it is for the purposes of these simulations.

page 7172 point 4: This needs clarification. Gross transitions are all losses and gains in area between two points in time. Net transitions are the sum of gross transitions between two points in time.

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