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Interactive Comment

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 #2, bgd-11-C3782-2014

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 critical and helpful review and suggestions. The following responses to your comments show how the manuscript will be improved.

General Comments

We will make it more clear that we argue for a more consistent and complete land coupling between IAMs and ESMs for robust scenario-based simulations of global carbon and climate. One of our main points is that ESMs need to simulate the scenario-prescribed land use and land cover in order to robustly estimate the impact on carbon and climate of anthropogenic emissions and land use. Land use and land cover are interdependent and need to be treated as such when used as a scenario condition for earth simulations. Furthermore, land use and land cover sometimes refer to the same thing. For example, forests, which are at the heart of this paper, can be a land use for sequestering carbon, yet are generally treated as land cover.

Our discussion does use the results to explain the problems arising from the CMIP5 land coupling design, but some reorganization and more thorough discussion of why these problems need to be fixed will improve the manuscript. We discuss the considerable impacts on the global carbon cycle on page 7168 as one of the reasons for improving the coupling, and intend to include additional figures showing these effects on vegetation carbon and atmospheric co2.

Summary of the paper

We actually did investigate the reasons for the discrepancies in forest area, and determined that it results from mismatches in model structure, assumptions, and definitions among all 3 models, such that not all appropriate information was passed between the models. We discuss this on pages 7166-7167, with references to three of our figures. The effects of veg-climate interactions and forest management between GCAM and CESM, as discussed on page 7168, are superposed on the incomplete sharing of information.

We actually suggest integrating land cover change with land use change, not replacing land use with land cover. While these two concepts are uniquely defined, they are interdependent; land use influences land cover and vice versa to generate the observed

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spatial distribution of vegetation.

More discussion needed

We suggest incorporating land cover and land use information, not replacing a land use scenario with a land cover scenario. So we could discuss the pros and cons of land use only vs. land use and land cover. We agree that we need to state our perspective on the purpose of RCP simulations. It would open up the discussion from one based just on the obvious impacts on the fidelity of the simulated carbon cycle to the prescribed scenario, which we present, to one that addresses the meaning and utility of scenario development and simulation.

In answer to your two example questions: in order to have a robust multi-model intercomparison of responses to atmospheric composition and land use/cover, the multiple models need to simulate the same basic earth (i.e. atmosphere and land changes), as prescribed by a given socio-economic scenario, which would also provide the most accurate projection of global change.

Again, we advocate adding land cover information, not replacing land use information. Whether this would reduce or increase multi-model spread is not known, but it should improve the uncertainty range because it would constrain the sampling space for a given land use/cover change scenario to a more realistic range. For example, on page 7167 we point out that another CMIP5 model increased forest area by 11%, when the prescribed increase was 24% from 2005-2100 (see Davies-Barnard et al. 2014). Additionally, another CMIP5 model (see http://www.biogeosciences-discuss.net/11/5443/2014/bgd-11-5443-2014.pdf) started ~24 M km^2 of forest in 2005 and increased this by 35% by 2100 (which still wasn't total area of prescribed afforestation), while CESM started with ~39 M km^2 of forest area and increased this by only 6%. The RCP4.5 scenario, as simulated by GCAM, started with about 41 M km^2 of forest. The differences among these models for this single scenario are too large to simply be covering a realistic sampling space; there is a lot of room for error reduction here.

Clarity needed

We will clarify manuscript with the aid of your specific comments, and also the comments by the other referee.

Specific Comments

page 7156 line 14: We argue that it will improve earth system simulations by making all components of the earth system, including the human components that drive the earth scenarios, more consistent with each other.

page 7158 line 24: Yes, we will clarify in the text that GCAM also makes use of heterotrophic respiration.

section 2.3.1 paragraph 2: Yes, this paragraph can be moved to section 2.1. We will probably keep it for completeness, and clarify it. We analyzed CESM outputs of NPP, HR, and vegetation and soil carbon densities to develop this particular feedback method. The carbon density values were too sensitive to changes in vegetation area, thereby masking the climate feedback that we wanted to implement. NPP and HR were more robust climate feedback proxies. Also, the the below ground factor is not the inverse of the HR ratio, this is incorrect; it is an average of the above ground NPP factor and the opposite fractional change of the HR ratio ((NPPratio + (1-(HRratio-1))/2)). The effect of soil carbon increases are accounted for by the increase in NPP. The GCAM carbon densities are used to determine how much carbon to value in a particular place. These scaling factors are also used by GCAM to adjust crop productivity. Both the carbon value and crop productivity are used to make land use projections in GCAM.

section 2.3.1: We will describe the relationship between pasture and grass and shrub in CLM. There is some discussion of this on page 7167, but this needs to be described in the methods.

section 3.1: We will clarify this section. Using CESM in place of CLM would reduce acronym usage. It was difficult to clearly distinguish the CMIP5 GCAM RCP4.5 scenario from the GCAM scenario used in the iESM (which is also RCP4.5). If we just use 'GCAM' for both of them the reader will not know to which we are referring. We will work to make this clear.

page 7166 line 1: We argue that this is a gap. One of our main points is that the ESMs need to simulate the scenario-prescribed land use and cover in order to estimate the impact on carbon and climate of anthropogenic emissions and land use. The range of carbon cycle and climate responses are going to come from differences in the ESMs' biogeochemistry and physics modules (see page 7169 lines 15-22). The range of land cover responses is robust only if 1) all the ESMs start with the same land use and land cover areas and spatial distributions (which they do not), 2) correctly simulate the prescribed land use changes (which they do not, e.g. afforestation land use is not passed to them), and 3) then use different assumptions about how land use changes affect land cover distributions (which they do). The bottom line here is that even condition 2 is not satisfied and so the range of land use scenarios in ESMs is unconstrained, rather than being given by the four RCPs, as designed. It is then quite difficult to compare the effects of land use on cover/carbon/climate when each ESM implements different land use under the same RCP scenario. More generally, the interdependence of land use and land cover requires more consistency among models and more complete information to robustly estimate the possible range of land cover responses to land use change, and how these responses impact carbon and climate. We will, as mentioned above, discuss the goals of CMIP5 and explain why more consistency and information is needed to meet these goals.

page 7166 line 10: We can clarify sentences to make the following more clear: The rest of page 7166 through line 7 of page 7167 focuses on the main source of the forest area inconsistency: the land use harmonization, its lack of land cover info, and its relationship to CESM. Page 7167 focuses on the role of the CESM land use translator in this inconsistency. The ESM simulates given areas of plant functional types, a type

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of land cover, and we discuss how this relates to pasture as a land use, via the land use translator, also on page 7167. The inconsistency does not arise from errors in the IAM, but on page 7168 we do discuss how certain land use assumptions in the IAM generate afforestation that might not be consistent with land use/management/cover assumptions in CESM (see figure 8). This study presents an experiment in using the land use translator to allow CESM to use the prescribed land use. We found that this is not enough, and that more consistency and information shared across the models is necessary for accurate simulations of scenarios. The culmination of the gained insights is presented in the list of suggestions for improving IAM - ESM land coupling on pages 7171-7172.

page 7168 lines 1-2: This needs some clarification, or maybe reasonable is not the right word to use here. The point is that for RCP4.5 we need CESM to have more forest area, so finding an upper limit, given the current structures of the translator and the model, and the available information, is a desirable constraint. Going beyond this constraint to add forest area is completely arbitrary and unwarranted.

page 7168 paragraph 1: Yes, this would be interesting. Comparing with Jones et al. 2013b figure 2 we see that the iESM vegetation uptake by 2040 due to more afforestation would noticeable change its veg carbon trajectory. More importantly, we see from this figure that RCP4.5 has a large spread of slopes in vegetation carbon change, which might be partially due to different levels of afforestation in the different models. Another large spread of slopes appears to be for RCP8.5, which has net deforestation and might also be affected by the lack of land cover info sharing. The slopes for the other two RCPs appear to be more consistent across models. This same paper plots the atmospheric co2 concentrations of the four IAMs that generated the RCPs (prescribed concentrations), and at 2040 the iESM with improved afforestation brings the atmospheric co2 concentration down by an amount comparable to the difference between the prescribed RCP4.5 and RCP6.0 concentrations. This being said, the emissions driven CMIP5 CESM RCP4.5 simulation has a co2 concentration that is on

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the order of 50ppm higher than the prescribed concentration at 2040

page 7168 line 17: The potential vegetation constraint is a main reason why CESM did not simulate the prescribed afforestation. And by incomplete we do mean that it is smaller than the GCAM forest area increase. We need to explain CESM's land cover in more detail in the methods. CESM with land use change cannot use the dynamic vegetation module that would change vegetation area based on climate. Only the land use change changes vegetation area in our simulations. Regionally, the land use initiated changes generally swamp the biogeographical climate-induced changes in vegetation area. Changes in CESM forest area track GCAM forest area changes annually. The main time-lag differences would be related to the biogeochemistry differences between the models, i.e. age and growth rate vs carbon amount and leaf area index. This contributes to carbon cycle differences between GCAM and CESM, which do not focus on here (we discuss this briefly on page 7169 lines 9-22).

page 7169 lines 21-22: Changes in land cover due to changes in climate are relatively small compared to changes in land cover due to land use change. At coarse resolution and regional to global levels, changes due to land use dominate. At fine resolution in local areas, however, climate induced shifts in vegetation can be very important for a variety of reasons, including biodiversity. Ideally, the climate-induced shifts would be included with the land use shifts, but there needs to be a mechanism for separating the effects of each, so that proper multi-model intercomparisons can be made. Models with the same configurations need to be compared (e.g. use vs use, use+climate vs use+climate, climate vs climate), otherwise the addition of climate induced shifts might confound results more than they would clarify them. Currently, the state of modeling appears to still be struggling with the dominant effects of land use. With respect to uncertainty in land cover area in general, it is of interest, and should generally be introduced at the scenario level for proper multi-model intercomparisons. This would make the best use of available state-of-the-art current day data sets model projections and their uncertainties, which could be better characterized as input to the global models.

Part of the reasoning here is that land cover and land use are interdependent, and thus should be addressed jointly. The climate-indued shifts in vegetation would most likely reside within the ESMs, however, but again, this is an additional process that needs a consistent land base to work from. With the iESM we are looking at one form of this climate-induced vegetation uncertainty on land use by adding climate impacts to the land use projections through productivity changes rather than spatial range changes. The land use model in GCAM then determines spatial distributions of land use and cover, albeit without a direct biogeographic comment. Overall, this is a complex and iterative process that still needs to be researched. Furthermore, uncertainty in land cover will always be introduced by the ESMs because they each implement the land surface differently. Some use plant functional types, some use land cover designations, and their categories of land cover are not identical (this is also the case for historical land use/cover data sets). So given the exact same input land cover distribution, each model will have a slightly different representation of the land surface based on its translation to its native land system. This structural model uncertainty is important, and yet it can be constrained to a more realistic range by clear definitions and accurate mappings between land use/cover systems.

page 7169 lines 24-27: Yes, the hypothesis that we test is whether we can match GCAM's forest area by modifying the land use translator. And the result is that we cannot, which means that more information is needed to meet the prescribed land use. And so if the GCAM afforestation land use area is passed through to CESM, then CESM will be able to simulate the correct afforestation area, like you say. We explain both in the methods and the discussion why the GCAM afforestation does not get passed through. The mechanism to pass it through does not exist. Only cropland, pasture, secondary, and primary land areas and transitions (and harvests, which we do not address here) are passed through. The results obviously show that this is not enough to do the job of providing the prescribed land use, even after modifying the land use translator. So we can say that a "lack of specific land cover type information being shared among GCAM, GLM, and CESM in the iESM as the primary cause of CESM

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simulating very little afforestation and effectively no change in herbaceous vegetation."

page 7171 lines 10-13: Yes, each ESM would need a scenario-specific method to meet the prescribed land use/cover. This is essentially the same as what was already done, but with the added constraint of using the land cover outputs of the four IAMs as additional constraints. As no land cover information was passed between IAMs and ESMs, each ESM used its own set of transitions between land cover types as it matched cropland and pasture area. Some models were able to use the primary and secondary areas and even the transitions between these four categories, but in the end each ESM decided which land cover to add or remove in response to changes in land use. So the land use area trajectory (cropland, pasture, secondary, primary), would not change, but how these land use changes affect land cover (and land uses such as afforestation) would change to better match the prescribed land use/cover scenarios.

The captions for figures 3 and 4 are very similar because of the descriptive explanations of certain processes within the flow charts, both of which depict the land use translator. But figure 3 does state it is for the OLDLUT, and figure 4 for NEWLUT.

Interactive comment on Biogeosciences Discuss., 11, 7151, 2014.