Anonymous Referee #2

Summary

The authors present a new land model that includes the effects of climate on land allocation by constraining irrigation due to water availability and by calculating yield based on current climate. The primary novelty here is that the land allocation scheme has been included in the land component of an earth system model. This enables land allocation to be determined by the changing state of the earth system in conjunction with estimates of demand for food and other land-based commodities. The model reproduces historical conditions well, and future projections show reasonable results. Future goals include full coupling with the atmosphere and ocean components to incorporate additional human-earth system feedbacks.

Overall impression

This is a big step toward full human-earth system coupling, with a couple of novel developments including the impacts of water scarcity on land allocation and the inclusion of land allocation in the land model. My main concern is that these developments presented in this paper are not highlighted as providing new information. The examples do not show the benefits of these developments over not having them, and as such their value is not made clear. The paper can be strengthened by some reframing that brings these novel improvements to forefront, along with more critical examination of their strengths and weaknesses. I recommend some considerable revisions, and please see the detailed comments that follow.

1) There are two novel developments here: water availability effects on irrigation/land allocation, and the inclusion of land allocation in the land model. They each have unique contributions that should be highlighted. The inclusion of land allocation in the land model is unique and enables direct response of land use to changing conditions, including both the climate and the water availability as determined through the hydrological model. While there is not yet feedback with the atmosphere, the response of growth/yield to climate is more detailed than is otherwise considered in IAMs and some other land use models, and is also directly embedded in the full land model, which is a feat in itself. The water/irrigation linkage to land allocation is even more novel, as there have been only regional studies on this with loose coupling, I know of only one IAM that has just finally made this work but without connections to a full land model. The uniqueness of this new system should be more clearly defined such that your examples show the benefits of these developments.

Thank you for suggesting a description of the novel developments in the paper. The novelty of the model is summarized in a new section (2.2 Novelty of MIROC-INTEG-LAND). The name of the model has been changed based on the suggestion of reviewer #1. In the revised manuscript, the title of Section 2 is “Overall feature of MIROC-INTEG-LAND”, and that of section 2.1 is “Model structure”. In the new section 2.2, we clearly emphasized the novelty of MIROC-INTEG-LAND as suggested. We also summarized the novelty of the model in Abstract.

2) Provide examples that show the benefits of your novel developments. This will require additional simulations that shut off water scarcity effects on potential irrigation and alternatively shut off the climate effects on yield. As it is, your examples just show outputs that can be generated by a variety of other models. You want to highlight the value added of your developments.

We again appreciate your suggestions. We agree that additional simulations that shut off the interactions between the sub-models should be helpful to show the benefits of our developments. Our response to these points is explained in the reply to your comments on page 16, lines 23-24 below.

3) Discuss how these developments relate to existing alternatives and what the limitations are. For example, IAMs and other land models can project land use/cover under changing climate and feed this information to a land model. Why not just do this in AIM and feed it to MIROC? What do you gain and lose with TeLMO inside MIROC? How is TeLMO different from AIM and when do you expect one to be more robust than the other? The same questions could be asked with respect to water.

The difference between TeLMO and IAMs, and the advantages of coupling (running the sub-models together) are discussed in the second and third paragraphs in Section 2.2 “Novelty in MIROC-INTEG-LAND” as follows.

2.2 Novelty of MIROC-INTEG-LAND

An important feature of MIROC-INTEG-LAND is that the land allocation model is coupled to the state-of-the-art land surface model, and that the impact of future climate and socio-economic changes on water resources and land use can be considered consistently. In general, future land-use changes are often assessed by using an IAM. However, as mentioned earlier, IAMs are not grid-based, but rather they divide the world into dozens of regions and describes the entirety of economic activity in these regions. Therefore, IAMs has a simplified description of the processes related to water resources and crop growth. In contrast, MIROC-INTEG-LAND provides capabilities to calculate complex physical processes over the land, and considers the changes in water resources, taking into account human activities such as irrigation and reservoir operation. Furthermore, process-based crop models allow for an explicit and detailed consideration of growth process of five different crops.

For the projection of future land use, IAMs usually 1) calculate the area of agricultural land by using yield information averaged over these regions based on the balance between supply and demand, and

2) allocate the agricultural land by using a downscaling approach (e.g., Hasegawa et al. 2017). As pointed out in previous studies (Alexander et al. 2017), the problem with this method is that it is does not allow an explicit consideration of spatiotemporal information such as yield and production cost when determining land use change. The Food Cropland Model in TeLMO addresses this issue by making it is possible to consistently consider the spaciotemporal information such as crop yields and the balance between supply and demand when allocating the agricultural land, by using the Food Cropland Down-scale Module and the International Trade Module as explained in Appendix B.

As for the projection of future land use change, TeLMO enables the calculation of future land use change as an offline simulation, by using the crop yield data calculated in advance. On the other hand, crop yield depends on water resource availability that is affected by the changes in soil physical processes due to future climate change, as well as the changes in irrigated cropland area caused by the increases in future food demands. MIROC-INTEG-LAND couples the models of land-physical processes, human water management, and crop growth processes with the land-use allocation model to consider these various interactions, as explained above.

In Section 6.4, we also compared the performance of TeLMO and AIM for the area of food cropland, pasture, and forest (Figure 7-9). The figures for pasture and forest area are added according to suggestions by reviewer #1.

4) One concern I have about the model itself is the inconsistency between the crop model for growth/yield and the biogeochemical / biophysical model for cropland. You may not be able to fix this right now, but it is a problem that there are two different crop growth models to represent different processes of the same land area. In particular, your yield model does not have explicit fertilizer, but your VISIT model does. For a variety of reasons, the growth values will not be the same between the two representations, but they should be because the growth determines the geochemical and physical characteristics of the cropland. In the end your yields are not consistent with how cropland affects the geochemical and physical processes in the land model that will eventually feedback to the atmosphere. This should be fixed before full coupling with the atmosphere.

In the revised manuscript, we added an explanation of the inconsistency among the sub-models in the integrated model. This is explained in accordance with your comment, "*It seems that there are two crop models: PRYSBI2 and also one in HiGWMAT. Please clarify how these are different and why they are separate.*", and "*page 8 line 14-16*" below.

5) Some of the description is not very clear or complete for the reader to understand what has been done or how the components interact. See comments below for details on what needs clarification. In particular, it isn't clear how the non-cropland is affected by climate in this model.

Explanation of the details in the sub-models and the interactions between the components are modified according to the suggestions. It is explained according to your comments, "*page 15, lines 19-21*", "*page 26, lines 8-24*", and "*page 27, lines 14-19*" below.

Specific comments and suggestions

Abstract

The abstract is not clear about what is presented here or what the outcomes of evaluation are. While some interactions from climate to land allocation are included, feedbacks between the land system and climate are not because the atmospheric inputs are fixed. Be clear about the novelty here, and state how well the evaluation performs.

Thank you very much for your suggestions. First, the abstract was modified to clarify the novelty of the model development as follows.

To investigate these interrelationships, we developed MIROC-INTEG-LAND (MIROC INTEGrated LAND surface model version 1), an integrated model that combines the land surface component of global climate model MIROC (Model for Interdisciplinary Research on Climate) with water resources, crop production, land ecosystem, and land use models. The most significant feature of MIROC-INTEG-LAND is that the land surface model that describes the processes of the energy and water balance, human water management, and crop growth incorporates a land use decision-making model based on economic activities. In MIROC-INTEG, spatially detailed information regarding water resources and crop yields is reflected in the prediction of future land use change, which cannot be considered in the conventional integrated assessment models.

In addition, we also state how well the evaluation performs and the outcomes of simulations. The final sentence of Abstract in the original manuscript as follows.

By evaluating the historical simulation, we have confirmed that the model reproduces the observed states well. The future simulations indicate that the changes in climate has significant impacts on crop yields, and thus on land use change. The newly developed MIROC-INTE-LAND could be combined with atmospheric and ocean models to develop an integrated Earth system model to simulate the interactions among coupled natural-human Earth system components.

Introduction

page 2, line 21: Bond-Lamberty this reference is incorrect throughout

The reference is modified in the main text.

Model structure

Sub models

It seems that there are two crop models: PRYSBI2 and also one in HiGWMAT. Please clarify how these are different and why they are separate.

The reason that different crop models are used for HiGWMAT and PRYSBI2 is that 1) HiGWMAT uses a crop model based on SWIM for the calculation of the irrigation process, and it has been validated that the water withdrawal of HiGWMAT in various regions is consistent with the statistical data, and 2) PRYSBI2 uses a crop model based on SWAT and crop yield in PRYSBI2 has been calibrated using the agricultural statistics. MIROC-INTEG-LAND uses different crop models to obtain realistic water withdrawal in HiGWMAT and to calculate realistic crop yields in PRYSBI2. The differences in the formulation between the crop models in PRYSBI2 and HiGWMAT are that the former uses more detailed crop modeling of the two-layer crop canopy, Farquhar photosynthetic CO_2 assimilation, and the reported planting date of Sacks et al. (2010), while the latter employs the simpler crop modeling of the single-layer crop canopy, radiation-use efficiency type biomass accumulation, and the hypothetical planting date that gives the highest yield under the given weather conditions. As pointed out by the reviewer, it is an important future work to tune the model parameters to obtain the realistic water withdrawal and crop yields by using a single crop model. In Section 3.1.2, this is explained as follows. The new reference (Okada et al. 2015) is added in the reference list.

The crop growth module is based on the H08 model (Hanasaki et al., 2008a, 2008b), where the crop vegetation formulations and parameters are adopted from the Soil and Water Integrated Model (SWIM) (Krysanova et al., 1998). The crop growth module in HiGWMAT estimates the cropping period necessary to obtain mature and optimal total plant biomass for 18 different crop types. Irrigation is activated during the entire growing season but only for the irrigated portion of a grid cell using a tile approach. Crop growth for the irrigation processes is simulated within the HiGWMAT model (i.e., independent of PRYSBI2).

The reason that different crop models are used for HiGWMAT and PRYSBI2 is that 1) HiGWMAT has been used a crop model based on SWIM, and it has been validated that the water withdrawal in various regions is consistent with the statistical data (Pokhrel et al. 2014), and 2) PRYSBI2 has been used a crop model based on SWAT, and crop yield in PRYSBI2 has been calibrated using the agricultural statistics (Sakurai et al. 2014). MIROC-INTEG-LAND uses different crop models to obtain realistic water withdrawal in HiGWMAT and to calculate realistic crop yields in PRYSBI2. The differences in the formulation between the crop models in PRYSBI2 and HiGWMAT are that the former uses more detailed crop modeling of the two-layer crop canopy, Farquhar photosynthetic CO_2 assimilation, and the use of the reported planting date of Sacks et al. (2010), while the latter employs the simpler crop modeling of the single-layer crop canopy, radiation-use efficiency type biomass accumulation, and the hypothetical planting date that gives the highest yield under the given weather conditions (Okada et al. 2015).

VISIT

page 8, lines 12-13: abandoned cropland recovers to mean biomass of what? and is always considered secondary, or can secondary land revert to primary?

It is the natural vegetation in the same grid. This is explained in the revised manuscript as follows.

regrowth of abandoned croplands is also simulated as the recovery of the mean biomass of the natural vegetation in the same grid.

page 8, lines 14-16: these fertilizer and crop calendar inputs seem inconsistent with the crop model. if the crop model doesn't use fertilizer inputs, then how are they used in VISIT? if crop growth is calculated with implicit fertilizer, then this specific nitrogen input doesn't match. And why would VISIT be using a crop calendar and not the crop model? your biogeochemical fluxes are not going to correspond with your crop growth.

As described in Section 3.2 and Appendix A.7, PRYSBI2 describes the effects of fertilizer by technological factors without considering the fertilizer input process. MIROC-INTEG-LAND adopted this method because crop yields have been calibrated by using technological factors in PRYSBI2. On the other hand, VISIT considers the fertilizer input processes in the manner described in Section 3.4, and it has been validated that the calculated carbon and nitrogen cycle is consistent with various observations (Ito et al. 2017). Therefore, the handling of fertilizer is different between PRYSBI2 and VISIT. As the reviewer pointed out, it is important to ensure that the fertilizer processes is consistent between these sub-models. The text in Section 3.3 has been modified as follows.

In PRYSBI2, the effects of fertilizer are included in the technological factors, and crop yields are calibrated based on the technological factors, As described in Section 3.2 and Appendix A.7. On the other hand, VISIT has been applied and validated at various scales from flux measurement sites to the global scale (e.g., Ito et al., 2017) based on the treatment of fertilizer input, as described above. The consistent treatment of fertilizer processes in PRYSBI2 and VISIT should be important future work.

Model coupling

Experimental settings

page 11, lines 3-19: which SSPs for which RCPs?

In this study, we use outputs of the SSP2 scenario calculated by AIM/CGE (Fujimori et al. 2017). Since the RCP8.5 scenario is not available in SSP2, we use the output of the baseline scenario from AIM/CGE for the MIROC-INTEG-LAND calculation of RCP8.5. This is explained in the revised manuscript.

Historical simulations

page 13, lines 1-3: The results in figure 5 do not all line up along the 1:1 line. You have to adjust this statement.

We modified the statement in the revised manuscript as follows:

For all crops, most of the relationship between the simulated and reported data was distributed around the 1:1 line.

page 14, lines 1-2: TeLMO crop area is not very similar to AIM, and it is more similar to FAO in most cases presented. Since AIM is a driver of TeLMO, more explanation is required here of why they are different. Furthermore, the similarity to FAO is more compelling as evidence for usability of TeLMO, than any similarity to AIM.

Thank you very much for your suggestions. The difference between TeLMO and AIM/CGE is due to the difference in crop yield as well as the mechanism for the allocation of the agricultural land. As explained in Appendix B-1, TeLMO can consider the spatial distribution of crop yield when allocating the agricultural land. On the other hand, in integrated assessment models such as AIM/CGE, land use change is calculated by aggregating crop yield information in the regions (AIM/CGE divides the world into 17 regions). In large countries such as Australia, Brazil and Russia, the allocation method in TeLMO may show good performance. This is explained in the revised manuscript.

In MIROC-INTEG-LAND, TeLMO uses the food demand and GDP per capita calculated by AIM/CGE under the socio-economic scenario SSP2 (Fujimori et al., 2017). Therefore, the difference between TeLMO and AIM/CGE is due to the difference in crop yield as well as the mechanism for the allocation of agricultural land. As explained in Appendix B.1, TeLMO can consider the spatial distribution of crop yield when allocating agricultural land. On the other hand, in AIM/CGE, land use change is calculated by aggregating crop yield information in the regions where the model calculation is performed (AIM/CGE divides the world into 17 regions). In large countries such as Australia, Brazil and Russia, the allocation method in TeLMO shows good performance.

Future simulations

page 15, line 8: why the maximum value? this would underestimate the land area because each crop may be grown in a cell, with varying yields.

+Comments on Appendix B:

page 22, lines 7-11: it isn't clear why you are using the max yield, and it sounds like it is per crop here, while in the text it sounded like it was the max across crops. don't you need to apply each crop yield to its own prices in the 30sec cells to get distinct ASI values for crops? maybe a crop with a lower yield has higher ASI due to higher price. so are you essentially just selecting one crop for the half-degree cell? this will underestimate cropland.

In the TeLMO food cropland model, the cropland area is calculated using the maximum value of the five crops in each grid. This formulation is due to the simplification of the model structure as described below. As pointed out by the reviewer, using the maximum yield to determine the cropland area would underestimate the cropland area. However, TeLMO applies an adjustment parameter (C_j in Eq. B-1) so that the cropland area of the base year can be close to the observed (LUH) data. For this reason, cropland area is not necessarily underestimated by the model. This is explained as below.

If the cropland area predicted by TeLMO is A_{TeLMO}, the actual cropland area is A_{Real}, the maximum yield is Y_{max}, the actual yield that determines the cropland area is Y_{Real}, the food demand is D, and the adjustment parameter is C_j, then

$$A_{TeLMO} \sim \frac{D}{Y_{max}} \times C_j$$

$$A_{Real} \sim \frac{D}{Y_{Real}}$$

At the base year (2005), $A_{TeLMO} \sim A_{Real}$ and thus

$$C_j \sim \left(\frac{Y_{max}}{Y_{Real}}\right)_{y=2005}$$

Therefore, the ratio of A_{TeLMO} and A_{Real} except the base year $y \neq 2005$ is

$$\frac{A_{TeLMO}}{A_{Real}} \sim \left(\frac{Y_{max}}{Y_{Real}}\right) \Big/ \left(\frac{Y_{max}}{Y_{Real}}\right)_{y=2005}$$

Namely, the ratio of A_{TeLMO} and A_{Real} can be approximated as the ratio of ${Y_{max}}/{Y_{Real}}$ between the calculation and base years. Since the actual calculation of TeLMO considers the food trade and allocates the cropland area at the grid level, this is not entirely the case. However, the cropland area in TeLMO is not necessarily underestimated because of the adjustment parameter.

As the reviewers point out, it is possible to formulate the prices for different crops and allocate the cropland areas according to agricultural suitability indices. In that case, it is necessary to increase the number of sectors in the general equilibrium model in the International Trade Module, and solve the prices for each sector. In fact, in the course of the development of TeLMO, we tried to determine the price for each crop and allocate cropland area according to each agricultural suitability index. However, the results obtained in this formulation were roughly similar to those obtained by the current formulation. On the other hand, in some cases, the solution did not converge due to the complexity of the general equilibrium model (particularly when demand increased). For this reason, we decided to adopt the current formulation. However, as the reviewers point out, calculating cropland area for each crop is a very important future work. In the main text, it is described as follows.

As described in Section 3.4 and Appendix B, TeLMO uses the yield calculated by PRYSBI2 (grid maximum value as shown in Figure 11f) and the food demand output of AIM/CGE.

The description in Appendix B.1.1 is modified as follows.

In TeLMO, total food cropland area is projected by using the maximum yield across the five cereal types (winter and spring wheat, maize, soybean, and rice). The reason for this formulation is explained in Section B.1.2. y_j in Eq. (B-1) is calculated from the yields of the five cereals types by PRYSBI2.

At the end of Appendix B1.2, it is explained as follows.

As explained in Section B.1.1, TeLMO uses the maximum yield of five cereals types to project the total cropland area. Alternatively, it is possible to increase the number of agricultural sectors in Eqs. (B-3) to (B-12), solve the prices for each crops, and allocate the cropland area according to the ASIs for each crop. Although we attempted this formulation in the course of our development of TeLMO, it was found that the results were similar to those obtained from the current formulation. On the other hand, the solution of general equilibrium models did not converge in some cases because the number of sectors increases in the equations. For this reason, we decided to adopt the current formulation, while recognizing that calculating cropland areas for each crop is an important future work.

page 15, lines 19-21: what is the basis for your bioenergy crop calculations here?

The method for the calculation of bioenergy crop yield is described in the revised manuscript as follows.

For biofuel crop yield $y_{bio,j}$, the yield for miscanthus or switchgrass, whichever is greater in a given cell, is calculated for the entire globe by using the biofuel crop model developed in Kato and Yamagata (2014). The biofuel crop model in Kato and Yamagata (2014) considers the future changes in climate based on the RCP scenarios. In this study, we also consider the future changes in fertilizer input based on the SSPs adopted in Mori et al. (2018). Because of the uncertainty in future fertilizer application for crop management, we set the high end of the N fertilizer input threshold according to Tilman et al. (2011). The nitrogen fertilizer application was set to increase from the current level according to the increasing rate of GDP in the SSP2 scenario up to 160 kg N ha^{-1} yr^{-1} if the fertilizer input at the country level was below 160 kg N ha^{-1} yr^{-1} in the 2000s. Also, the phosphorus fertilizer input in each country was set to follow the same annual increase rate as the nitrogen fertilizer application.

page 16, lines 23-24: Not sure what you mean here. You haven't untangled land use effects here, just showed results of land area changes and the biomass affected. Many ecosystem and earth and integrated assessment models do this. what is unique here? If you were to show how the land allocation and the biomass effects differed due to the climate effects on yields, then this would show the benefit of this model. To do this you have to do another set of runs where the yields are the base year yields plus the non-climate changes in yield, and compare these to the runs you have done. Alternatively, you could show how the inclusion of water availability in determining irrigation changes the crop area/production by turning off the irrigation dependence on the available water.

Thank you very much for your very constructive suggestions. According to the reviewer's comments, we performed additional simulations where climate effects on yield are switched off (new Figure 16) to shows the benefits of this model. We removed this sentence of the original manuscript, and added the new paragraphs at the end of Section 7. In fact, we are now preparing a paper using MIROC-INTEG-LAND to investigate the impacts of various natural and socio-economic factors (climate, irrigation, fertilization effects, population, food demands, etc.) on land use and land ecosystems. Therefore, details of the analysis on interactions between sub-models will be presented in the next paper. In the revised manuscript, we added discussions as follows.

Figure 16 shows the results of simulations to evaluate the effects of climate change on crop yield and land use. In Figure 16, the RCP8.5 simulations with climatic factors (temperature, water vapor, wind speed, soil moisture, soil temperature) and CO_2 concentration fixed at 2006 (noCL+noFE), those with climatic factors fixed (noCL), and those with varying climate and CO_2 concentration (CL+FE) are compared. The CL+FE simulations are the same as the RCP8.5 results shown in Figure 12. As shown in Figure 16a, in the noCL+noFE simulations, the crop yield was much lower than that in the CL+FE simulations. In the noCL+noF experiment, the crop yield is increased due to the technological development (Section 3.2 and Appendix A.7). The reason that the yield in the CL+FE experiment is higher than that in noCL+noFE experiments is that the crop yield increases due to the fertilization effect in the former. In the noCL+FE experiment (Figure 16), the crop yield is approximately 1.7 times as large as in the noCL+noFE experiment. Although there is a great deal of uncertainty in the treatment of fertilizer effects in crop models (Sakurai et al. 2014), the increase in crop yields is significant in the simulations by MIROC-INTEG-LAND.

As shown in Figure 16a, the crop yield is significantly smaller in the CL+FE than in the noCL+FE experiment. This result indicates that climate change can significantly reduce crop yields. One of the reasons for this reduction in crop yield is that the growing season is shortened due to a rise in surface air temperature, adversely affecting the growth of crops (Sakurai et al. 2014). The impact of climate change on crop growth increases with increasing temperature, and in 2100 crop yield in the CL+FE experiment is projected to decrease roughly 60% relative to the yields in the noCL+FE experiments.

Due to the changes in crop yields caused by the changes in climate and fertilization effects, future cropland area will also change significantly. As shown in Figure 16b, the noCL+noFE experiment requires more cropland area compared to the CL+FE experiments, due to the smaller increase in crop yields (Figure 16a). As explained in Figure 12, cropland area could expand in the first half of the 21st century to meet the increasing demand due to population growth, and then gradually decrease in the latter half of the 21st century. On the other hand, in the noCL+FE experiments, the increase in crop yield is larger than that in the CL+FE experiment, and thus the cropland area in 2100 will be about 76% of that in 2005. In sum, it is found that the changes in climate and fertilization effects have large impacts on crop yields and land use change.

Caption of Figure 16 is added as follows.

Figure 16: Time series of changes in a) cropland yield (maximum across five crops at each grid, t/ha), and b) food cropland area (a fraction of total land area) based on the forcings of the five climate models under the RCP8.5 scenario. Simulations with climatic 5 factors and CO_2 concentration fixed at 2006 (light green, noCL+noFE), those with climatic factors fixed (cyan, noCL), and those with varying climate and CO2 concentration (red, CL+FE).

Implications

page 16, lines 30-31: this is where things get more interesting

Thank you very much again for your suggestions. The analysis of the interactions and feedbacks is presented at the last few paragraphs of Section 7 in the revised manuscript. According to this modification, the first paragraph of Section 8 is revised as follows.

With MIROC-INTEG-LAND, it is possible to calculate the interaction between climate, water resources, crops, land use, and ecosystems. The discussion in Section 7 suggests the type of feedback processes that can occur. While this study showed only the results of the SSP2 scenario, in the SSP3 scenario, where the world is divided, the demand for food will be greater and more cropland area will be needed (O'Neill et al., 2017). Investigating the impacts of various natural and socio-economic factors (climate, irrigation, fertilization effects, population, food demands, etc.) on land use change and land ecosystems is an important future research direction as an extension of the present study.

page 17, lines 6-8: it seems like you have outputs in this paper that could be used for this
In the original manuscript
MIROC-INTEG1 can also be used to evaluate the effectiveness of climate mitigation measures by quantitatively evaluating the cultivated land area of biofuel crops and the budget of greenhouse gases via the terrestrial ecosystem model, VISIT.
Thank you very much for your suggestion. This sentence is removed in the revised manuscript.

Figures and tables
Figure 3 What do you mean by multi-model mean? You are using only one model here.
We modified the manuscript as follows.

Simulated results are the average of five climate model simulations. Grey shading indicates the uncertainty range shown by one standard deviation from the mean.

Figure 10 What is the vertical axis? Is it the annual change in cropland area as a fraction of total land area, or is it the cropland in that year as a fraction of total land area?
It is the cropland in that year as a fraction of total land area. The Figure caption of Figure 12 (Figure 10 in the original manuscript) is described in the revised manuscript.

Figure 12: Time series of changes in cropland area relative to land area based on the forcings of the five climate models. The vertical axis is the cropland area in that year as a fraction of total land area.

Appendix A

page 17, line 28: what are these? can you give the types of data if not able to list them all here?

We modified "A.1 Input data" in the revised manuscript as follows.

As input data, the PRYSIB2 Version 2.2 uses the planting and harvesting date (Saccs et al. 2008), soil field capacity (Scholes et al. 2011), and atmospheric data (average, maximum and minimum daily temperature, daily shortwave and longwave radiation, daily humidity, and CO_2 concentration). We use the same atmospheric data as HiGWMAT described in Section 5 (i.e., ISIMIP fast track data by Hempel et al. 2013).

page 19, line 3: i think you mean water stress and shouldn't this go into section A.5?

As you pointed out, the water stress is explained in A5. It is described in the revised manuscript.

page 19, line 11: so there is a cold stress factor applied on top of the temperature dependent equation?

We removed the sentence in the original manuscript "*For soybean, we considered cold stress in addition to the temperature stress explained above. The details are the same as in version 2.0.*". The cold stress was not considered in the MIROC-INTEG because of technical reasons.

page 20, lines 7-16: it isn't clear what this is or how it is applied. is it a fraction that is applied to a given yield and then added to that yield? what are equations 32 and 33?

"equations 32 and 33" in the original manuscript were Eq. (A-5) and (A-6). The trend of the parameter relevant to agricultural management is expressed by substituting Θ obtained in Eq. (A-14) into Eq. (A-5) and (A-6).

Appendix B

page 22, lines 7-11: it isn't clear why you are using the max yield, and it sounds like it is per crop here, while in the text it sounded like it was the max across crops. don't you need to apply each crop yield to its own prices in the 30sec cells to get distinct ASI values for crops? maybe a crop with a lower yield has higher ASI due to higher price. so are you essentially just selecting one crop for the half-degree cell? this will underestimate cropland.

This is addressed in the above comments for page 15, line 8.

page 25, lines 20-21: for bionenergy crops, does this mean that these are fixed values, or are they dependent on the atmospheric inputs? More info is needed here.

We consider changes in climate and socio-economic factors for the calculation of bioenergy crops. The manuscript is modified as follows.

For biofuel crop yield $y_{bio,j}$, the yield for miscanthus or switchgrass, whichever is greater in a given cell, is calculated for the entire globe by using the biofuel crop model developed in Kato and Yamagata (2014). The biofuel crop model in Kato and Yamagata (2014) considers the future changes in climate based on the RCP scenarios. In this study, we also consider the future changes in fertilizer input based on the SSPs adopted in Mori et al. (2018). Because of the uncertainty in future fertilizer application for crop management, we set the high end of the N fertilizer input threshold according to Tilman et al. [2011]. The nitrogen fertilizer application was set to increase from the current level according to the increasing rate of GDP in the SSP2 scenario up to 160 kg N ha^{-1} yr^{-1} if the fertilizer input at the country level was below 160 kg N ha^{-1} yr^{-1} in the 2000s. Also, the phosphorus fertilizer input in each country was set to follow the same annual increase rate as the nitrogen fertilizer application.

page 26, lines 8-24: Is this NPP for pasture calculated beforehand, offline? Does it include matching climate drivers to the scenarios here? Or are these NPP numbers independent of the climate change?

The NPP used in the pasture model was calculated in offline simulations in advance, with fixed boundary conditions at 2005. This is explained in the revised manuscript.

The results of an off-line simulation by VISIT (Ito and Inatomi 2012) assuming the entire world to be grassland are used here for NPP_j. The boundary condition of the VISIT off-line simulations is fixed at year 2005.

page 27, line 10: where is the base-year managed forest area from?

The base year of the managed forest is also 2005. It is added in the revised manuscript.

Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data (Friedl et al., 2010) are used for the base-year forest area (2005)

page 27, lines 14-19: also for forest, are these NPP values calculated beforehand, offline? and are there matching values corresponding with the scenarios here, or are they a single set of values for all sims?

As in the case of the pasture model, the NPP in the Forest Model is calculated by offline simulations with fixed boundary conditions. This is explained in the revised manuscript.

calculated by VISIT (Ito and Inatomi 2012) off-line simulations assuming the entire world to be forest with fixed boundary conditions (2005).