Reviewer 2

We thank reviewer 2 for the detailed and thorough comments. Our replies to the comments are inserted below in blue colour.

Dear authors
The topics in the manuscript ”CM2Mc-LPJmL v1.0: Biophysical coupling of a process-based dynamic vegetation model with managed land to a general circulation model” could be interesting for the readers in GMD and a central topic in this special issue ”The Lund-Potsdam-Jena managed Land (LPJmL) dynamic global vegetation, hydrology and crop model - developments, evaluations and documentation”. Authors tried to describe a new earth system model based on climate model CM2Mc coupled with LPJmL. The simulation outputs by the CM2Mc-LPJmL seemed to nicely agree with the previous simulation results in both historical and future period. The current draft is readable. However, I feel that it is not sufficient in describing the model. Therefore, I did not make an acceptance decision in the current draft of the version.

The major comments are as follows;
1. I understand that creating a new ESM is challenging, but I did not understand what was new about this new ESM compared to the existing ESM. For example, it describes forest fire and permafrost schemes, but it is not clear whether these are new to the existing ESM. At least, there are no results showing any changes due to the introduction of these schemes into the simulation. The significance of new coupling DGVM with an atmospheric circulation model rather than extending the existing ”ESM” is also unclear. It would be nice to have more explanation on this point.

2. Honestly, I don’t know how much description is appropriate in describing such a huge model. Therefore, this is just a hunch, but I felt that the description of each elemental model was still too small. For example, as a person who deals purely with GCMs, is the description of biogeochemical models sufficient? At least, I can hardly imagine the contents of AM2 model and MOM5 models.

An important goal of our work is to couple the state-of-the-art DVGM LPJmL to a reasonably fast atmosphere-ocean model. This opens up research possibilities involving the interaction of and feedback between climate system and biosphere, including land use, which are not possible with either a simpler land model, nor with stand-alone LPJmL. Using a coarse-grid atmosphere-ocean setup enables simulations on centennial to millennial time scales, and/or ensemble runs.
The aim of this paper is not to describe a completely new ESM but the coupling of existing parts. We used the existing ESM CM2Mc from GFDL and replaced the land surface module LaD with LPJmL. Hence, in our opinion, it was not necessary to describe all parts of the ESM, which are individually published and described in this configuration in Galbraith et al. 2011. Instead, we focus on the coupling between FMS and LPJmL5 and the changes implemented in LPJmL5. In the introduction and discussion we stated the advantages of LPJmL5 compared to the standard land model component used in CM2Mc, which include

dynamic vegetation, process-based fire, permafrost and an advanced land use scheme. While we are showing the impact of land use in greater detail it is not within the scope of this paper to present and evaluate these features. They are part of the stand-alone model LPJmL5 and are individually published in the referenced papers which we also cite in our paper. Our aim is to show that the coupling between LPJmL5 and the ocean - sea ice - atmosphere components works, gives reasonable results in climate and important vegetation variables, as well as the climatic stability, which opens possibilities for new research. For more information about atmosphere or ocean Earth system components, specific processes such as fire dynamics, the handling of crop growth and harvest in LPJmL5 we refer to the individual papers where these modules or features are described in greater detail. The current paper informs about the steps to facilitate a successful coupling of a DGVM to an Earth system model. The significance of our resulting model is raised in the introduction and described in more detail in the discussion (4.3).
The coupling of LPJmL5 to CM2Mc is motivated by the option to study climate feedbacks arising from changes in land processes such as dynamic vegetation, process-based fire, permafrost and an advanced land use scheme with explicit simulation of crop growth, incl. sowing and harvesting as well as managed grassland. The new coupled system allows us to investigate the detailed response of the biosphere to the combined response to climate and land-use change, while being computationally efficient. Other ESMs, such as CLM5 (Lombardozzi et al. 2020,https://doi.org/10.1029/2019JG005529), show that more and more ESMs are moving in that direction. Ongoing model intercomparison outline also that diversity in modelling approaches is helpful for charting possible future directions of our Earth system. Our evaluation results give us confidence in the robustness of our results. Detailed responses to your individual comments can be found inserted below.

1Individual comments

L89–94 It seemed that the limited variables are interconnected

Here, we are not quite sure what the reviewer's concerns are.
In this section the FMS coupler is described, which standardizes the interfaces between the model components and handles the fluxes between them. Hence through the coupler, which has some functionality of a LSM, the different variables are interconnected. We provide the most important variables for the land side (humidity, roughness, albedo and temperature) in the fast time step and the coupler calculates, e.g., the drag or the flux of moisture to the atmosphere. These variables are then provided to the land model and the atmosphere in the next time step. Fig. 1 aims to illustrate the FMS functioning. We hope this sufficiently addresses the reviewer's concern.

L89–94 I'm not familiar with ESMs. So, for me, it is hard to imagine how a coupler work between models. How do you reconcile the conservation of energy and mass as variables are exchanged between models with different resolutions?

We thank the reviewer for noticing here a lack of more detailed description. We added a few sentences to 2.1.1:
"*All model components are simulated on different spatial and temporal scales and the coupler is the interface directly connected to the different parts. It interpolates the different scales to a common grid and adapts the respective fluxes to the grid of the receiving model*

component. Usually the variables are not directly exchanged between model components. For instance, the land model calculates the humidity of the canopy layer, and the atmosphere the humidity of the lowest atmospheric layer. The coupler calculates the moisture flux between both layers and provides them to the different models on their respective spatial and temporal scale, while the different humidity variables are not exchanged. By tracking these explicit fluxes of energy and water, the coupler ensures the conversation of these quantities."

2.1.2 & 2.1.3 Please don't use abbreviations in the section title. Like 2.1.1 or more insightful title is better.
2.2 Same above.
Thanks for pointing this out, indeed it helps to improve readability. We changed it in the revised document to Modular Ocean Model 5 (MOM5) and Atmospheric Model 2 (AM2).

L105 What are the input variables for this component. Please specify them as in L118.
This paper is about the coupling interface between the land model and the FMS coupler. As BLING is a component inside the ocean it is beyond the scope of this paper. Further information about BLING can be found in Galbraith et al. (2010). We improved the paper text to clarify this in 2.1.2:

"Enclosed in the ocean component MOM5, the Biogeochemistry with Light, Nutrients and Gases (BLING) model is run. It was developed at Princeton/GFDL as an intermediate-complexity tool to approximate marine biogeochemical cycling of key elements and their iso-topes. For further details we refer to Galbraith et al., 2011."

L110 dynamic core of ?
The dynamic core in the atmospheric model as presented in Lin et. al, 2004. In the revised manuscript we changed the sentence to:
"It uses the finite volume dynamical core as in (Lin, 2004),..."

L111 Sorry, what is a C and D grid. Perhaps, it is a very common term in the climate model study field.
While they are indeed very common terms, we deleted the remark about the C and D grids, since the atmosphere grid structure is mostly irrelevant for our coupling work. Interested readers are referred to the more detailed description in the referenced papers. We thank the reviewer for pointing to this possibility of clarifying the text. We rewrote this section as stated in the next remark.

L112 What do the tracers mean? What do the dynamics suggests?
Tracers are conservative or non-conservative properties (e.g. humidity), that are transported (advected or diffused) between grid cells.
Dynamics refer to the motion and thermodynamic state in the atmosphere. We agree with the reviewer, and rewrote this section to improve clarity. It reads now:

"*The atmospheric module in CM2Mc is GFDL's Atmospheric Model version 2.1 (AM2, Anderson et al. 2004). It uses the finite volume dynamical core as in Lin (2004), as implemented in CM2.1 (Delworth et al., 2006) with a latitudinal resolution of 3° and a longitudinal resolution of 3.75° and 24 vertical levels, the lowest being at 30m and the top at about 40 km above the surface. For the coupled setup, we use a general atmospheric time step of 1 hr at which variables are exchanged with the coupler. Dynamic motion and the thermodynamic state of the atmosphere are calculated on a 9 min time step, while the radiation scheme has a time step of 3 hrs. The coupled model includes an explicit representation of the diurnal cycle of solar radiation. For a more detailed description of the model and its configuration, see Galbraith et al. (2011) and Delworth et al. (2006).*"

L121 LPJmL5 -> LPJmL ver. 5? Please add the citation for this version.
The citation for LPJmL5 is in the first sentence of the presentation of LPJmL 2.2: Von Bloh et al. 2018.
All model versions that build on the LPJmL5 version published by von Bloh et al. 2018 have the nitrogen cycle implemented which can be deactivated in the model code to simplify a study. We realize that the formulation in lines 121-22 were perhaps misleading. The sentences now read:

"All LPJmL (sub-)versions that build on the LPJmL5 version published by von Bloh et al. (2018), include the nitrogen and nutrient cycle. Because further adaptations would be necessary to include the nitrogen cycle in the coupled model, we concluded that it is beyond the scope of this study and deactivated it in this study."

L126 Please summarize all plant functional types in the manuscript or the supplemental material. Although the simulation results are presented in Fig 8, the readers can only reach the abbreviation about PFT.
We thank the reviewer for this useful suggestion and added a list of all plant functional types to the Appendix B.

L131 Which dataset was used for the prescribed land-use input?
This information is given in Section 2.4, Model setup and forcing.
"...and land-use informationare from Fader et al. (2010)"

2.3.2 Section 2.3.2 should be incorporated into Section 2.2 (LPJmL part).
We disagree with this suggestion, because Section 2.3.2 is the most important and core section of the methods used for the coupling work. It explains the changes to LPJmL in order to prepare the model for the coupling. Section 2.2 just gives an overview of the current stand-alone model LPJmL to provide the reader with the basic information on the main functionalities of the DGVM. To couple this model to CM2Mc we had to implement several

new features, including a new canopy module with a calculation of the energy balance and humidity-driven evapotranspiration, which are not part of the standard LPJmL model.
We added a statement in the beginning of 2.3. to clarify this:

"While Section 2.2 described the standard LPJmL5 model as previously published we introduce in Section 2.3 our adaptations to LPJmL5 in order to be coupled with the FMS coupling framework."

L174–179 It is better to describe this sentence in the introduction.
We agree that part of this information is important for the introduction. We wrote a similar, more general statement in the introduction in L 51-55:

"With increasing process-detail and the number of processes captured in the biosphere components of ESMs rising, new challenges in correctly representing potential feedback mechanisms might arise. This includes error propagation resulting from changes in climate that could be amplified by, e.g., increased tree mortality, which then changes land-surface characteristics over time (Quillet et al., 2010). Hence, a bidirectional and stable coupling of a DGVM with a full water, energy and carbon cycle remains a challenge (Forrest et al., Pokhrel et al. 2016)"

We think, however, that coming back to this point in a more detailed manner is important to explain and contextualize the changes to LPJmL also in the methods. Part of this paragraph in L174-179 is too detailed and presumes more context than the introduction can provide.

L321 Please add the citation for the "historic land-use data from 1700".
Although it was also before stated in 2.4 "Model setup and forcing", we follow the recommendation and add the citation in the revised manuscript here as well. .
"...prescribed as described in Fader et al. (2010)"

L354 Please provide here which variables y i are evaluated by this metric.
Section 2.6 is structured in a way that in the first part the different variables which are evaluated are presented and in the last part the used metric is presented. Hence y_i signifies all the variables introduced before: temperature, precipitation, vegetation. For clarification we added a sentence in the end of the chapter:

"We use this metric for the evaluation of the performance of temperature, precipitation and above ground biomass."

L367: 3.1.1 How about the stability in other variables in other model components such as PFT distribution, C stock in terrestrial and Ocean ecosystems?

This is an interesting question. Since this paper is mostly about the description of the coupling approach and a basic evaluation of the biosphere, we regard the global mean temperature as a sufficient indicator for a stable equilibrium between climate and land biosphere. With a stable climate, as shown in the paper, it is assumed that other internal model variables are also getting stable.

The reviewer raises an interesting point on the stability of the terrestrial carbon stock. Since we did large modifications on the biophysical part of LPJmL, and the DGVM is now running in a coupled mode, we agree it is a good idea to also provide a curve of total carbon in the biosphere for 1000 modeling years, which can be found now in the supplement. Large changes in the carbon pool integrate all changes in the PFT distribution and composition as well as short term reactions such as fire disturbance.

The evaluation of the stability of C stocks in the ocean is out of scope for this paper, since we did not do any changes in the ocean model and have a strong focus on the terrestrial biosphere. The approach of our evaluation is explained in the last paragraph of the Introduction (L72-76). To discuss the relationship between a stable climate and generally stable stocks in the different model components we added to 4.1:

"By achieving a stable climate in terms of surface temperature and precipitation, other variables in the model as for instance carbon stocks of the biosphere (see Fig. S8 in the Supplement) and ocean carbon stocks are also assumed to stabilize (even though possibly on a different time scale)."

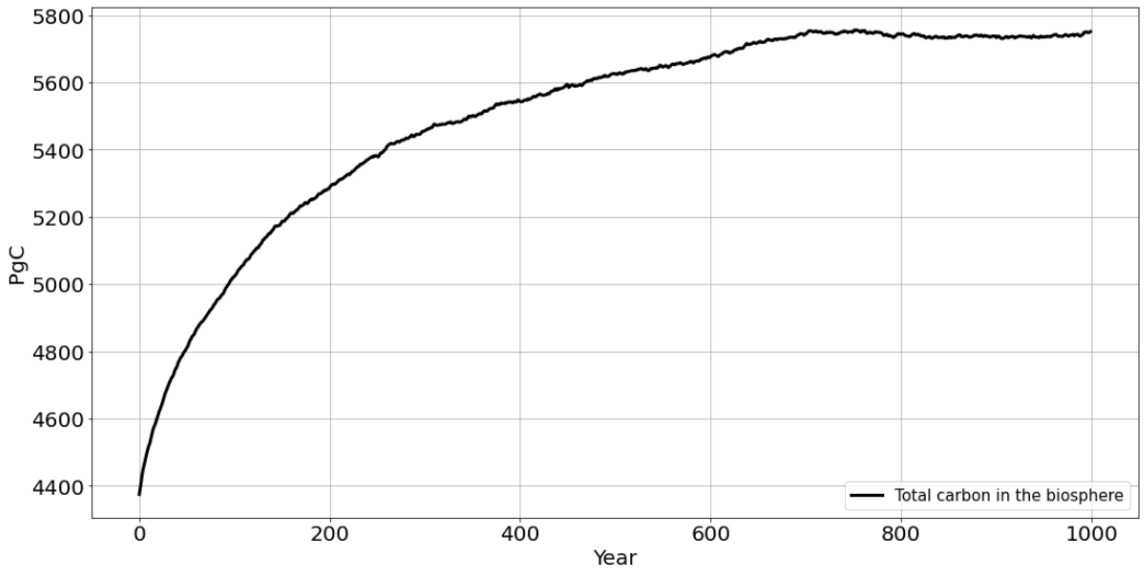

Fig. 1: Total carbon in the biosphere (vegetation, litter, soil) for the piControl run.

L410 Are there any improvement in the CM2Mc-LPJmL output that should be mentioned, compared to CM2Mc-LaD?

The explicit comparison between CM2Mc-LPJmL and CM2Mc-LaD is available in the Supplement S3. Generally the biases in CM2Mc-LPJmL are slightly larger.

LPJmL, however, is an advanced DGVM which includes vegetation dynamics, permafrost dynamics, fire disturbances and a comprehensive managed land module, which are feedbacks, which might increase instabilities in the model results. Using a dynamic vegetation model opens up research possibilities about interaction/feedback/etc , which are not possible with either the simple LaD nor stand-alone LPJmL. We added to 3.1.3 and 3.1.4 a reference to the figures in Supplement Section S3.

2L414 & Figure 6 I don't know the manner of climate science, but why do you compare annual precipitation in mm/day instead of mm/year? It is hard to intuitively understand the size of the bias.
The basis of the data in Figure 6 are daily values, which are presented in a mean from 1994-2003. Hence, it makes sense to show the results in units of mm/day, as done in other studies (e.g. Anderson et al. 2004).

L450– There are no information about PFTs in detail. I can see only abbreviation in the legend of Figure 8. So, please add this information in material and method or in appropriate place.
We thank the reviewer for this useful suggestion and added a list of all plant functional types to the Appendix B.

L485 If the results of the comparison with CMIP5 are important, it would be better to include them as a figure in the draft instead of sending them to the supplement.
In our opinion, these comparisons are useful but not very important, because the direct comparison between our model and CMIP5 models is difficult. These models employ a much more detailed atmosphere and a much finer grid-size, resulting in better constrained climate and vegetation. While a direct comparison is difficult, our results are, however, in the range of CMIP5 which is an important plausibility check for our new coupled system. We therefore believe that putting these comparisons to the supplement is sufficient while maintaining the clarity of the main text.

L587–590 Some of this text could be taken to the intro and explained as to why we are creating a new ESM using the coupler.
This is a good suggestion, but to our opinion, similar information as to why we are coupling LPJmL to CM2Mc is stated in the introduction:

"Benefits of coupling LPJmL5 include the use of the process-based fire model SPITFIRE (Thonicke et al., 2010; Drüke et al., 2019), its advanced land use and land management scheme, the representation of permafrost and a state-of-the-art water cycling (Schaphoff et al., 2018a). By using FMS as the coupling infrastructure we remain flexible in terms of other ESM components. The coarse CM2Mc model grid enables us to have a relatively fast and computationally low-cost Earth system model, which allows conducting many model realisations under different land use and trace gas settings. While CM2Mc uses the relatively old, but fast atmospheric model AM2 (Anderson et al., 2004) in a coarse resolution setup and the ocean model MOM5 (Galbraith et al., 2011), it will be possible to employ the latest GFDL model developments in our coupled system in the future."

Figure 1 Figure 1 is not referred in the text. Are there any exchange between MOM and LPJmL? How about atmospheric pressure between AM2 and LPJmL.
We thank the Reviewer for noting this. We now refer to this Figure in section 2.3. In the current implementation there is no direct exchange between MOM and LPJmL, but of course

several indirect links exist via, e.g., exchange of heat, changes in the sea surface temperature, which influence climate and thus land surface and vegetation.
It is true that we are using surface pressure, provided by the coupler. There are however no direct or large feedbacks between vegetation and surface pressure, hence pressure is much less important in this context as, e.g., temperature and humidity. For clarification we added the most important variables to the caption of Figure 1:

“Schematic overview of CM2Mc-LPJmL and the most important variables exchanged between LPJmL5, FMS and AM2.”