Response to Referee Comment C7504–C7508.

This paper presents an approach to improving the representation of plant diversity in ecosystem models. The authors utilize the TRY plant trait database to generate a linear regression-based predictive model of three plant traits which is driven by climate and soil moisture variables. The model has reasonably good predictive power for Vcmax and Jmax but performs more poorly for specific leaf area. The model is applied within the JSBACH land surface model to adjust these three traits each year in each grid cell.
The resulting model is slightly better at predicting the distribution of plant types, but now significantly overestimates GPP.

Response:
We thank the reviewer for his elaborate commentary on our manuscript.
Please note that three traits were adjusted each year for every PFT independently within every grid cell.

This approach is probably the most transparent way of including the variation of plant traits observable in databases into a dynamic vegetation model, and thus it addresses a key concern with predictions of future and present vegetation behavior, which is that 'static' plant traits significantly underestimate both diversity of plants and the capacity of plants to adjust to their environmental conditions.

My issues with this approach are primarily that I do not really think that the new model predictions of how plant growth adjusts with climate/trait relationship have any significant meaning. This is primarily to do with the fact that the choice of traits appears to be slightly arbitrary, and ignores the concomitant changes in other traits that are implied by virtue of altering SLA, Vcmax and Jmax.

Response:
The selection of traits is motivated more extensively in a comment later on (at comment P18912, L10) and is not arbitrary. But as from the current description this might not be apparent, we will explain this more thoroughly in the revised manuscript.

Briefly; we selected all traits implemented in the current version of JSBACH that could be linked to traits observations. Despite the fact that this choice of traits is limited in itself, it presents the most comprehensive way for incorporating traits variation into JSBACH that is currently possible. Therefore, it certainly has a meaning and it may even have provided a conservative estimate of the impacts of traits variation on model behavior.

The most obvious example of this is the leaf lifespan trade-off with SLA, which, while being documented extensively by many of the authors of the paper, is ignored here. Given this tradeoff, increases in SLA are very likely to be associated with shorter leaf lifespans, and ignoring this relationship means that the plants with higher SLA are not paying the full 'cost' of this new life history strategy.
Under these conditions, it would be unsurprising if changes in the competitive ability of different plants were to result from changing SLA because there is no cost associated with having thinner leaves.

Response:
We acknowledge that in reality there is an important trade-off between SLA and LLS determining plant survival strategies, and that without this trade-off some important restrictions in the plant response is missing.

In many DGVMs, for example LPJ, LAI is modeled in relation to SLA, which in turn is calculated based on a PFT-specific fixed LLS values. In such a case, the relationship between SLA and LLS is directly implemented. However, in the default model of JSBACH the phenology module is not carbon based and therefore SLA does not play a role in determining LAI and has been decoupled from LLS. Furthermore, SLA is PFT-specific and fixed in JSBACH, whereas LLS (the inverse of leaf shedding rate, as it is modeled in JSBACH) is a composite of different variables; it varies within a phenology type as depending on the developmental phase of the vegetation(growth, vegetative or rest phase), and according to different environmental drivers (primarily temperature and soil moisture). Productivity does not play a role in phenology, only in determining shifts between vegetation phases, for which the condition if NPP of the previous year has been positive or negative is evaluated.

As a consequence of this approach, in the default JSBACH model, the effects of SLA on the carbon balance are very limited (much more limited than in most other DGVMs) and SLA is basically decoupled from phenology, and thus LLS. This setup may not reflect correlations found between LLS and SLA between species across large scales, but the developers of JSBACH had a good reason for not coupling SLA to phenology (and thus to LLS): much of the phenological development of a plant comes from a remobilization of carbon from previous year reserves instead of from real-time productivity. If real-time productivity is used, this results in an underestimation of LAI. Therefore, they uncoupled phenology and productivity. Whether one agrees with such implementation or not primarily relates to JSBACH and not to our approach to incorporate traits variation. In fact, by incorporating variation in SLA, the uncoupling of SLA and LLS has been reduced, and SLA and LLS are now allowed to covary based on climate, even though there is no direct trait trade-off or impact of SLA on LLS in the model. In this way one could say the model consistency has been improved by allowing SLA to vary. In the revised manuscript, we will add this explanation.

This is less true in the case of the Vcmax changes, as JSBACH also increases respiration costs when Vcmax increases, but increases in photosynthetic capacity also imply other changes in, for example, the amount of sapwood required to transport increasing amounts of transpired water and in the quantity of roots required to supply Nitrogen for the higher N demanding tissues. While tackling all of these tradeoffs is challenging, I think that including the leaf lifespan trade off in the calculations is critical, as is at least discussing the potential for other traits to alter in sync with these three chosen traits.

Response:
We do agree with the observation of the referee that there are many trade-offs among traits. However, many (of the mentioned) trade-offs between traits are not possible to model, simply because the related physiological processes are not presented in JSBACH (which e.g. does not yet have a N-cycle), although increasingly efforts are made to include such processes and some of these trade-offs as well. We were limited by what is currently available in terms of traits in JSBACH and unfortunately could not incorporate abovementioned trade-offs.

Besides the discussion on the SLA-LLS trade-off, we will add a section to the discussion in the revised manuscript on trait trade-offs affecting ecosystem behavior and the potential impacts of those additional trait variation and trade-offs on model behavior. Probably this implies that with the current model setup with variation in three traits, we have conservatively assessed the impacts of traits variation on model behavior.

Similarly, more discussion is needed of alternative methodologies for representing plant trait diversity. For example, while it does not use trait databases in this way, the 'adaptive DGVM' framework has contained methods for adjusting parameter values with environmental conditions for some time. Similarly, many plant traits are actually variable in some existing DGVMs, including Vcmax within the LPJ model (as discussed in a previous comment). Further, other models integrate *trait variation by increasing the number of plant functional types such that diversity is better represented (e.g. the JEDI model) and others (ED1.0, CLM4.0) have already utilized trait data to asses mean parameter values. Ignoring the wider literature on this topic will make the paper a less interesting contribution to the discussion.*

Response:
We agree with the referee that a more elaborate discussion about other methodologies is needed, as another referee gave the same comment. We refer shortly to other approaches (e.g. O-CN and JULES –SF) in the introduction and discussion, but we agree this should be done more extensively. We will discuss in more detail the JeDi and aDGVM models in the revised manuscript.

We know that some models in part have utilized observational trait data to determine mean parameter values for PFTs (even JSBACH does), or are planning to do this. We have not spent much discussion on this, as this was not the focus of the research. Even though we also performed a simulation with trait means based on observational data, this was done, not because we thought this was a new approach, but to contrast it with the simulation with variable traits and show how variation in traits allowed for feedbacks with climate. We will explain this better in the revised manuscript.

With respect to the varying Vcmax values in LPJ: we are aware that Vcmax varies in LPJ, but this is also the case for Vcmax in JSBACH. We however, incorporated variation in $Vcmax_{25}$, which is a reference value at 25 °C, used to calculate Vcmax at a local given environmental temperature. In this way extra variation in the actual Vcmax is allowed for.

Specific Comments. P18909 L10: Reporting the deviations of the original trait values from the new ones doesn't strike me as the most interesting aspect of this paper. I would report on the strength of the climate-trait predictive model, as that forms the core of the methodology.

Response:
We agree the strength of climate-trait relations is important and we do reflect on this in the results. We will also add this to the abstract. However, we think the discrepancy between default trait values and observations is also relevant to the abstract as it shows differences among the different simulations.

P18910 L20: This method doesn't address within-community variation, so this comment is slightly misleading.

Response:
We agree we should explain better the relationship between communities and PFTs. In JSBACH, within a grid cell, different PFTs are present. Each of these PFTs can be said to represent a community. Based on this analogy, we believe it is justified to employ the assembly theory approach to PFTs in JSBACH as well. We will explain this in the introduction of the revised manuscript.

P18911 L18: Habitat filtering may lead to convergence, but the figures in Wright et al. 2005 seem to indicate that within community variation is still very high. Presumably this database can offer some insights into the strength of trait convergence. Could this be discussed in some more detail?

Response:
Trait variation within communities is indeed very high, but on global scales trait convergence prevails over trait divergence. Based on a large global database, this was recently analyzed and discussed in detail by Freschet et al. (2011). We would like to refer to this publication for this analysis. It provides an incentive to focus on trait convergence and the mean response of the community as affected by habitat filtering. Moreover, a DGVM provides a mean value of a trait for a

PFT (in a given grid cell) and by working with mean community trait values we match these properties as much as possible. We will explain this in the introduction of the revised manuscript.

P18912 L10: Could there be some discussion of why you chose these three traits, particularly with reference to the fact (discussed later) that Vcmax and Jmax are very closely correlated?

Response:
We selected all traits that a) had been defined as PFT-specific traits in JSBACH, b) that could be related to observational traits and c) had a sufficient number of geo-referenced observations in the TRY-database. This resulted in these three traits only, despite being the most comprehensive selection possible (given the constraints of the model). The JSBACH model with a N-cycle might have more traits that could be varied, but this model has not yet been validated. We will clarify this motivation in the revised manuscript.

P18912 L 6: This sentence about how this DGVM is representative of other DGVMs is imprecise and could be omitted.

Response:
We agree this might not have been correctly formulated and we refer to our response to the first comment of referee 2, who made the same remark.

P18912L15: How do the feedbacks of plant traits on to their environment work in this study?

Response:
Traits do not have a direct effect on climate, but changes in traits propagate to climate by modifying different plant properties and fluxes. We did not describe these pathways, as there are many direct and indirect effects. For example, $Vcmax_{25}$ and $Jmax_{25}$ determine productivity (GPP) and indirectly (for $Vcmax_{25}$) via respiration, NPP. Productivity in turn affects transpiration, which will modify soil moisture and air temperature. Notably, NPP determines the competitive ability of PFTs. Via shifts in vegetation, different PFTs become dominant, with according differences in plant properties in e.g. albedo and vegetation roughness, modifying heat and water fluxes.

As SLA in JSBACH is largely decoupled from the carbon cycle, effects of SLA on climate are more moderate, but it co-determines carbon storage and as such (combined with productivity) affects the amount of litter going to the litter pools, influencing decomposition rates and fire frequency as well.

While in the default simulation with fixed traits there are interactions between vegetation and atmosphere (of course necessary for the coupling of a DGVM to an atmospheric model) as well, the variation in traits may allow for enhanced positive or negative feedbacks, as it may amplify or dampen certain effects of vegetation on climate (see temperature differences in fig 5). We will clarify this in the revised manuscript by giving some examples.

P18913 L 22: This description of SLA is slightly odd. Surely it controls the relationship between leaf area and leaf mass?

Response:
Phenology in JSBACH is not carbon based. As such SLA does not play a role in determine LAI or productivity, while it does in most other DGVMs. SLA does however determine the amount of carbon that can be stored in the green and reserve pool (in combination with LAI). We refer to the earlier comment about the relationship between SLA and LLS for a more elaborate explanation of the role of SLA.

We will make sure that the parameterization and use of SLA in JSBACH is explained more thoroughly in the revised manuscript, as it seems that various comments of the reviewer arise from unfamiliarity with this aspect of JSBACH. As many readers may be unfamiliar with this, while it is critical for interpreting the results, we will emphasize this aspect.

P18915 L 8: What are 'global quantitative deterministic predictions' in this context?

Response:
This formulation is indeed not clear and can just be left out.

P18917 L 26: AS far as I am aware, the Saatchi et al. 2012 biomass data are the most up to date, especially for the tropics.

Response:
Saatchi et al. focuses on tropical forests, and we want to have a global estimate of all vegetation types. We prefer to have a fully consistent comparison for all PFTs, and therefore we used Robinson (2007) instead.

P18919 L 22: This part of the paper - reporting how predictable plant traits are from climate drivers - is to me the most interesting section and could be expanded a lot. It would be interesting to see a) how the traits relate to individual climate variable and b) how the regression models predicts that they vary in space.

Response:
At a: our aim was to derive the best (empirical) model to relate traits to the environmental drivers. Therefore, we chose multiple drivers to maximize our predictive ability. Other previous studies (e.g. Wright et al. 2005; Ordoñez et al. 2009) have analyzed trait relations to various individual climate drivers. Therefore, we did not emphasize this aspect, but we can provide estimates of single trait-climate relationships in an appendix, if the editor thinks this is necessary.

At b: how the regression model predicts that traits vary in space is described in sections 2.3 and 2.4. The regression models as implemented in JSBACH predict trait variation in space as a function of the spatially different environmental conditions. In each grid cell, traits are predicted based on the local environmental variables as modeled in the grid cell, which results in spatial variation in climate and consequently variation in traits at a global scale. How much variation this generates within each PFT can be seen in Fig. 2.

P18920 L 15: The GPP predictions are now much higher, even though the values of Vcmax are in theory much more accurate. Some discussion of the reasons for this would be useful. How does the model treat within-canopy variation of photosynthetic capacity, or colimitation of photosynthetic rates, or stomatal conductance? This is obviously a major structural issue that needs addressing before this can be deployed in any standard version of the JSBACH model.

Response:
The correlation between GPP increase and $Vcmax_{25}$ or $Jmax_{25}$ increase (see e.g. Fig 3 and Fig. 4) suggests that indeed changes in $Vcmax_{25}$ and $Jmax_{25}$ seem the dominant drivers of the changes found. We will make this more explicit in the revised manuscript.

JSBACH employs a Farquhar photosynthesis scheme, accounting for co-limitations of photosynthetic rates and stomatal conductance. Also, above a certain LAI, Vcmax and Jmax are reduced within the canopy according to a constant scaling factor. In our approach, we did not change any of these formulations. Given that we modulate Vcmax and Jmax at the top of canopy, their relative impacts on the aspects mentioned by the reviewer should remain grosso modo the same. One exception to this rule could be a change in co-limitation, because $Vcmax_{25}$ is allowed to partly vary independently from $Jmax_{25}$. It is far from straightforward to analyze the impacts thereof on modeled GPP, but we suspect that those impacts are moderate compared to the impacts of changes in $Vcmax_{25}$ and $Jmax_{25}$.

P18924 L15: Similarly, it would be useful to see some graphical depiction of the biomass outputs of the different models, either latitudinal plots or maps?

Response:
The goal was to compare biomass data with global estimates. As we compared the data with Robinson (2007), we are limited to the data format of him. Therefore, unfortunately, we can't compare latitudinal gradients or global maps.

P18926 L 25: If this approach is broadly accepted and applied, then why would this paper be novel? I don't think it is broadly applied, so it seems strange to suggest that here, and is in conflict with most of the introduction.

Response:
The method where traits are related to environmental conditions is broadly applied (see citations in the text), but incorporating this into a DGVM to model trait variation is novel. We will clarify this in the revised manuscript.

P18926 L 5-10: The comparison with the nutrient studies is slightly odd, as 1) those models are much more complex and are predicting trait values rather than assigning them from empirical look-up tables and 2) their aim is to incorporate nutrient dynamics, not variable PFT definitions. I think this section is a bit unnessecary.

Response:
In the introduction we mention that such models indeed have a different goal when modeling trait variation. We do think these models should be mentioned, as they incorporate more variation in the model, even though this was not the primary goal. We will rephrase this accordingly. In addition, we will expand this section and discuss some other DGVMs that implemented more variation in vegetation, as the referee requested in an earlier comment already.

P18926 L 15: Does the word 'causality' really fit here? Should this sentence not use 'correlation'?

Response:
We agree the term 'correlation' is more appropriate here and we will adjust this in the revised manuscript.

P18927 L1: I think the timescale of 1 year is reasonable, but it is likely that plants vary in their plasticity as well as their mean trait values, so there is probably no 'correct' answer here.

Response:
We fully agree that there will be between-species variation in plasticity and presumably among PFTs as well (although we are not aware of studies analyzing this). Despite such differences, current analyses on within-species variation of leaf economics traits (Kattge et al. 2011; Albert et al. 2010; Messier et al. 2010) suggest that all PFTs will be sufficiently plastic to adjust their leaf economic traits at yearly time scales to the extents forced by year-to-year differences in climatic drivers.

P18929 L3: The GPP values are made significantly worse here, so I don't think that 'DGVMs are improved' is the best conclusion here. I would concentrate on the fact that some plant traits (vcmax & jmax, not SLA) are highly predictable from climate drivers.
This is the strongest message here. Obviously, these key traits have large influences on ecosystem models, but as you state at the beginning, the models are already 'tuned' to give OK results, so whether they get better or worse is largely irrelevant. If they get worse, it is likely that correcting one set of parameters reveals compensating deficiencies in another set of parameters or processes. Certainly, the representation of plant diversity and plasticity of the traits in question is improved by this process, and that is almost certainly a good thing.

Response:
We agree our statement might be too strong and we can't extrapolate our results to other DGVMs, so we will moderate our statements in the revised manuscript. However, we believe that JSBACH has been improved at least in certain aspects (e.g. vegetation distribution, carbon biomass), especially as the default model has been tuned previously to approximate realistic results and we did not expect an improvement of model performance. But we consent that this question is not the main goal of our research and as relevant as our proof of concept to improve the functional representation of vegetation and the resulting model inter-comparisons.

P18939 L5: You haven't tested all DGVMs here (that would be an interesting figure: : :) so you can't make this claim.

Response:
We indeed cannot extrapolate our results to all DGVMs, even though we think most other DGVMs have the same problematic fixed PFT-classification, suffer from a lack of realism in some way and will benefit from more variation. But we can't claim this so we will adjust this in the manuscript and moderated our statement.