

Response to anonymous referee #2

This study addresses three issues of the vegetation feedback:

- a) The uncertainty of the simulated vegetation feedback is determined by using a single model multi-physics ensemble. The authors contrast the uncertainty in the impact of changes in plant physiology to the uncertainty in the impact of vegetation shifts. This approach allows to identify the main source of uncertainties in the vegetation feedback.*
- b) The asymmetry of the vegetation feedback is assessed by analysing the vegetation feedback for enhancing and reducing atmospheric CO₂. The impact of changes in plant physiology and the impact of vegetation shifts are shown separately.*
- c) The strength and the zonal distribution of the vegetation feedback is considered relative to other feedbacks such as cloud, lapse rate, and ice albedo feedback.*

All three issues are relevant when dealing with the vegetation feedback. The large spread of the vegetation feedback determined in different studies makes a clear estimation on the uncertainty of the vegetation feedback essential. The vegetation feedback has been assessed for enhanced atmospheric CO₂ in previous studies, while contrasting the vegetation feedback for halving and doubling CO₂ is new. Studies which compare the vegetation feedback with other feedbacks are rare and needed, when discussing the impact of vegetation dynamics in climate change.

However, I am not convinced about merging these three issues to one study. To merge the asymmetry and uncertainty of the vegetation feedback could be reasonable, even though it might be challenging to motivate and structure such a study. A connection between asymmetry, uncertainty, and a comparison of the vegetation feedback to other feedbacks is difficult for me to see. Addressing too much issues in one study arises the risk of lacking a main aim leading to a list of results without relevance. I have the impression that this manuscript contains too much issues and the main results are buried under the large amount of results.

I recommend to exclude the comparison of the vegetation feedback to other feedbacks and to focus on the asymmetry and uncertainty of the vegetation feedback. The motivation to address the asymmetry and the uncertainty of the vegetation feedback should be described more carefully in the introduction. The structure of the results section could be improved to illustrate the main results clearly.

We will restructure the paper to highlight the main results more clearly. However, in our opinion it is useful to have a comparison of the vegetation feedback with the fast climate feedbacks in order to provide a framework where different feedbacks can be compared in a consistent way. We are aware that too many results can cause confusion to the reader and we will restrict the comparison of the climate-vegetation feedbacks with the fast climate feedbacks to two main issues: (1) Globally vegetation feedback is rather weak compared to the fast feedbacks, but their uncertainties are of comparable magnitude. (2) Vegetation feedback is very heterogeneous, and regionally this feedback is of comparable importance with the fast climate feedbacks.

The motivation to address the asymmetry and the uncertainty of the vegetation feedback together in the same study will be better explained in the introduction. It is known that the strength of fast feedbacks can be state dependent (e.g. Colman and McAvaney, 2009; Yoshimori et al., 2011). For instance (Colman and McAvaney, 2009) found that the albedo feedback is weaker in warmer climates. The knowledge about asymmetry of climate feedbacks is thus crucial for any attempts to derive climate (or Earth system sensitivity) from past climate states. It is also reasonable to assume that not only the magnitude of the feedbacks can be state-dependent, but also their uncertainty. This is because different processes might be more or less important depending on the state of the system. As an example, larger areas are covered by

snow in colder climates, so that the uncertainties in the parameterization of snow related processes will result in larger uncertainties in a cold than in a warm climate. Asymmetry and uncertainties in the feedbacks are thus not fully decoupled but rather have to be considered together. This discussion will be included in the revised introduction.

Comments on the content and structure of the manuscript

Abstract

1. Results on uncertainties and asymmetry are presented in a clear and brief way in the 2nd paragraph 7 to 14. The mechanisms which drive asymmetry are specified in the last paragraph. It might be clearer to describe the asymmetry and the driving mechanisms together.

The 3rd and the 4th paragraph will be swapped, so that the asymmetry and the mechanisms, which are responsible for it, are discussed together.

2. In the 3rd paragraph (line 10 to 18), findings on the vegetation feedback related to other feedbacks follow. The connection to the asymmetry and uncertainty remains unclear.

The paragraph on the vegetation feedback and comparison with other feedbacks will be rewritten. We will first describe how the strength of the vegetation feedback compares to the other fast climate feedbacks and then add a sentence where we compare the uncertainty that we found for the vegetation feedback with uncertainties due to inter-model spread for the fast climate feedbacks. This will shift the focus more on the uncertainty analysis and will better connect this paragraph with rest of the abstract.

3. I guess with term 'Charney feedback' in line 16/17 refers to the feedbacks introduced in Charney et al. (1979). The term Charney feedback might be mixed up with the 'Charney effect' introduced by Charney (1975), which is suggested to amplify Sahelian droughts. Using the term 'fast feedbacks' such as the authors use it in line 17 avoids possible confusion.

We will replace 'Charney feedbacks' with 'fast climate feedbacks'.

Introduction

4. The introduction includes a broad review of recent studies on vegetation climate interactions and emphasises the spread in the results which motivates a study on the uncertainties of the vegetation feedback. A motivation for a study on the asymmetric behaviour of the vegetation feedback is lacking.

The motivation for a study on the asymmetric behaviour of the vegetation feedback will be given in the introduction (see our response to the general comment above)

5. In the introduction, the connection between the different issues should to the specified.

A comprehensive explanation of the link between asymmetry and uncertainties will be included in the introduction. We will also explain why we think it is important to compare the strength and uncertainties in the climate-vegetation feedback to the fast climate feedbacks in a common framework.

6. In the methodology section (12974/11-17), a motivation for using a single-model multi-physics approach is given. Why not mentioning this motivation in the introduction?

The motivation for using a single model multi-physics ensemble approach will be given in the introduction based on the discussion in the methodology section (12974/11-17).

7. The paragraph 12972/8-21 interrupts the motivation for assessing the uncertainty of vegetation feedbacks. A motivation for connecting a comparison of the vegetation feedback to other feedbacks with an estimation of the uncertainties of the vegetation feedback is missing.

The paragraph 12972/8-21 will be shifted to 12973/3.

The motivation for including a comparison of the vegetation feedback with the fast climate feedbacks is given in response to the reviewer's general comment and will be given in the introduction of the revised manuscript. As far as the uncertainties in the climate-vegetation feedback are concerned, to our knowledge this is the first study which systematically addresses this issue. Our multi-physics ensemble approach allows us to estimate magnitude and uncertainties in the climate-vegetation feedback and to compare them with magnitudes and uncertainties of the fast climate feedbacks as reported in (Soden and Held, 2006) for different climate models. It is a useful method to allow a direct comparison of the relative importance of the different feedbacks. To this end we will revise Figure 11 by replacing the uncertainty ranges of the fast climate feedbacks (water-vapour, cloud, lapse-rate and albedo) which results from our study with the total range from a multi-model ensemble (Soden and Held, 2006).

Results

8. *What causes the warming named in 12981/18? Is the albedo lower due to a smaller cloud cover? Or does a weaker latent heat flux cause the warming?*

The warming is caused by a reduced surface latent heat flux and a lower planetary albedo due to less cloud cover. The effect of cloud cover changes dominates in the boreal zone, while the weaker latent heat flux is more important in the tropics. This will be explained in the revised manuscript.

9. *12983/23 to 12984/2: I have the impression that the results from the physiological changes and vegetation shifts are repeated. Is this paragraph necessary?*

We think that this paragraph is needed to explain the effect of vegetation distribution shifts on the LAI. However, we will remove the sentence in 12983/25 which is a repetition.

10. *12984/10 How does a smaller desert in central Asia cause warming?*

The main effect of a desert reduction in central Asia is a decrease in albedo which warms the surface. This will be specified in the revised manuscript.

11. *Results on the uncertainty of the vegetation feedback get lost in the analysis of the asymmetry. To display the results clearer, the uncertainty analysis should be separated from the asymmetry analysis. Further, the uncertainty analysis should be more detailed, because this is one major topic of this study.*

12. *The structure for the asymmetry analysis is not clear. I have the feeling that in the part from 21984/3 to 12986/7 the author lists results rather than illustrates the asymmetric behaviour of the vegetation feedback. There are relevant results, but the reader needs to organise the results herself/himself to get a picture of the asymmetry. Maybe it would be more convenient to discuss the results for vegetation feedback for 1/2 CO₂ and 2*CO₂ separately.*

We will revise the discussion from 21984/3 to 12986/7. The part from 21984/19 to 12986/7 will be reorganized into a new subsection describing the total vegetation-climate feedback including all the processes and it will be separated into two parts. In the first one we will discuss the ensemble mean results focussing on the asymmetry between 1/2 CO₂ and 2xCO₂. In the second part we will discuss the uncertainties in more detail. However, since uncertainties and asymmetry are related to some extent, they can not be cleanly separated and some overlap will be unavoidable.

13. *The sentences in 12986/20-25 gives a good explanation for the asymmetry. Wouldn't it make sense to provide this explanation already in 3.2.3?*

The sentences in 12986/20-25 will be moved to section 3.2.3.

14. *Section 3.3: As already mentioned, the relevance of the comparison of the vegetation feedback to other feedbacks in a study on uncertainties and asymmetries is difficult to see for me.*

The relevance of a comparison of the vegetation feedback to other feedbacks in this study is elucidated in the response to point 7 above.

Comments on the language

12968/9: *'-0.1-0.2' should be '-0.1 to 0.2' to avoid confusion.*

Will be corrected.

12969/14: *'and' is missing, '...the surface, and the exchange...'*

Will be corrected.

12969/21: *'act' should be 'acts'.*

Will be corrected.

12970/5: *The subject to the verb 'reduce' is missing.*

Will be corrected.

12973/20 - 12980/15: *Tense not consistent in the methodology section. For instance, it is 'we consider' (12974/17), but 'we included' (12974/19) or it is 'satisfied' (12977/26), but 'constitute' (12977/26).*

We will homogenize the tenses in the methodology section.

12974/16: *It might help the reader to refer to table 1 and table 2 already in this paragraph.*

A reference to Table 1 and 2 will be given in this paragraph.

12975/18: 'to' is missing in 'assigned to'.

Will be corrected.

12979/16-19: This part is a repetition of 12979/5-7.

The sentence from 12979/16-19 will be removed.

12981/11: Why is 'prescribed' in brackets?

The brackets will be removed.

12982/4: This sentence is confusing, because it looks like the closing stomata enhances evapotranspiration.

The sentence will be reformulated.

12982/6: 'Betts et al.,1997' shouldn't be in brackets.

The brackets will be removed.

12983/4: 'increase' should be 'decrease'.

Will be corrected.

12983/9: One sentence can't be one paragraph. Is the sentence really necessary?

The sentence will be removed.

12984/3-5: This part seems to be longer than necessary. Is the first sentence needed? The second sentence expresses the same information as the third sentence.

The first sentence will be removed and the second and third will be merged into one sentence.

12984/4: *'acts' should be 'act'.*

Will be corrected.

12984/12: *Vegetation dynamics enhance the uncertainty relative to what? I guess relative to the physiological effect of vegetation.*

We will specify that vegetation dynamics enhances the range of uncertainty relative to the physiological and fertilization effect.

12984/12: *'enhances' should be 'enhance'.*

Will be corrected.

12984/14-17: *'into account' should be after 'under higher CO₂'.*

Will be corrected.

12984/21: *'-0.1-0.3' should be '-0.1 to 0.3' to avoid confusion.*

Will be corrected.

12984/21: *Why is the temperature difference due to dynamic vegetation for doubling CO₂ here -0.1 to 0.3 K and 0.1 to 0.2 K in the abstract?*

Because in the abstract we refer to the global temperature, while in 12984/21 we discuss temperature over land only.

12984/28: *'most relevant' should be 'largest'.*

Will be corrected.

12985/22: *Figure 10 might be denoted earlier to illustrate the method.*

We will add a reference to Figure 10 at the end of the sentence in line 12985/22.

12985/26: 'correlation' needs to be shifted: '...highest correlation between...'

Will be corrected.

12985/27: 'to' should be 'of' in '...sign of the correlation...'

Will be corrected.

12986/4-5: It should be 'albedo effect' and 'evapotranspiration effect'.

Will be changed.

12985/11 - 12986/7: Subdividing the paragraph makes structure clearer.

The paragraph will be divided at 12985/22.

12988/11: Is 0.5_C the ensemble mean?

We will specify that we are referring to the ensemble mean.

Figures

Figure 1a): The label of the axes are not intuitive.

The labels of the axes will be changed and an explanation will be given in the caption.

Figure 6): The colour for RPL-R and RPLV-R is hard to distinguish.

We will enhance the color difference between RPL-R and RPLV-R.

Figure 12), caption: It should be '...ensemble are plotted...'

Will be corrected.

Figure 9): Just as an idea, might it be possible to merge a) and c) as well as b) and d) by hatching the uncertainty over the temperature difference? This would facilitate the evaluation of temperature changes.

This would be easily done for 1-d plots but we are concerned that for the 2-d plots shown in Fig. 9 this would result in poor readability of the figure. We thus prefer to keep Figure 9 as it is.

Figure 10): Using the same size and layout as for figure 9 makes a comparison of the two figures easier. The annual mean should be separated as in figure 9.

Figure 10 will be adapted to the format of Figure 9.

References

Colman, R. and McAvaney, B.: Climate feedbacks under a very broad range of forcing, *Geophysical Research Letters*, 36(1), 1-5, doi:10.1029/2008GL036268, 2009.

Soden, B. and Held, I.: An assessment of climate feedbacks in coupled ocean-atmosphere models, *Journal of Climate*, (2003), 3354-3360, 2006.

Yoshimori, M., Hargreaves, J. C., Annan, J. D., Yokohata, T. and Abe-Ouchi, A.: Dependency of Feedbacks on Forcing and Climate State in Physics Parameter Ensembles, *Journal of Climate*, 24(24), 6440-6455, doi:10.1175/2011JCLI3954.1, 2011.