Anonymous Referee #2

We would like to thank the referee for valuable comments. Below the refrees comments are shown in *italics*, the replies are shown in normal type.

General:
This work endeavors to evaluate the influence of GCM characteristics on long-term terrestrial carbon cycling. Four GCMs and three emission scenarios were used to drive a single DGVM, LPJ-GUESS, and results were analyzed using an insightful and novel (for this field) statistical method (SVD). The results were used to generate a statistical emulator, which was applied to more rigorously explore the role of GCM characteristics on uncertainty in the terrestrial carbon balance.

In general, the work presented here is publishable. The methods applied represent a combination of novel techniques and rigorous analysis that comes at the problem from multiple perspectives. Unfortunately, the merits of the work are obfuscated by the presentation, which is frequently difficult to follow and appears to lack a cohesive narrative thread to guide the unfamiliar reader.

Comment 1:
The paper would benefit from some earlier and clearer explanation for why certain variables are being defined, and how these fit into the larger purpose of the work. While variable definitions are provided, their greater purpose often is not. In a paper that employs such a variety of methods, some of which are clearly difficult to succinctly describe, the link between variables as they are defined in the methods and as they are evaluated in the results needs to be stronger. In most cases, the significance of a variable to the narrative of this work is only made clear after the methods section, and sometimes as late as the discussion or even conclusions. This is particularly so for alpha, which is introduced with little emphasis yet turns out to be crucial to this work's key results. Gamma is similarly obscure until it suddenly jumps into the limelight during discussion. In a paper as dense in method as this we need some indication, at first mention, of what we should expect to return with special significance in the results section.
Reply:
Thank you for this advice. We have now added a new section, 2.1, providing an overview of the approach. In this section we describe each step in our approach shortly and introduce key factors, such as the parameters α and γ. We have also clarified the different method sections. The new section reads as follows:

"Here we summarise the methodological steps used in this paper to investigate and quantify the uncertainty induced by GCM characteristics on simulated carbon fluxes.

1. To characterise patterns and variability in global carbon cycle response to GCM-simulated climate change as accurately as possible, we first simulate future carbon fluxes by forcing a full process-based DGVM, LPJ-GUESS (see section 2.2), with output data from four GCMs (section 2.3) under three [CO_2] pathways (A2, A1B, B1). This results in 12 different trajectories of future carbon fluxes.

2. DGVM simulations often result in widely different results in terms of carbon balance depending on the choice of forcing GCM. Based on the initial results from Step 1, we hypothesised that differences in SST variability account in part for the observed discrepancies in simulated carbon fluxes among DGVM simulations. To evaluate this hypothesis, we applied EOF analysis to simulated SSTs from each of the GCMs to separate the long-term trend (mainly warming) seen in all the GCM projections from other aspects of variability (section 2.4). SST variation in space and time emerges as the most important component of this residual variability in all the GCM projections analysed. By correlating the dominating patterns of SST variability, as characterised by the second EOF mode in our analysis to carbon fluxes simulated by LPJ-GUESS, we analysed the impact of differences between the GCMs originating from differences in simulated SSTs and their influence—via circulation patterns—on local land surface climate.

3. Having established GCM-simulated warming and SST variability as important determinants (factors) of change in global terrestrial ecosystem carbon balance, as simulated by LPJ-GUESS, we wished to quantify the relative contribution of, and the residual variation not explained by, each factor. As global simulations with a full DGVM and the subsequent analysis of the considerable output data set generated are expensive, we parameterised a statistical emulator mimicking the LPJ-GUESS results when forced by global temperature and [CO_2] as sole drivers (section 2.5). To account for GCM-dependent differences in carbon balance response, proxies for two GCM-dependent factors were included as parameters in the emulator model. The first of these parameters, α, is a modifier on global gross primary production (GPP) and reflects the character or intensity of SST variability as simulated by different GCMs. The second parameter, γ, is a scalar which translates the anomaly of global *mean* surface temperature in a GCM climate projection relative to a modern baseline to the corresponding anomaly in global *land* temperatures.

4. In the last step we employed a factorial simulation approach using the statistical carbon cycle model emulator to attribute and partition variability (uncertainty) in future carbon balance changes to variability in the main global drivers and uncertainty stemming from differences in GCM behaviour, as encapsulated by α and γ (section 2.5). An analysis of variance (ANOVA) was applied to the output of 192 synthetic simulations with the emulator model, spanning the observed space in the drivers (CO_2 concentration and associated temperature change from the original ensemble of GCM projections), α and γ."

Comment 2:

As another reviewer has already mentioned, most readers will not be familiar with SVD or the technical jargon that accompanies it. The impact of many results is undermined by the ubiquitous presence of the term "mode" - a very fuzzy word with a very specific meaning in this context. Please provide some insight into the practical meaning of this statistical jargon. Additionally, no information about initialization or validation of the statistical model is provided.

Reply:

The text describing the SVD analysis is now rewritten. We define the concept of modes explicitly and use the term as consistently as possible throughout the text.

We have added text describing that the emulator was initialized with the carbon pool values of year 1901, the first year of the historical simulation with LPJ-GUESS.

We performed a validation analyses and now present the results in supplementary material. We made an additional calibration of the emulator, excluding one scenario per GCM, thus

excluding 30% of the data. The results show that the emulator is not very sensitive to this, and that it would not change the conclusion drawn in the paper if this smaller subset were used instead of all the data as it is now. We have also added a section in the main paper explaining the method and the results of the validation study.

Comment 3:
The final 2 paragraphs of section 2.4 need to be revised to more clearly explain how the various elements presented in this section are integrated to create the 192 carbon balance trajectories. Additionally, some clearer explanation of just what insights ANOVA testing of alpha and gamma will offer is required.
Reply:
The section describing the sampling is now clarified. The ANOVA gives information on which factor induces the largest spread in simulated total carbon pool when applying the statistical emulator. This has been clarified in the text.

Comment 4:
Finally, though LPJ-GUESS is a widely applied and well-tested tool, it is not reality. The authors are encouraged to keep this distinction present throughout the paper. Once LPJ-GUESS has been introduced it all but disappears from the papers vocabulary, and results and their implications are discussed as though they pertain to reality and not the reality of LPJ-GUESS. There is of course an overlap here, but this excellent analysis is ultimately exploring a specific DGVM. Some acknowledgement of the weaknesses (and strengths) of LPJ-GUESS would be good to see, and would offer an excellent segue into some discussion on the how the implications of these LPJ-GUESS-specific results may be extrapolated more generally.
Reply:
We have altered the text to clarify that we are using simulated carbon fluxes from LPJ-GUESS. Additionally it is clearly stated in the new section giving an overview of the approach how the output data from LPJ-GUESS come in to the final analysis.

In a new section in the discussion we also acknowledge that DGVMs can project different carbon balance in response to the same forcing and discuss the implications of this. We also cite a recent comparative study that compares DGVMs to each other and to independent data on carbon balance response to climate.

Comment 5:
13687:23 Suggested citation: Friendlingstein et al 2006: Climate–Carbon Cycle Feedback Analysis: Results from the C4MIP Model Intercomparison.
Reply:
Thank you. The reference is now inserted.

Comment 6:
Methods: 13689:23 "We focused on sea-surface temperature (SST) as an overall indicator of those aspects of GCM-simulated climate of importance in terms of impacts on global ecosystem carbon balance." What are "those aspects" and what justification (evidential or discursive) can you provide for the choice of SST for this purpose?

Simply stating this choice seems to be a weak foundation on which to build this entire paper.

Reply:

Previous studies have found SSTs to be a dominant controller of global weather patterns. We have added a section that describes this:

"We focused on sea-surface temperature (SSTs) as an overall indicator of those aspects of GCM-simulated climate of importance in terms of impacts on global ecosystem carbon balance. SST records for recent decades clearly reflect the general trend in global temperatures (Dai, 2013). Additionally, variability in SSTs has been shown to have a large influence on regional precipitation trends (Hoerling et al., 2009) and low latitude precipitation (Dai, 2006). ENSO is the dominant process of SST variability. ENSO has been shown to be the strongest controlling factor for global precipitation variability (Dai et al., 1997). "

Comment 7:

13690:4 Are there any pertinent differences between SVD and EOF that we should be aware of?

Reply:

SVD is an algorithm that can be used to calculate EOFs or PCA, as in this paper. We have now clarified this and now refer to the method as EOF-analysis instead of SVD analysis.

Comment 8:

13690:5-10 The concept of modes needs to be explicitly addressed and explained if readers not familiar with the details of SVD are to grasp the significance of both the method and the results you have obtained by applying it.

Reply:

We have revised the description of the SVD/EOF analysis and added new text explicitly explaining the concept of modes.

Comment 9:

13690:10 What are the "3 products"? Spatial loading patterns, time series and singular values?

Reply:

We have removed this section from the rewritten description of the analysis since it probably confuses the reader more than it helps given that we do not recreate the data in this paper. But yes, those are the three products.

Comment 10:

13690:15-27 As presently described, the acrobats explained in this paragraph are bewildering.

Reply:

We have clarified this section. As mentioned above we now explicitly describe the concept of modes, and the same clear and simplified terminology is now used in this section as well.

Comment 11:
13691:1 "Where" should not be capitalized
Reply:
Changed according to your suggestion.

Comment 12:
13691:9 Employing alpha values without some explanation for what they are only adds additional confusion to an already challenging paragraph. This section requires attention to better elucidate why is a scenario-independent measure of SST is required.
Reply:
We now introduce alpha in a previous section (2.1). We have also clarified this section:

"To characterise the influence of GCM-dependent SST variability, we defined a parameter, α. To relate α to the GCMs SST variability, we needed a scenario-independent measure of SST variability. The global mean warming trend is well separated from other variability—not directly due to increased radiative forcing—in the EOF-analysis of the SSTs of the SRES A2 simulations. The inverse of the SCF of the first mode could therefore be used as a proxy for the relative importance of variability not directly related to climate change. The global warming is, by contrast, not always well separated in the SSTs of the lower emission scenarios, A1B and B1, and the SCF was not found to be a useful proxy of SST variability for these scenarios. Therefore, to be able to compare the α values from the statistical carbon cycle emulator with a scenario-independent measure of SST variability we calculated the global average standard deviation of all the detrended SST time series."

Comment 13:
13692:1 "Where" should not be capitalized
Reply:
Changed according to your suggestion.

Comment 14:
13692:7 Why was alpha set to zero during the historical period?
Reply:
Alpha could be assigned any value during the historical period. It would be countered by an equal change but of opposite sign of the parameter $\beta 1$. So it does not matter what value we assign alpha to during the historical period. Setting alpha to zero means it does not have any influence during the historical time. It also implies that the alpha value for a specific GCM can be directly interpreted as a modification of annual GPP in the unit of the model, Pg C.

Comment 15:
Results: 13695:5 Some specific indication of what in the figures appears to represent "ENSO patterns" would be worthwhile.
Reply:
We have added a description of "ENSO patterns"; variability centered in the central tropical pacific.

Comment 16:
Fig 2: Correlation of -1 and +1 are both indicated by black - how do we tell whether the figure is indicating +1 or -1? Additionally, people who are colorblind cannot distinguish between red and green.
Reply:
The color scale of the figures has now been changed.

Comment 17:
Fig 6: Overlapping colors obscure the actual extent of red and blue and green. This may be difficult to resolve given the nature of the figure and results.
Reply:
The overlap is intentional, meaning to convey that the carbon balance results overlap so much between scenarios, that the explanation for the large spread in carbon balance must lie elsewhere.

Comment 18:
Supplementals: Entire first page is one single paragraph, which makes for heavy reading.
Reply:
Changed to two paragraphs.