Response to Reviewer 1

General comments

At the moment, this paper feels like a model evaluation paper. There are a lot of results here and it would be nice to see the key results promoted a bit more. Then I would like to see separate results and discussion sections. At the moment, it is a bit mixed up. After the model description section (section 2), I would like section 3 to be the results section, section 4 to be the discussion section and section 5 to be the conclusions section.

R: We appreciate Reviewer #1's carefully reading and insightful comments and suggestions. We have made revisions according to the reviewer's comments/suggestions. They really help us to substantially improve the paper. Please find our responses below for each comment.

The purpose of this paper is to investigate the effects of climate regime shift during the 1980s on ecosystem trends, by comparing the contribution of three primary drivers (i.e. atmospheric CO_2, global warming, and climate variability) on vegetation cover fraction, LAI and GPP trends, during the periods before and after the 1980s. Studies on this subject show that the contributions of each drivers are model dependent (Beer et al, 2010; Zhu et al, 2016; Huntzinger et al, 2017). Although SSiB and TRIFFID are both well-evaluated models, the coupled version SSiB4/TRIFFID is used for the first time in this study. It is necessary, therefore, to include an evaluation step before its application.

We deemphasize the model evaluation section with fewer paragraphs in our revision. Figure 4 (presenting the vegetation cover fraction) is moved to the appendix. Figure 6 and Figure 7 is modified to show the difference between simulated and satellite-derived LAI and GPP, separately.

The results and discussion sections are separated in the revised manuscript. Key results are emphasized during the discussion and also in the conclusion section.

Meanwhile, the structure is adjusted in the revised manuscript as following:

1. Introduction
2. Model description, experimental design and data
   2.1 Model description
   2.2 Experimental design
   2.3 Data
      2.3.1 Preliminary initial condition
      2.3.2 Meteorological forcing data
      2.3.3 Observation-based data
3. Results
   3.1 Vegetation initial condition

The Princeton meteorological dataset is used to drive the SSiB4/TRIFFID model. There is data available from 1948-2010. Why have you not performed the model experiments for this time period?

R: We have downloaded three versions of Princeton meteorological dataset with the ending year of 2007 (v1x), 2010 (v1) and 2014 (v2.2), respectively. v1 had merged the data v1x plus the data from 2008-2010. However, when we compared the two versions (i.e. v1x and v1), we found that although v1x and v1 are generally consistent before 2007, there was an abrupt shift in some variables (such as wind speed) after 2007 (See Response Figure **1**). To ensure the consistence and minimize the uncertainties associated with the meteorological forcing data, we decided to stop the simulation at 2007. The v2 data, which starts to be available in later 2016, is quite different from the v1 data (Response Figure 1, blue line) for a number of variables. Since by that date we had finished most of our work, and since these few additional years should make no great difference, we have stuck with the v1x data.
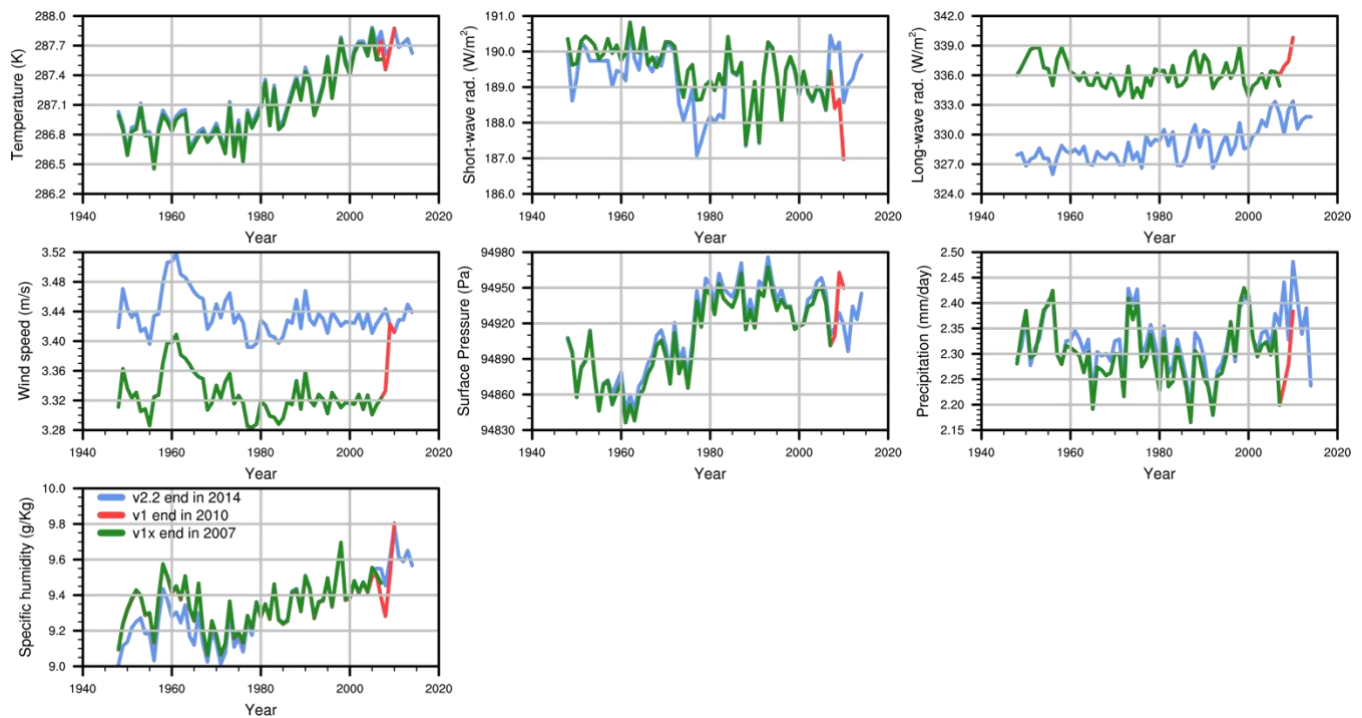
Response Figure 1. Comparison between different version of Princeton meteorological datasets over global land (-180º W,180º E, -60º S, 75º N)

Specific comments

5   Page 1

Abstract

Change the abstract from 3 paragraphs to 1.

R: It has been merged to 1 paragraph in the revised manuscript.

Lines 18-20: You state that more than 40% of the global land area has shown significant trends in LAI and GPP since the

10   1950s. Is this for the period 1958-2007 or from the 1958-1980s? When you mean positive trends, I assume that is an increase

in LAI and GPP and the opposite for negative trends? It is better to explicitly state this.

R: Approximately 40% of the global land area shows significant trends in LAI and GPP is for the period 1957-2007. We have

clarified it in the revised manuscript.

Yes, the positive trends imply an increase in LAI and GPP and opposite for negative trends. This has been clarified in the

15   revised manuscript.

Lines 22-27: The last paragraph goes straight into which environmental driver affects LAI and GPP the most. Add a line to

place the results in context.

R: We have made a number of modifications so that the manuscript flows better.

Page 2

Introduction

Line 3: Remove e.g. when adding references to the end of statements. "...at global and regional scales (e.g. Garcia et al., 2014)" should be "...at global and regional scales (Garcia et al., 2014)". This happens throughout the manuscript. Please remove all occurrences.

R: Removed in the revised manuscript as suggested.

Line 4: Change "...by altering fluxes exchanges, energy balance, carbon cycle, etc." to "...by altering the exchange of carbon, water and energy between the atmosphere and land surface".

R: Done.

Line 5: Put references in chronological order. Do this throughout the manuscript.

R: Done

Lines 5-6: Add a reference for this.

R: References have been added.

Line 8: Change the definition of LAI from "defined as the one-side leaf area in a unit area" to "defined as the one-sided leaf area per unit ground area"

R: Thanks, Corrected in the revised manuscript. Thanks.

Line 10: Increasing rate of what? Do you mean a strengthening of the land C sink?

R: Yes. It is a strengthening of the land carbon sink. We have explained this better in the revised manuscript.

Line 26: Put the word atmospheric before CO_2.

R: Added atmospheric before CO_2 in Line 26 and all other occurrences.

Line 27: I would say simulate rather than predict since you are not performing model runs into the future.

R: Changes have been made in Line 27 and other occurrences.

Line 28: What are the associated surface characteristics? Give one or two examples (e.g. roughness length, albedo).

R: Roughness length, albedo, and etc. are the characteristics that we intended to express here. This has been clarified in the revised manuscript.

Lines 30-31: I would like a reference at the end of this statement. Instead of using the phrase "since the later 1980s", use "towards the end of the 1980s" or "since the second half of the 1980s".

R: Changed to "towards the end of the 1980s". A reference has been added.

Page 3

Lines 8-9: Add some references at the end of this sentence.

R: References have been added in the revised manuscript.

Lines 9-10: Give an example of some other external forcing.

R: For instance, wind speed and sea surface pressure. This has been added tothe revised manuscript.

Line 15: Change "by applying a dynamic global vegetation model" to "by using the SSiB4/TRIFFID (Simplified Simple Biosphere model version 4/Top-down Representation of Interactive Foliage and Flora Including Dynamics) DGVM...". Just use the abbreviation from now on.

R: Changes have been made in the manuscript according to this suggestion.

5   Lines 19-24: Remove these lines and add your research questions here.

R: Lines 19-24 were removed. The research questions in this paper are: 1) how do the vegetation trends change before and after the 1980s? 2) What is the effect of climate regime shifts during the 1980s on the vegetation trend change? These questions have been added to the manuscript.

2 Model description, observational datasets, and experimental design

10   Move section 2.4 (Experimental design) to just after the model description section.

The structure of this section should be:

2.1 Model description

2.2 Experimental design

2.3 Data

15   2.3.1 Meteorological forcing data

2.3.2 Observation-based data

R: We have modified the structure of this section based on the reviewer suggestion.

Line 25: Change 2.1 title to "Model description".

R: Done

20   Line 26: Change "...is a biophysically based model incorporating estimates fluxes of radiation..." to "...is a biophysically based model which simulates fluxes of radiation...".

R: Done.

Lines 29-32: Change this sentence to "The TRIFFID DGVM (Cox, 2001) was coupled to SSiB version 4 (Xue et al., 2006) to calculate vegetation dynamics, including relevant land-surface characteristics of vegetation cover and structure."

25   R: Done.

Page 4

Line 2: Delete "Some parameters were also updated in this process".

R: Deleted.

Lines 2-7: I don't think you need this here. Please add a description of how GPP and LAI are calculated in SSiB4.

30   R: Lines 2-7 have been removed from the revised manuscript, and the following sentences on how GPP and LAI calculation in SSiB4/TRIFFID are added.

"SSiB estimates net plant photosynthesis assimilation rate, autotrophic respiration and other surface conditions such as canopy temperature and soil moisture for TRIFFID. TRIFFID updates the coverage of a PFT based on the net carbon available to it

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and the competition with other PFTs, which is controlled by Lotka-Volterra equations and carbon pool for leaf, wood, and root for each plant functional type. LAI is calculated based on the leaf carbon pool and leaf phenology.

2.2 Meteorological forcing data

In this section, please add more information regarding the Princeton dataset. How was it created? Where did you download it from?

R: We have modified this paragraph to including the data source and how it was created.

Line 11: "modelling" instead of "modeling".

R: Done.

Lines 13-14: Add units.

R: Done.

2.3 Observation-based data

Can you make a section called Data? Add a brief paragraph detailing what datasets were used as input (meteorological, vegetation, soil) to SSiB4/TRIFFID and those used to evaluate the model. Then add the Meteorological forcing data and Observation-based data sections as subsections.

R: We have rearranged the data information and made a section called Data (section 2.3), which includes three subsections: 2.3.1 introduce preliminary initial condition (covering the vegetation map and soil used as input in the quasi-equilibrium simulation) ; 2.3.2 Meteorological forcing data (covering the Princeton global meteorological dataset used as forcing data for quasi-equilibrium and real-forcing simulations); 2.3.3 Observation-based data (covering GLC2000 and MODIS for vegetation distribution evaluation, GIMMS and GLASS LAI data for LAI evaluation and FLUXNET-GPP for GPP evaluation). The following has been added to summarize the datasets used as input and those used to evaluate the model.

"A SSiB vegetation and soil map is used as the preliminary initial condition for the quasi-equilibrium simulation. 3-hourly meteorological forcing data and its long-term average are used to drive SSiB4/TRIFFID in the real-forcing and quasi-equilibrium simulation, respectively. The satellite-derived products are used to validate and calibrate the model to produce proper vegetation spatial distribution and temporal variability."

Line 17: Is this the land cover map used by the model or is it used to evaluate the model after spin-up? Where did you download it from? Did you have to do any processing of the land cover map for the study? What is the native resolution of the database?

R: The global land cover map was used to evaluation the model results driven by 1948-2007 meteorological forcing data. It was download from http://forobs.jrc.ec.europa.eu/products/glc2000/glc2000.php. This dataset consists of a global map with one legend, as well as regional maps with separate legends containing more detailed classification for certain regions. We used the 1000 m resolution reginal products to generate land cover fraction map by counting the percentage of each PFT in a 1-degree grid. Then the regional fraction maps were merged to obtain a global land cover fraction map. Furthermore, a land cover map for dominant type at 1-degree resolution was generated based on the vegetation type having the largest coverage in a 1-degree grid box.

Line 19: Please explain what S1 is? "SPROT" should be "SPOT".

R: "S1" stands for SPOT-VEGETATION standard product S1: daily maximum of NDVI composite of spectral reflectance at the top-of-canopy. We have modified this sentence to "The Global Land Cover (GLC) database for the year 2000 (Bartholome et al., 2002) used the data from Satellite Poul l'Observation de la Terre at the spatial resolution about 1000 m" .

Line 23: What do you mean by dominance in the GLC2000 dominance map? Is this a map in which the PFT that has the most coverage in each grid box is the dominant PFT? Line 25: Provide a brief explanation of the differences between the GLC2000 and MODIS land cover map?

R: As mentioned in response to the previous question "Did you have to do any processing of the land cover map for the study?", the high resolution (1000 m) vegetation type product was converted to vegetation fraction map by counting the percentage of each PFT in a 1-degree grid. Then the dominant vegetation map (at 1-degree resolution) was generated, by assigning the type with maxim fraction cover in each grid of the fraction map.

GLC2000 and MODIS are derived from different sensors on-board different satellite and in different classification system. GLC2000 is based on the daily data from VEGETATION sensor on-board Satellite Poul l'Observation de la Terre (SPOT) 4, while MODIS land cover map is based on the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra-1 satellite. MODIS produces the vegetation every year which another product only has GLC2000 and GLC 2014. We feel GLC data may have better quality control.

Line 26: Do you mean assess and not access?

R: Thanks. This typo has been corrected.

Lines 27-28: Where did you download GIMMS, GLASS and MODIS LAI datasets from? Can you provide a couple of sentences on the differences between these LAI datasets. Did you have to do any processing of the LAI data?

R: The Global Inventory Modeling and Mapping Studies (GIMMS) LAI (refer to LAI3g, the third generation) was downloaded from https://ecocast.arc.nasa.gov/data/pub/gimms/. A neural network algorithm was trained to using the AVHRR GIMMS NDVI3g (covering the period July 1981 to December 2011) and best-quality Terra MOIDS LAI (covering the period 2000 to 2009) for the overlapping period 2000-2009. Then the trained neural network algorithm was used to generate corresponding LAI dataset at 15-day temporal resolution and 1/12-degree spatial resolution for the period from July 1981 to December 2011.

The Global Land Surface Satellite (GLASS) LAI was download from http://www.bnu-datacenter.com/. The GLASS LAI was generated from AVHRR reflectance (1982-1999) and MODIS reflectance (2000-2012). The GLASS LAI provides observations at 8-day temporal resolution and 1 km spatial resolution for the period from 1982 to 2012.

The MODIS LAI includes products derived from Terra and Aqua platform and product derived from the combination of the two platforms. The MODIS products are at 8-day temporal resolution and 500 m spatial resolution.

GIMMS LAI and GLASS LAI are used to evaluate the spatial distribution and temporal variability of model simulation. We didn't use MODIS LAI for the comparison directly. GIMMS LAI and GLASS LAI products are averaged to monthly mean, and then regridded to 1-degree spatial resolution.

Above information is included in the revised manuscript.

Page 5 Lines 1-2: Change from "...remapped to 1-degree spatial resolution and a monthly temporal interval." to "...regridded to 1-degree spatial and monthly temporal resolution."

R: Done

Lines 3-4: This sentence would be better written as "SSiB4/TRIFFID GPP was evaluated using the upscaled FLUXNET GPP (hereafter referred to as FLUXNET-MTE) (Jung et al., 2009; Jung et al., 2011)." Also where did you download the data from? Provide more information on how the dataset was created.

R: The sentence is re-written and additional information is provided. The FLUXNET-MTE GPP was downloaded from https://www.bgc-jena.mpg.de/geodb/projects/Data.php. The FLUXNET observations of carbon dioxide flux were upscaled to the global scale using the machine learning technique, model tree ensembles (MTE), which was trained to predict site-level GPP based on remote sensing indices, climate and meteorological data, and information on land use. This data set provides global monthly mean GPP at 0.5-degree spatial resolution for the period from 1982 to 2011. The FLUXNET-MTE GPP was regridded to 1-degree spatial resolution.

Line 7: Change "MTE-GPP data was remapped to 1-degree spatial and a monthly temporal resolution." to "FLUXNET-MTE GPP was regridded to 1-degree spatial and monthly temporal resolution.".

R: Done.

Lines 9-10: Change this sentence to "In this study, SSiB4/TRIFFID was used to simulate the global vegetation distribution and assess the sensitivity of ecosystem trends to climate and eCO2."

R: Done.

Line 10: Remove "For this purpose". "performed" instead of "conducted"

R: Done.

Lines 13-14: Remove the sentence "Meanwhile, the effect of largescale disturbance (LSD) on restricting tree expansion to savanna areas was investigated." Put this in the results/discussion sections.

R: Moved to the results/discussion sections.

Line 17: Remove "firstly". What are the multiple biotic variables?

R: "firstly" is removed. The multiple biotic variables stand for vegetation coverage, LAI and GPP. It has been replaced by "vegetation coverage, LAI and GPP" in the revised manuscript.

Pages 6-14

3 Vegetation initial conditions

This section should now be your results section. Each subsection should have the questions as the heading, so the reader does not have to go back to the introduction again. In each subsection, have a sentence that summarizes the main finding. This makes it easier for the reader to understand the key findings.

I suggest the following. Obviously, you should add your own question after each subsection number. I have only added what I think the section should be about.

3 Results

3.1 Evaluating the quasi-equilibrium simulation. Comparison to land cover map. Effect of large-scale disturbance.

3.2 Evaluating GPP/LAI.

3.3 Assessment of vegetation temporal variability.

3.4 External forcing effects on ecosystem trends.

R: The structure of results section has been modified accordingly in the revised manuscript.

3 Results

3.1 Vegetation initial condition

3.2 Evaluation of simulated ecosystem

3.3 Simulated vegetation temporal variability and trend changes

3.4 Attribution of three external forcings on ecosystem trends

We will add a sentence as the beginning of each subsection to point out the main content in this section.

The discussion section (section 4) should have 4 subsections, each discussing the corresponding results from section 3. The Conclusions section will be section 5.

R: The discussions currently in Section 3 have been moved to the discussion section, which now consist of 4 subsections.

Page 6

3.1 Quasi-equilibrium simulation

Lines 3-16: The first 2 paragraphs could be moved to the discussion section.

R: Done.

Lines 17-25: Move this paragraph to the beginning of this section.

R: Done.

Line 11: Do you mean allocation instead of reallocation? Line 12: Don't start a sentence with "Figure X shows...". Make a statement regarding the result and reference the figure in brackets at the end of the sentence. Do this throughout the manuscript.

R: Yes, it is "allocation". This has been corrected in the revised manuscript.

Thanks for pointing out, we have gone through manuscript to reduce use of this phrase.

Line 23: Delete the phrase "That being said".

R: Deleted.

Page 7 Lines 3-5: Delete the sentence "Detailed comparison of the simulated...".

R: Deleted.

Line 27: You could reference Figure 4 here.

R: Done

Page 8 Line 28: Re-write this sentence as "The spatial correlation coefficient between model and FLUXNET-MTE GPP is 0.93 (P<0.05) (Figure 7)".

R: Modified as suggested.

Line 30: The standard way to quote global GPP values is in PgC/yr. Remove 1135 gC/m2/yr.

R: Modified.

Line 32: Lack of N-limitation.

R: Corrected.

Page 9 Line 8: Change "for the model validation" to "for model evaluation".

5   R: Changed.

Page 10 Line 6: I don't think you need Figure 9 as it is referenced only once. You could add a reference at the end of the sentence instead.

R: Figure 9 has been moved to the appendix, and relative references were added.

Lines 6-7: State the temperatures as Celsius instead.

10   R: Done

Lines 18-19: Remove the information regarding the stipples (dots) on Figure 10 as it is already included in the caption.

R: Done

Lines 24-25: Reference a figure at the end of this sentence.

R: This sentence refers to Figure 10 (Figure 8 in the revised manuscript). It is added in the revised manuscript.

15   Page 11 Can you include a few sentences on how elevated CO2 affects GPP/LAI in the model as part of the discussion?

R: Yes. SSiB uses Collatz et al model to calculate photosynthesis process (Zhan et al, 2003) which is given the following equations:

$$A_n = \frac{g_b}{1.4} \frac{C_a - C_s}{p}$$

$$GPP = A_n + R_d$$

20   where A_n is the net CO_2 assimilation, g_b is stomatal conductance to latent and sensible heat transfer, C_a is the atmospheric CO_2 concentration, C_s is the CO_2 concentration at leaf surface, p is the air pressure, and is R_d the dark respiration rate of the canopy. Based on above equations, increase in C_a leads to a larger A_n, then a larger GPP.

Vegetation in TRIFFID is presented as leaf, root, and wood carbon, and for each a corresponding carbon pool is updated the based on the net carbon available to it and the competition with other PFTs, which is controlled by Lotka-Volterra

25   equations. LAI is calculated based on the leaf carbon pool and leaf phenology. Larger GPP leads more carbon goes in to the vegetation carbon pool in leaf, root and wood, then larger LAI.

A summary of these explanations have been added to the discussion section.

Page 12 Lines 6-8: Remove these lines.

R: Removed.

30   Page 14

6. Conclusion

I would like to see some more discussion in the Conclusions section. It is a bit short. Of the three sensitivity experiments, please state which one is the most important and why?

R: This is a valid point, we agree that the conclusion concerning driver contributions is a bit short. We have included additional discussion in the revised manuscript.

Line 9: Change "to the climate variability" to " to climate variability".

R: Changed.

5 Lines 10-11: Delete the phrase "The results show". Use "We have shown that the SSiB4/TRIFFID model can simulate the vegetation distribution and temporal variability for the X time period."

R: Done.

Lines 28-30: Is there a University service for making the data available rather than a google drive account? Can you obtain a doi for the data? Also can you specify what data you have made available?

10 R: We have uploaded the available data to a University server and will indicate the available data in "data availability" section.. We will request a doi from your journal for the data when we submit the revision.

Figure 2 Can you use different colors for the lines as they are difficult to distinguish? Figure 4 I don't think you need this figure. Can you remove?

R: We have redrawn Figure 2 with different colors to make it clearer. Figure 4 has been moved to the appendix.

15 Figure 5 Can you include the MODIS dataset since you mention it on Page 4, line 24?

R: We have added a vegetation map for MODIS.

Figure 6 Please plot the differences (model - obs) instead.

R: This figure has been replaced.

Figure 7 Plot the difference instead.

20 R: We have redrawn this figure to show the difference.

Figure 8 You haven't said what the black line is? Is this SSiB4/TRIFFID?

R: Yes, it is SSiB4/TRIFFID. It has been added to the revised manuscript.

Change first line of caption to "Comparison of standardized LAI anomalies between simulation and observations for 9 sub-regions."

25 R: Done.