Response to reviewer

Reviewer # Questions and our responses

We extend our deep appreciation to Reviewer for the constructive comments and suggestions toward improving our paper. Acknowledgement was added in the revision.

Reviewer:

This paper reports a set of factorial simulations of global vegetation biomass responses to changes in atmospheric CO_2, temperature, precipitation, and radiation based on a well-developed dynamic vegetation model, SEIB-DGVM. The purpose of this study is to "systematically determine the long-term variability of carbon-sequestration potential and understand its response mechanisms, and estimate trends in partitioning of potential biomass carbon-stocks of vegetation biomass".

However, after reading through this paper a couple of times, I do not think these questions are answered. The authors should keep it in mind that these results are simulations from a model. One cannot just run the model and tell us what they are. The simulations must be correctly evaluated before taken as conclusions. A detailed analysis of simulation results, model formulation, and uncertainty evaluation is necessary either in Results or in Discussion.

I also had a hard time in following the description of model description (Section 2.3 Carbon-stock of vegetation biomass partitioning). Please improve this section.

Response: We greatly appreciate your detailed summary and excellent comments which helped us to clarify our logic flow and presentation.

Feedbacks from terrestrial ecosystem to greenhouse effect noticeably strengthen carbon-sequestration potential. However, the enhanced trend and drivers of carbon-sequestration potential at the global scale in past hundred years is unclear. To answer the question that how carbon-sequestration potential of vegetation biomass partitioning would respond to the impact of changes in climate and carbon dioxide (CO_2), we used the spatially explicit individual-based dynamic global vegetation model (SEIB-DGVM) as research tool to simulate the historical trend of potential vegetation carbon-stock and verified modelled result. Then, we set factorial simulations to isolate and quantify the contributions of changes in climate and CO_2 to the variation of the carbon-sequestration. Based on the results of factorial simulations, we found that the interaction of terrestrial water availability and driving factors (CO_2, precipitation, temperature, radiation) adjusts the response magnitude of carbon-stock to changes in driving factors. We suggested that the long-term trend in increased vegetation biomass carbon-stocks is driven by CO_2 fertilization and temperature effects that are controlled by water limitations.

SEIB-DGVM is the first biogeochemical model with three-dimensional representation of forest structure (Sato et al. Ecological Modelling, 2007, 200(3-4): 279-307), and has been widely used in simulating carbon cycle and vegetation succession. In this research, we evaluated the SEIB-DGVM version 3.02 and used it to investigate the variation trend and drivers' contributions of vegetation carbon-stock partitioning. Due to the limitations in empirical formulas and coefficients, the artificial uncertainty still exists in SEIB-DGVM. So, we first verified the accuracy of SEIB-DGVM. The evaluation results shown that simulated value calculated by SEIB-DGVM has a high degree of consistency with observed value. Based on prior knowledge, we found that debate and uncertainty exist in the estimation of global potential vegetation carbon-stock. Compared with these results from the literature and the state-of-the-art dataset, the potential vegetation carbon-stock modelled by SEIB-DGVM was within the reasonable range. According to verification results, we thought that SEIB-DGVM is an available research tool, which could supply a way to investigate the change trend and drivers' contributions of carbon-sequestration potential. We discussed uncertainty-induced result errors in simulation of vegetation carbon-stock (see Original, Page 14, Lines 513-524), while more detailed discussion and model description would be added into revision to help readers understand better.

Point-to-point responses to all the comments are given below.

1. line 89: "Large gaps in our knowledge of the effects of various drivers on the partitioning of carbon-stocks in vegetation biomass remain." Through this paper, the definition of "carbon-stock" is confusing. If it is referred to as the biomass, you do not have to use it. Just use "biomass".

Response: Thanks for your constructive suggestion. Yes, the definition of "carbon-stock" is the carbon content of biomass. With the increase of atmospheric CO_2 concentration, the capacity of vegetation carbon sequestration remarkably enhanced to maintain a balanced carbon cycle. Biomass increase is one of manifestation of the enhanced carbon sequestration capacity. To reveal the feedback from vegetation carbon sequestration to increase atmospheric CO_2 concentration, we thought carbon-stock is an appropriate proxy for the carbon-sequestration capacity.

2. There Lines 123~124 "Neither the CRU nor NCEP datasets included downward shortwave and longwave radiation." I used these data and I know they have downward shortwave and longwave radiation at 6-hourly time step. Go to TRENDY site, where you can find the links to these data.

Response: Thanks for your careful review and valuable suggestion. The climate forcing of TRENDY obtains from CRUNCEP, which is a combination of CRU monthly data and NCEP reanalysis data. Based on empirical functions (Sato et al, Ecological Modelling, 2007, 200(3-4): 279-307.), we employed historical data from CRU and NCEP to calculate the shortwave radiation and the longwave radiation at midday. We would conduct a comparation about radiation from the CRUNCEP and empirical functions in revision.

3. Line 177: “Carbon-stock of vegetation biomass partitioning” I think it does not have to say “carbon-stock” if it means carbon content of biomass. Biomass can be defined as unit of carbon (e.g., kg carbon per unit of land)

Response: Thanks for your careful review and constructive suggestion. As the CO_2 concentration rise, the vegetation carbon sequestration capacity increases for moderating CO_2 concentration buildup and stabilizing carbon cycle. Changes in vegetation biomass is an aspect of the variant of carbon sequestration capacity. To reveal the interaction among the components of carbon cycle, carbon-stock is an appropriate proxy for investigating the response of vegetation carbon sequestration capacity to other components’ changes.

4. Line 194: I am not clear about this equation. Does “(

$$max_1 = (crown_{area} + \pi crown_{diameter} crown_{depth}) \frac{LA_{max}}{SLA}$$

)” have any physical meaning? LAmax seems to be a maximum leaf area. However, it is said to be “maximum leaf area of PFTs per unit biomass (m^2 m^{-2}),” per unit biomass of what? Why is the unit m^2 m^{-2}?

Response: Thanks for your valuable comment. According to previous literature (Sato et al, Ecological Modelling, 2007, 200(3-4): 279-307., Page 287), terms in parenthesis indicate a surface area of tree crown (except basal plane), which is assumed to have a cylinder shape. By multiplying the crown-surface-area (m^2) by maximum-leaf-area per unit crown-surface-area (LA_{max}, m^2 m^{-2}), we have the maximum-leaf-area (m^2) that size of the crown of the tree allows. By dividing it with specific-leaf-area (SLA, m^2 g^{-1}), the maximum-leaf-area is converted into maximum-lead-biomass (g) of the crown. LA_{max} is the plant functional type specific maximum leaf area per unit crown surface area excluding the bottom soffit (m^2 m^{-2}).

5. Line 204: "Grass leaf biomass is supplemented"? stop to grow?

Response: Thanks for your detailed comment. In plant growth phrase, the non-structural carbon of photosynthetic production is allocated to grass leaf consistently. When the leaf area index of grass equals the optimal leaf area index, it stops to allocate non-structural carbon to grass leaf. The grass leaf biomass stops to grow.

6. Line 206: Any scientific basis for this equation? Why is it like this?

Response: Thanks for your detailed comment. The equation (5) in Line 206 comes from previous literature (Sato et al, Ecological Modelling, 2007, 200(3-4): 279-307., Page 288, equation (36)). The lai_{opt} represents the daily net primary production is the maximizes value under this leaf area index, derived from gpp_g – cost lai_g/SLA.

The gpp_g is the daily gross primary production (g day^{-1} m^{-2}. Kuroiwa, Function and Productivity of Plant Population. Asakura-shoten, Tokyo, pp. 84-141 (in Japanese)). The cost is the maintenance respiration rate per unit biomass (dimensionless). The lai_g is the leaf area index of the grass layer (m^2 m^{-2}). SLA is the PFT-specific leaf area per unit biomass (m^2 g^{-1})

The equation (36) is derived from equation (19) and (34) according to Sato *et al.* (2007), calculated as follows:

$$gpp_g = 0.090936\int_{y=0}^{lai_g}\int_{t=0}^{dlen} p_{single}\,dt\,dy$$

$$= 0.090936\frac{2dlen\,p_{sat}}{eK}\ln\left(\frac{1+\sqrt{1+(par_{grass}eK\,lue/p_{sat})}}{1+\sqrt{1+(par_{grass}eK\,lue/p_{sat})e^{-eK\,lai_g}}}\right) \quad (19)$$

$$stat_{leaf} = gpp_l - cost\,\frac{la}{SLA}\,\frac{1}{10\,crown_{depth}} \quad (34)$$

$$lai_{opt} = \frac{\ln par_{grass} - \ln\{p_{sat}/lue[(1-(cost/SLA)/0.09093dlen\,p_{sat})^{-2}-1]\}}{eK} \quad (36)$$

where gpp_g is gross primary production of grass layer (g day^{-1} m^{-2}), $stat_{leaf}$ is benefit per cost of maintaining leaf mass (g g^{-1} day^{-1}), gpp_l is gross primary production of each crown layer (g day^{-1}), $cost$ is the cost of maintaining leaves per unit leaf mass per day (g DM g DM^{-1} day^{-1}), la is leaf area (m^2), $crown_{depth}$ is crown depth (m), lai_{opt} is optimal leaf area index (m^2 m^{-2}), par_{grass} is the grass photosynthetically active radiation (μ mol photon m^{-2} s^{-1}), p_{sat} is the light-saturated photosynthetic rate (μ CO_2 m^{-2} s^{-1}), lue is the light-use efficiency of photosynthesis (mol CO_2 mol photon^{-1}), $dlen$ is day length (hour), and eK is light attenuation coefficient at midday.

7. Lines 214~215: This sentence is funny "When total woody biomass is more than 10 kg DM, which defines the minimum tree size for reproduction, 10% of non-structural carbon is transformed into litter." The authors are talking about "reproduction" limit of biomass, and then they tell you if this requirement is met, some non-structure carbon (NSC) will be converted to litter. Then, what is reproduction? Is it "10% of non-structural carbon is transformed into seeds"?

Response: Thanks for your detailed comment. The SEIB-DGVM assumes that each tree consumes 10% of NSC for reproduction. This 10% NSC is used for every process of reproduction, including having flowers, pollen, nectar, fruits, and seeds. As reproduction is a very diverse process for plant species, this kind of assumption is required for simulating vegetation at large geographic scales. This simple assumption of the SEIB-DGVM was actually taken from the LPJ-DGVM, and many other DGVMs also employ this assumption.

8. Lines 216: "the remaining structural carbon is allocated to sapwood biomass" What is "structural carbon"?

Response: Thanks for your detailed comment. We reworded the sentence "the remaining non-structural carbon is allocated to sapwood biomass" in the revision.

9. Lines 222 "Terrestrial water availability represents a significant source of variability in the ecosystem carbon cycle" This sentence is not necessary.

Response: Thanks for your detailed suggestion. We deleted the sentence in the revision.

10. Lines 232 “According to the flexible allocation scheme, SEIB-DGVM allocates and stores the biomass carbon …” the phrase “According to the flexible allocation scheme,” is not needed.

Response: Thanks for your detailed suggestion. We deleted the phrase in the revision.

11. Lines 236~238 This sentence disrupts the description of model formulation. Reword it.

Response: Thanks for your detailed suggestion. We reworded the sentence in the revision as below:

“The root-shoot ratio (R/S) has been used to distinguish and investigate the variation trend of inner biomass partitioning of carbon-sequestration potential (Zhang et al., 2016).”

12. Lines 253~254: “The plant functional types are favored for establishment by the environmental conditions in each grid cell.” Reword this sentence. I could not understand what it wants to say. Does it mean the environmental conditions will select out PFT(s) in each grid cell?

Response: Thanks for your detailed comment and constructive suggestion. Yes, the establishment of PFT(s) is determined by environmental conditions. For example, the SEIB-DGVM assumes that boreal broad-leaved summer-green trees can only establish when the midday photosynthetically active radiation that averaged for the previous year exceeded 700 μmol photon m^{-2} s^{-1} at the surface of the grass layer.

We reworded the sentence in the revision as below:

"The establishment of plant functional types are determined by the climatic conditions in each grid cell."

13. Lines 260~268: section "Factorial simulation scheme" Clarify this section please. It is really difficult to understand it.

Response: Thanks for your detailed comment and constructive suggestion. We added more information about "Factorial simulation scheme" in order to help readers understand better.

"In order to further quantify the relative contributions of varying atmospheric CO_2 concentrations, precipitation, temperature, radiation, and other factors, we performed six factorial simulations. Other factors included wind velocity and relative humidity, which had remarkable effects on change in vegetation carbon-stock at regional scale. In simulation S1, atmospheric CO_2 concentration and all of climate variables were varied. In simulation S2, only atmospheric CO_2 concentration was varied, and climate variables were held constant (Climate variables of the transient period (1901-1915) were repeatedly inputted). In simulation S3 (or S4, S5), atmospheric CO_2 and precipitation (or temperature, radiation) were varied, and other climate variables were held constant. In simulation S6, atmospheric CO_2, wind velocity, and relative humidity were varied, and other climate variables were held constant. Finally, S2 was used to evaluate the effects of CO_2 fertilization on carbon-stock variation. The differences of S2-S3, S2-S4, S2-S5, and S2-S6 were used to evaluate the response of carbon-stock growth to precipitation, temperature, radiation, and other drivers, respectively."

14. Line 260: What are "Other drivers" in Table 1? You only listed "atmosphere CO_2, precipitation, temperature, and radiation". Specify them please.

Response: Thanks for your detailed suggestion. Other drivers included wind velocity and relative humidity (see Original, Page 10, Lines 263-264).

Follow your suggestion, I added more introduction of other factors in Table 1. We rewrote the sentence as below:

"In the last simulation S6, historical atmospheric CO_2 concentrations and other climate variables (wind velocity and relative humidity) were input, excluding precipitation, temperature, and radiation."

15. Line 265: What is "carbon-stocks trend"?

Response: Thanks for your detailed comment. We rewrote the sentence, "the contribution of CO_2 to the trend in carbon-stocks trend" was changed to "the contribution of CO_2 to the trend in carbon-stocks".

16. Line 295: I don't understand "In terrestrial vegetation biomes, there is a high correlation between biomass carbon-stock density and NPP per unit (Erb et al., 2016; Kindermann et al., 2008)". Why does it need "In terrestrial vegetation biomes"? per unit of what?

This is supposed to be the results. Why does it have citation here?

Response: We greatly appreciate your insightful comment. To evaluate the accuracy of potential vegetation carbon-stock modelled by SEIB-DGVM, we tried to find a dataset including global potential vegetation carbon-stock from 1916 to 2015. To our best effort, we only collected the spatial pattern of potential vegetation carbon-stock (see Original, Page 14, Lines 326-329). According to previous conclusions (Erb et al., 2016; Kindermann et al., 2008), we knew that there is a high correlation between net primary production (NPP) and carbon-stock in regions covered by vegetation. We cited literatures to reveal this correlation of NPP and carbon-stock, and used NPP as a proxy of the carbon-stock to assess model accuracy. We collected long-term series observations of NPP to verify the modelled NPP of SEIB-DGVM from 1916 to 2015. The general agreement of observed NPP and modelled NPP suggested that it is possible to use the SEIB-DGVM model to evaluate the long-term trend of potential vegetation carbon-stock.

17. Lines 295~302: If this paragraph is to describe another dataset, it should be Method and Data section.

Response: Thanks for your constructive suggestion, the section was moved to Method and Data.

18. Lines 303~314: Same for this section. Move it to the data analysis method section.

Response: Thanks for your constructive suggestion, the section was moved to Method and Data.

19. Lines 331~332: Move to Method section.

Response: Thanks for your constructive suggestion, the section was moved to Method and Data.

20. Lines 335~336: I am confused by the definition of "carbon-stock". Is it new growth of biomass or the biomass a plant has?

Response: Thanks for your constructive suggestion. Vegetation carbon-stock is the content of vegetation. The turnover time of carbon-stock in trunk organ is more than one year. The year-to-year assimilative carbon is stored at vegetation organs until it is transformed into litter. We changed "the year-to-year accumulation of carbon in the terrestrial plant without external interference" to "plant grow in the assumed absence of external interference under current climate".

21. Line 349 “a conclusion consistent with prior knowledge (Erb et al., 2018; Schimel et al., 2015)” should be in discussion.

Response: Thanks for your constructive suggestion, the section was moved to Discussion and Conclusion.

22. Lines 355~357 “Based on the carbon-stock partitioning method, we found that the integrated carbon-stock as well as the above- and belowground carbon-stocks over the period of 1916–2015 exhibited a remarkable spatial heterogeneity.” This sentence does not have information. Say it directly: What the spatial pattern is.

Response: Thanks for your constructive suggestion, the detailed information of spatial pattern was added in the revision as follow:

“Integrated carbon-stock and AVBC exhibited an increasing trend in eastern South America, southern Africa, and northern Asia, while declined in central North America, northwest South America, and central Africa. BVBC showed a more widespread increase in North America, southeastern South America, and Europe, while had a decrease trend in part region of Asian.”

23. Lines 369~372: “Biomass carbon allocation between above- and belowground vegetation organs reflect the changes in individual growth, community structure and ecosystem function, which are important attributes in the investigation of carbon-stocks and carbon cycling within the terrestrial biosphere (Hovenden et al., 2014; Fang et al., 2010; Ma et al., 2021)” this sentence should be in discussion. Present your own results. Throughout the results section, this type of evaluations to their own results should go to discussion.

Response: Thanks for your constructive suggestion, this section and other similarity sections were moved to Discussion and Conclusion in the revision.

24. Line 466 "4 Conclusions and discussions" Change it to "4 Discussion and conclusion".

Response: Thanks, we changed "4 Conclusions and discussions" to "4 Discussion and conclusion".

25. For a modeling paper, the uncertainty of simulations should be evaluated. One cannot pretend these simulations to be the sure thing and "offer perspectives" based on them directly. Many patterns are just artifacts from model assumptions and model response equations, which are highly uncertainty.

For example, in line 495, the authors found "the long-term change in carbon-stocks is tightly coupled to terrestrial water availability". Then, it should be talked about that how the model simulates water effects on vegetation and to what extent this formulation can be trusted.

Response: We greatly appreciate the reviewer's insightful comment. Yes, there is uncertainty in the simulation results of SEIB-DGVM because of model assumptions and empirical equations. To assess the effects of uncertainty on model, we evaluated the simulation accuracy of NPP and potential vegetation carbon-stock. Based on the result of verification, we thought that SEIB-DGVM is an available research tool, which could supply a way to investigate the change trend and drivers' contributions of vegetation carbon-stock.

Based on photosynthesis, plant assimilated carbon and allocated non-structural carbon to plant organs. In SEIB-DGVM, terrestrial water availability affected vegetation carbon-stock by controlling leaf phenology and the rate of photosynthesis. We added detailed information about the effect of water limitation on vegetation in SEIB-DGVM, equations as follow:

$$p_{sat} = PMAX ce_{tmp} ce_{co_2} ce_{water}$$

$$ce_{water} = \sqrt{stat_{water}}$$

$$stat_{water} = \frac{max(pool_{w(1)}/Depth_{(1)},\quad pool_{w(2)}/Depth_{(2)}) - W_{wilt}}{W_{fi} - W_{wilt}}$$

where p_{sat} is the single-leaf photosynthetic rate (μ mol CO_2 m^{-2} s^{-1}); $PMAX$ is the potential maximum of photosynthetic rate (μ mol mol^{-1} CO_2 m^{-2} s^{-1}); ce_{tmp} and ce_{co_2} are the temperature and CO_2 concentration effect coefficient (dimensionless), separately (Raich et al, Ecological Applications, 1991, 1(4), 399–429. Brooks and Farquhar, Planta, 1985, 165(3), 397–406.); ce_{water} is the water effect coefficient (dimensionless); $stat_{water}$ is the physiological status of water availability (dimensionless).

Recent version of the SEIB-DGVM appropriately reproduce geographical distributions of GPP (gross primary production) and biomass in the African continent, where plant productivity and structures are mainly controlled by aridity (Sato and Ise 2012, Sato et al. 2015). These results demonstrate that the model appropriately treats water effects on vegetation.

Sato, H. and T. Ise (2012). "Effect of plant dynamic processes on African vegetation responses to climate change: Analysis using the spatially explicit individual-based dynamic global vegetation model (SEIB-DGVM)." Journal of Geophysical Research-Biogeosciences 117(G3): 202-215.

Sato, H., et al. (2015). "Effects of different representations of stomatal conductance response to humidity across the African continent under warmer CO_2-enriched climate conditions." Journal of Geophysical Research-Biogeosciences 120(5): 979-988.

Thanks again for your time and efforts put on this manuscript, which is acknowledged in the paper