Dear Chris,

Thank you very much for handling our manuscript.

In your decision letter, you pointed out the major weakness of our approach, which is the assumption of homogenous rainfall characteristics during the wet season. In this reply, we addressed this concern directly and at length, and also made corresponding revisions in the manuscript.

Specifically, we demonstrate that though our approach does show some effects in regions with highly seasonal rainfall or bi-modal rainfall patterns (please see the detailed response), overall the simulations forced with observed rainfall and forced with the synthetic rainfall are highly correspondent with a close-to-unit slope and a high R^2 (see the Figure below) at the continental scale, as well as a constant bias (i.e. interception). The limitation of the approach is further minimized by only focusing on the relative change of GPP, i.e. the change normalized by the simulated baseline GPP (forced by the synthetic rainfall model). Thus our analysis largely reduces the impact of errors associated with the above-mentioned absolute GPP difference.

Meanwhile, we have been upfront and honest with this limitation since the original submission. We have brought many cautions in interpreting results for regions which are possibly deviated from our assumption. We have also included sufficient discussion of this limitation since our original submission.

It is also worth noting that the limitation of our approach is at least partly due to fundamental data limits on stochastic parameter estimation. To reliably estimate rainfall characteristics (i.e. rainfall frequency and intensity) usually requires a long time series. Estimates from short periods, e.g. monthly data, would be biased by edge effects, which are going to be large in low rainfall situations (where there are only 3-4 storms per month, maybe fewer at the start/end of the growing season). Thus, there is always a tradeoff between simulating long periods (more reliable estimates but constant for this period) verses short periods (less reliable estimation but can vary for short period) of parameters. The current method that we choose is also a consequence of this tradeoff, as we only have 13-year TRMM rainfall data available to estimate our rainfall parameters.

Regardless, we believe that our paper represents a significant advance beyond what has been done before in both scientific value and even methodology. There has been very little prior work in ecohydrology that focuses on the tradeoffs between different rainfall characteristics, esp. the consideration of rainy season length. The bulk of scientific literature within dryland ecohydrology (see the detailed response below) is usually based on the approach of the Marked Poisson Process (i.e. the same assumption with ours), without considering any effects of rainy season length. Our approach at least explicitly incorporates the important aspect of rainy season length. We thus hope the editor could fully consider the value of our work, which we believe can open up more interesting follow-up studies, including an improvement of methodology when longer rainfall observations become available.

We also provide detailed one-to-one response below. We hope that our responses and revisions have addressed your concerns so that our manuscript could move to the next stage.

Best wishes,

Kaiyu Guan, Stephen Good, Kelly Caylor, on behalf of all the authors

Detailed Response:

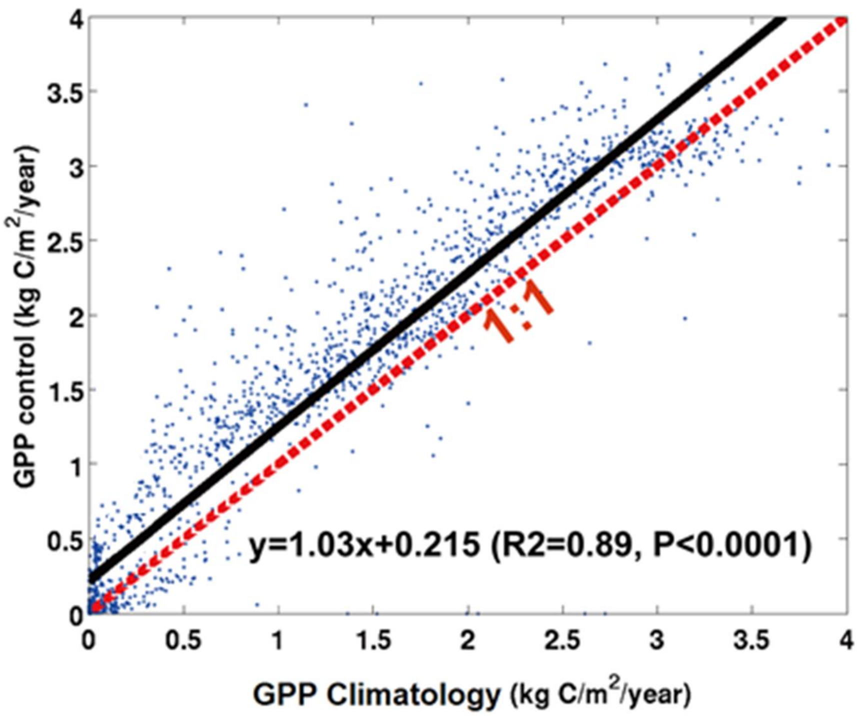
This work lends some insights that are valuable however I see one major weakness. As R1 pointed out, the approach to representing rainfall with constant wet season statistics averaged over the wet 90% of the year smooths out any real seasonality at a monthly time scale, with the effect, for example, of making 8 months uniformly wet (albeit with stochasticity from random draws) and 4 months uniformly dry. This completely cuts off the seasonal amplitude. Given that the goal of this work is to test sensitivity to possible shifts in intra-seasonal rainfall variability, it seems crucial to accurately represent rainfall seasonality. Can anything be done at this stage to address that weakness which seems rather significant? I fear that it would involve quite a lot of additional work to revise by creating monthly or bi-monthly rainfall statistics and to then simulate the response for the continent. Even so, it seems appropriate to raise this point and to encourage you to address it.

Response:

Thanks for pointing this out. Meanwhile, it needs to be noted that we never hide this methodological limitation. The assumption of the seasonal rainfall process (i.e. treating wet/dry season rainfall homogeneous) has been fully discussed in "4.1 Limitation of the methodology". We admit that this assumption may be violated sometimes, esp. for those with very long rainy season or bi-modal situation, and we have put enough caution in interpreting the corresponding patterns in our original manuscript.

Second, we inter-compared our model simulated GPP forced with observed rainfall (x-axis of the following figure) and forced with our synthetic rainfall based on the derived rainfall features (y-axis), with their spatial pattern shown in Figure S1. We find that they are highly correspondent in terms of a close-to-unit slope and a high R^2 (we have reported this validation result in our methods section of the manuscript). We admit that there is an effect of our assumption, as we see a positive interception between the two simulated GPP, meaning that our assumption of homogeneous rainy season rainfall would overall increase GPP, and dry regions have slightly more deviations in this aspect. The spatial patterns (Figure S1 c, d) of these two simulated GPP patterns do show an overestimation in regions of the Horn of Africa and southern Africa, whose rainfall seasonality are more deviated from a homogeneous pattern. However, given these errors, we can satisfactorily reproduce the land cover distribution (Figure S1 a, b), and the two GPP are highly correlated with almost a consistent bias (interception). Based on this, we have gained a good confidence that this rainfall model can generate reasonable GPP values across the continental Africa.

One reason to explain the good performance of our rainfall model here is that we are using a dynamic vegetation model which can simulate time-varying leaf phenology. Thus even though in some regions our rainfall model may simulate more rainfall at the beginning (and/or the end) of the rainy season, our dynamic phenological scheme (i.e. requires time to develop leaves for tropical trees and grasses) would respond less to these errors.



Third, all our derived GPP sensitivity terms are all relative changes, i.e. the changes normalized by the simulated baseline GPP (forced by the synthetic rainfall model). These results further reduce the impact from the errors of the absolute GPP difference shown above.

Fourth, we need to point out that our study methods and conclusions are both novel and relevant within the field. We are the first to show the ecological importance of rainfall frequency, intensity and rainy season length spatially explicit **at the continental scale using the model simulation**. Furthermore, we are only able to discern this novel result because of our inclusion of seasonal phenology (explicit rainy season length + dynamic phenology), something prior approaches in this topic have not ever included. We thus would like to put our work in the context of previous studies:

One of the key assumption of our rainfall model, Marked Poisson Process, come from the classic work by Ignacio Rodríguez-Iturbe and his co-authors in 1980s-1990s related to the stochastic rainfall process. In those work, they demonstrated that treating wet season rainfall in the many dryland/semi-dryland are statistically homogeneous can help generate reasonable results for rainfall process.

<u>*References include:*</u>

Rodríguez-Iturbe, I.; Gupta, V. K. & Waymire, E. (1984), 'Scale Considerations Modeling of Temporal Rainfall', Water Resource Research 20(11), 1611-1619.
Rodriguez-Iturbe, I., & Eagleson, P. (1987). Mathematical models of rainstorm events in space and time. Water Resources Research, 23(1), 181–190.
Rodríguez-Iturbe, I., Isham, V., Cox, D. R., Manfreda, S., & Porporato, A. (2006). Space-time modeling of soil moisture: Stochastic rainfall forcing with heterogeneous vegetation. Water Resources Research, 42(6).

Based on this rainfall model, major stochastic ecohydrology theory and literature in the recent two decades were derived. Many of these theory and findings have been verified by field data and experiments. All these work share the same assumption that we used for the rainfall process, i.e. homogeneous rainfall characteristics during rainy season.

<u>*Selective References include:*</u>

Rodriguez-Iturbe, I., & Porporato, A. (2004). Ecohydrology of Water-Controlled Ecosystems: Soil Moisture and Plant Dynamics. Cambridge, UK: Cambridge University Press.
Porporato, A., Daly, E., & Rodriguez-Iturbe, I. (2004). Soil water balance and ecosystem response to climate change. The American Naturalist, 164(5), 625–32. doi:10.1086/424970
Porporato, A., Laio, F., Ridol, L., & Rodriguez-iturbe, I. (2001). Plants in water-controlled ecosystems : active role in hydrologic processes and response to water stress III . Vegetation water stress, 24, 725–744.
Laio, F., Porporato, A., Ridol, L., & Rodriguez-iturbe, I. (2001). Plants in water-controlled ecosystems : active role in hydrologic processes and response to water stress II . Probabilistic soil moisture dynamics, 24.
Daly, E., Porporato, A., & Rodríguez-Iturbe, I. (2004). Coupled dynamics of photosynthesis, transpiration, and soil water balance. Part II: Stochastic analysis and ecohydrological significance. Journal of Hydrometeorology, 5, 559–566.
D'Odorico, P., Porporato, A., Laio, F., Ridolfi, L., & Rodriguez-Iturbe, I. (2004). Probabilistic modeling of nitrogen and carbon dynamics in water-limited ecosystems. Ecological Modelling, 179(2), 205–219. doi:10.1016/j.ecolmodel.2004.06.005

One of the key limitation of these previous work is the lack of consideration of rainy season length, which we believe is a very important factor. We thus added the rainy season length to the previous method (Marked Poisson Process). Thus our method is an important step to move the ecohydrology literature forward by explicitly considering the rainy season length.

We also need to point out the technical difficulty of estimating time-varying parameters of a Poisson process with limited data (here only 13-year TRMM rainfall data, the only spatially-temporally-consistent large-scale rainfall data that we can rely on). Un-biased estimates of rainfall frequency and intensity, based on the Marked Poisson Process, requires long sampling periods; so monthly estimates would be biased by edge effects, which are going to be large in low rainfall situations (where there are only 3-4 storms per month, maybe fewer at the start/end of the growing season). Thus it is always a tradeoff to use long periods (more reliable estimates but constant for this period) verses short periods (less reliable estimation but can vary for short period) of parameters. The current method that we choose is also a consequence of this tradeoff.

Based on all these evidence, we argue that our methodology is better, or at least no worse than, other existing methods. While the 1st Reviewer raised this concern in the first place, he/she also commented that "While the realism could be improved here, I must admit that it is unlikely to have a major impact on the qualitative dynamics that are demonstrated with the current approach." We hope to bring to the editor's attention that though the current approach have space to improve (just as any other rigorous scientific studies), our work can open up many exciting future work on this topic, which is largely understudied before.

To sum up, we feel that we have enough evidence to defend our approach in the context of the existing literature, and we think that there is no need to redo all the simulations, which otherwise would require a few hundreds of thousands CPU computing hours. To reinforce our argument, we added the above figure into the supplementary materials, and we also revised the "4.1 Limitation of the methodology" and other parts of the manuscript to reflect some of the above replies.

In addition, the writing is awkward in a few places, including:

Response to R1's comment, original L571: this sentence is still not correct, linked to the major comment above. Maybe you can restate this as: "Sensitivity to rainy season length (i.e. S...) underscores the combined importance of event depth and season duration which act to tradeoff with each other in the experiments performed here.." You could reword this but I think it is important to stick to what your synthetic experiments really represent which is something different from seasonality which I would argue is only weakly represented in your treatment.

Response: We accepted this suggestion and revised accordingly.

We actually were very cautionary to explain "seasonality" in our work's context. In the abstract, we mentioned "We generated different rainfall scenarios with fixed total annual rainfall but shifts in: i) frequency vs. intensity, ii) rainy season length vs. frequency, iii) intensity vs. rainy season length." Our original manuscript in the "4.1 Limitation of the methodology" clearly claims: "We only consider rainy season length for rainfall seasonality, and neglect the possible temporal phase change; in reality, rainfall seasonality change usually has length and phase shifts in concert." We never tried to confuse readers for what we actually did.

Response to R2's comment P7587, L13-16 (original version) is still not clearly worded. Please try again.

Response: Please see the revised version below:

"The GPP sensitivity with respect to MAP and rainfall intensity (Fig. 6c) shows an unclear pattern, and also contains relatively large uncertainties. These large uncertainties arise mostly because the rainfall intensity of all the modeled regions cluster in a relatively narrow range (Fig.

A4c), and meanwhile the simulated GPP sensitivity for these regions also have large variance (Fig. A4d). “

"...limitations can be possibly overcame by" change overcame to overcome.

Response: This has been changed.

"Cautions are required that our simplified..." This sentence is unclear and awkward. Please clarify.

Response: Please see the revised version below:

“It is noted that our treatment of changing rainy season length while assuming the homogeneity of rainfall statistics (i.e. frequency and intensity) within the rainy season may slightly overestimate the importance of rainy season length.”

I believe "Market" should be replaced with "Marked" Poisson Process throughout the manuscript.

Response: Yes, it is a typo and we have corrected it in the revised manuscript.