Interactive comment on “Observed Water- and Light-Limitation Across Global Ecosystems” by François Jonard et al.

François Jonard et al.

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Reviewer #1 (Second review of Jonard et al., bg-2022-25)

I appreciate the efforts made by the authors to address my and the other reviewers' comments which have improved the paper. At the same time I believe that some of the revisions need to be refined and/or expanded before the paper can be published:

-- regarding main comment (1) from my previous review

I appreciate the additional analyses implemented by the authors to test the effect of the seasonal cycles on the results. Also, I agree with the new definition of the growing season as the time of year between peak and median NDVI. Building upon this I would suggest to perform the SIF-SM and SIF-PAR analyses also using a shorter growing season (as they do in the rebuttal) but to define this in a consistent way with the main analysis and to only change the NDVI threshold from median to e.g. 75%. This will more effectively remove seasonality than simply reducing the growing season length to 3 or 4 months. Moreover, a more quantitative assessment of the agreement of the resulting spatial patterns (through e.g. correlations between maps) in terms of the slopes and regimes is needed rather than concluding that they are similar (this is also valid for the results obtained with GOME-2 SIF as provided in Figure S4). Finally, these results also need to be added to the supplementary material to inform all readers.

Authors R1: We performed the analysis using a shorter growing season defined based on an NDVI threshold of 75%, as suggested by the reviewer. The results for the model type, model slope, and model threshold for both SIF-SM and SIF-PAR relationships using this new definition of the growing season are shown in Fig. R1 and R2 and are also added in the supplementary material (see Figs. S7 and 8).

As suggested by the reviewer, we also compared the regime classifications for both growing season definitions (NDVI threshold of 50 and 75%). As you can see in Fig. R3a and b, the majority of pixels (64% and 56%, respectively) have the same regime classification for both methods (green pixels). Looking at the SIF-SM relationship, as we move to shorter growing season, we increasingly get more detection of the zero-slope regime and less detection of the linear sloped regime. By constraining more and more to a part of the growing season, we detect the energy-limited regime more and more. This reduction of match of regimes between the growing season definitions is therefore more explained by constraint to energy-limited regime (a physical aspect we expect) rather than an artifactual one due to seasonality considerations.

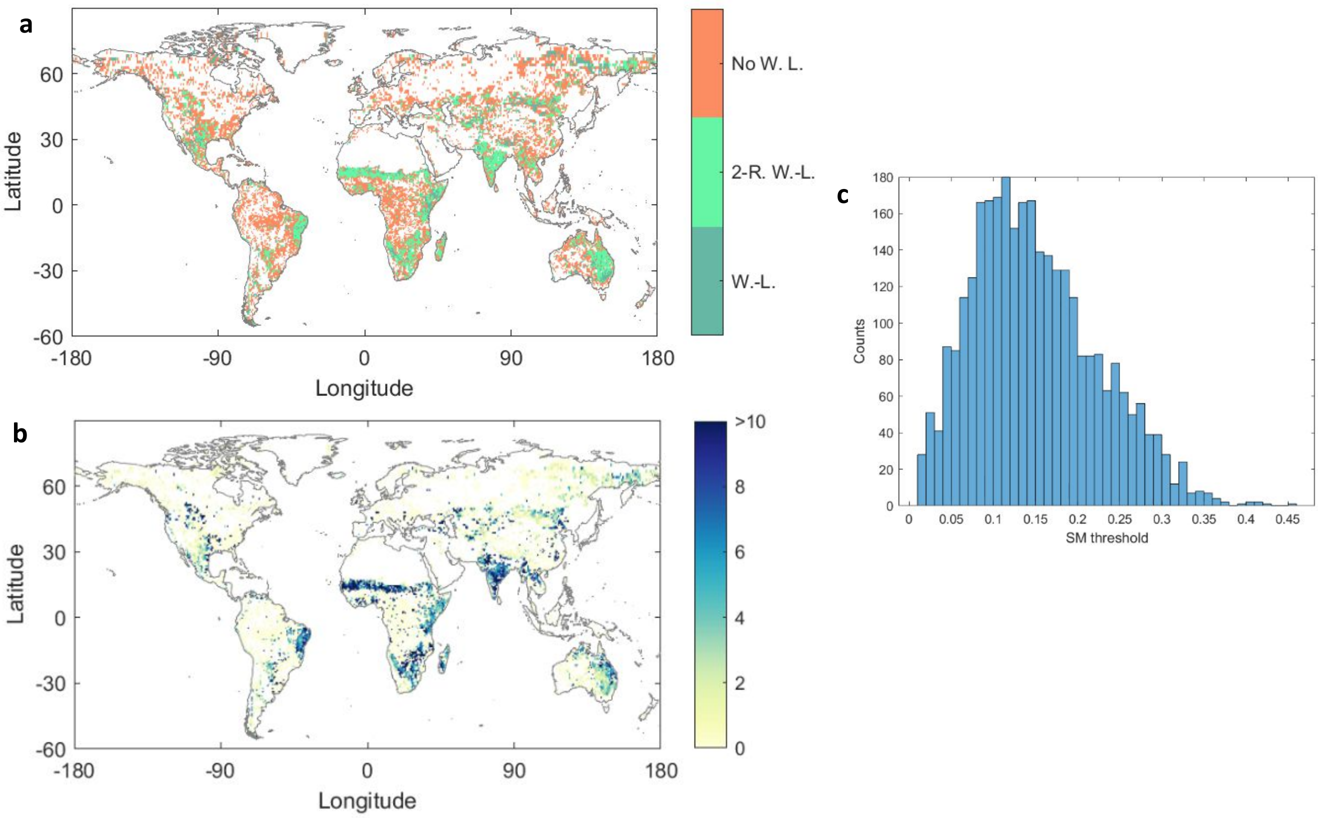

Fig R1. Estimated SIF-SM relationship features based on a shorter growing season defined using an NDVI threshold of 75%. (a) Model type, (b) model slope [mW m^{-2} nm^{-1} sr^{-1}] in the water-limited regime, and (c) model threshold [m^3 m^{-3}].

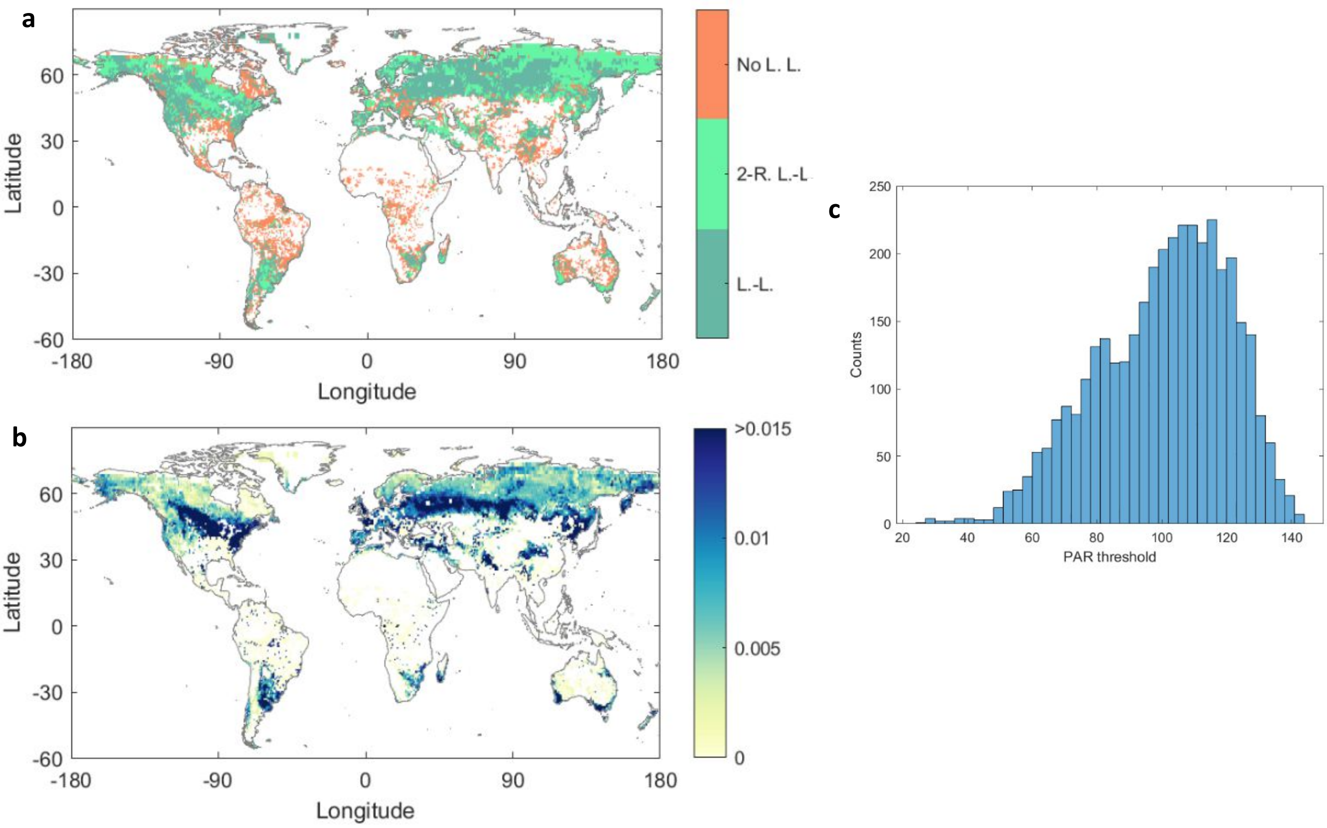

Fig R2. Estimated SIF-PAR relationship features based on a shorter growing season defined using an NDVI threshold of 75%. (a) Model type, (b) model slope [10^{-3} nm^{-1} sr^{-1}] in the light-limited regime and (c) model threshold [W m^{-2}] for the SIF-PAR relationship.

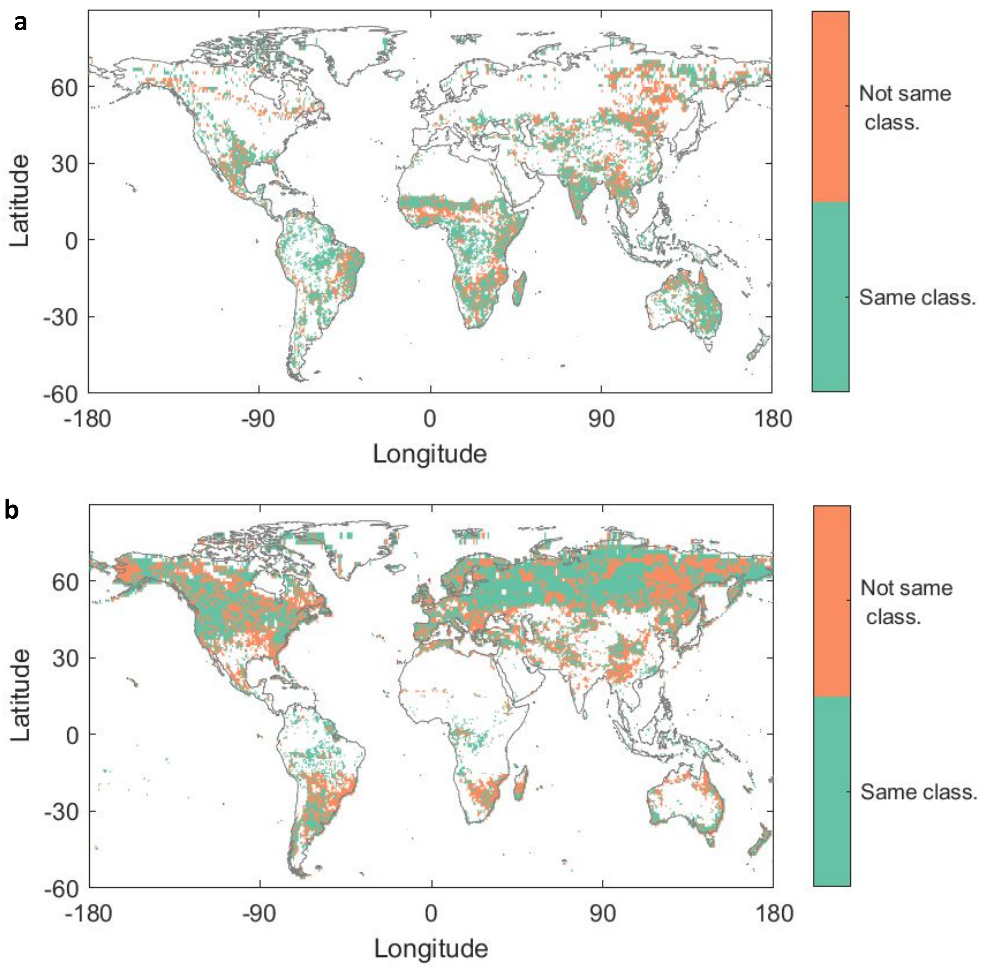

Fig R3. Comparison of model selection for the SIF-SM (top figure) and SIF-PAR (bottom figure) relationships considering two different growing season definitions, i.e., based on the 50th and 75th percentile of NDVI. Locations where the selected model is the same for both definitions are shown in green, while locations where the selected model is different are shown in orange.

-- regarding main comment (2) from my previous review

Also for this point I appreciate that the authors have taken mine and others' comments serious and have implemented several additional analysis which provide more insights into the limitations of their study.

However, I do not agree with the statement that R2 are "well above 0.5 in the regions where linear and two-regime models are found" in line 549. Furthermore, I would suggest to generally exclude grid cells from the analysis where linear or two-regime models are detected but the R2 is low, e.g. below 0.2.

Authors R2: We think that R^2 is not the best metric to screen pixels of the maps presented in Figs. 6 and 7 (see main manuscript). In particular, R^2 does not allow to assess the goodness of fit for a broken-linear (non linear) model. Instead, this is why we emphasize that the R2 and coefficient of variation metrics need to be considered together as shown in Fig. S6. Furthermore, we want to show all the information and not limit to an arbitrary R^2 threshold. We changed the sentence by (lines 560-572):

"However, R^2 is not appropriate for measuring the goodness of fit for nonlinear (here broken-linear) models. This is why the R^2 and the coefficient of variation (CV) of the model fit have been considered together as shown in Fig. S6. The R^2 values are higher in regions with high SIF sensitivity to SM or PAR (higher slopes in Figs. 6b and 7b). They tend to be lower in regions with more energy limitation (for SIF-SM), for example. This does not mean that the model fit is uncertain, but that the SIF-SM slopes are approaching zero as physically expected. The coefficient of variations being low corroborates acceptable model fit in these cases, such as in the Congo and Amazon Basins. However, low R^2 values can be observed in other regions that don't conform to this claim. For example, boreal regions tend to have lower R^2 values, which may be related to instrument and/or retrieval noise. Some of these locations may have additionally low R^2 due to the simplified form of our models. However, we expect a large influence of SIF retrieval noise considering that retrieval error variance tends to be higher in SIF retrievals than for satellite-based vegetation metrics or modeled leaf area index (Dechant et al., 2022). As such, R^2 values of 0.5 and 0.6 are relatively good fit given SIF retrieval noise that will limit higher R^2 values."

Dechant, B., Ryu, Y., Badgley, G., Köhler, P., Rascher, U., Migliavacca, M., Zhang, Y., Tagliabue, G., Guan, K., Rossini, M., Goulas, Y., Zeng, Y., Frankenberg, C., and Berry, J. A.: NIRVP: a robust structural proxy for sun-induced chlorophyll fluorescence and photosynthesis across scales, Remote Sens. Environ., 268, 112763, 10.1016/j.rse.2021.112763, 2022.

Regarding my suggestion to perform bootstrapping to determine the uncertainty of the regime and threshold classifications I would like to clarify that this should be performed *in time* rather than *in space* as the authors described it in the rebuttal. Anyway, I do not fully agree with the arguments of the authors for not performing the bootstrapping, but if they would like to avoid this I would suggest to tone down the statements on the regime and threshold identification in the manuscript where e.g. now in the abstract and conclusions exact numbers of the occurrence of two-regime behavior are given while in some grid cells another regime/model would probably fit almost equally well (which the bootstrapping would allow to test).

Authors R3: We performed the bootstrapping analysis on 100 pixels randomly selected from the pixels classified as a 2-regime model in Fig. 6(a) of the main manuscript. We randomly generated the locations of the selected pixels, which results in a distribution across the globe.

We added the following text in the results section (lines 574-580): "An uncertainty analysis using bootstrapping (1000 iterations) on 100 randomly selected pixels across the globe revealed that the mean bootstrapped standard deviation of the SM-SIF slope, SM-SIF thresholds, PAR-SIF slopes, and PAR-SIF thresholds are 5.2 mW m^{-2} nm^{-1} sr^{-1}, 0.02 m^3 m^{-3}, 0.004 10^{-3} nm^{-1} sr^{-1}, and 5.5 W m^{-2}, respectively. The SM-SIF regime selection was the same 76% of the time for the 2-regime model, but the PAR-SIF regime selection tended to be more uncertain (same selection 60% of the time). This may be because the functional form of the PAR-SIF relationship is less-well defined in many locations than the SM-SIF functional form. An example of pixel is shown in Fig. S9."

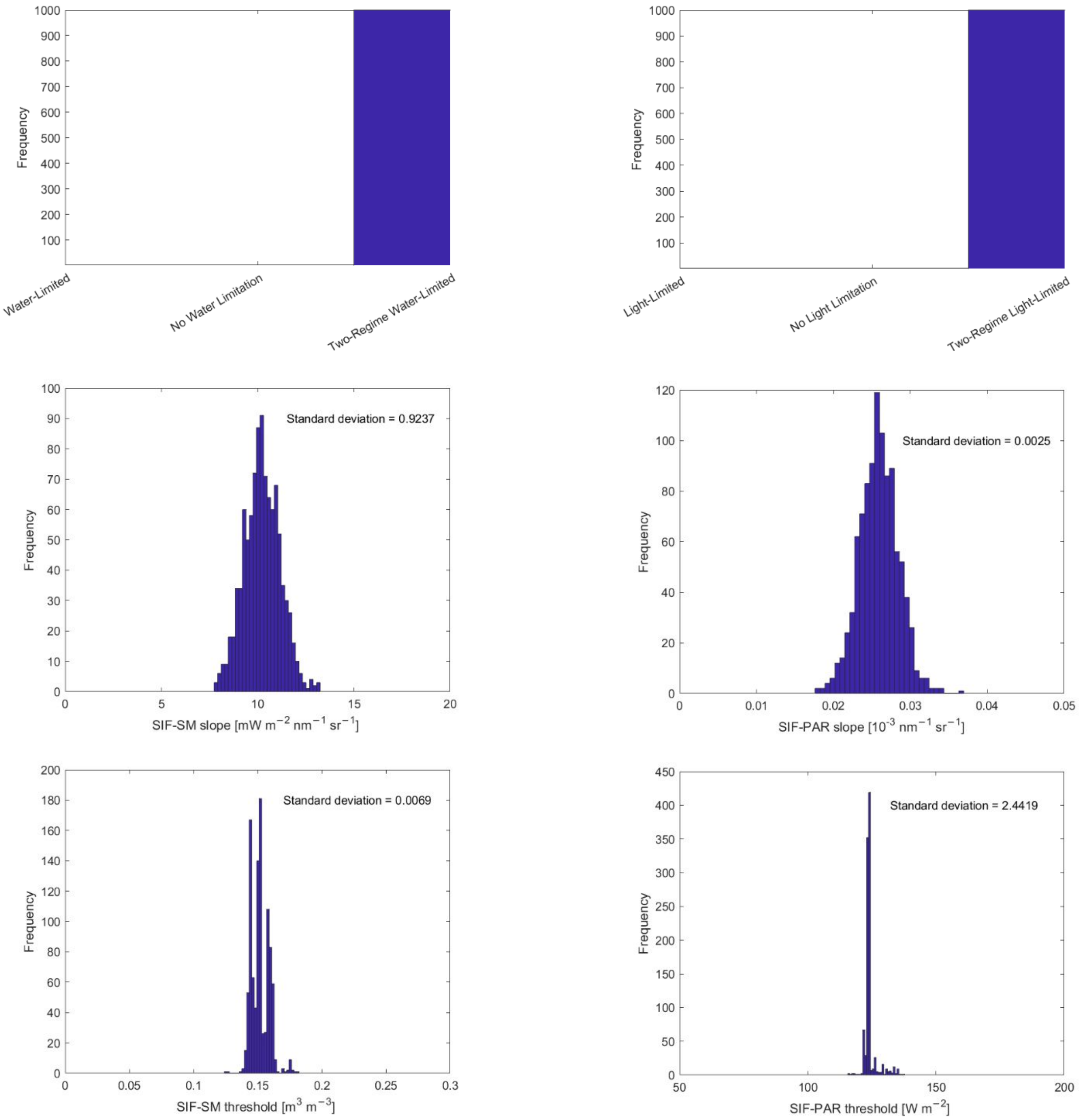

Fig R4. Uncertainty analysis of the model selection, model slope and model threshold using bootstrapping (1000 iterations) for two representative locations. Left column: pixel in the Central African Republic (latitude/longitude: 9.65°N/22.78°E) showing a two-regime water limitation. Right column: pixel in Argentina (latitude/longitude: 32.79°S/63.11°W) showing a two-regime light limitation.

Minor comments:

- line 43: It should be Li et al. 2021

Authors R4: This has been corrected.

- lines 303 and 563: BIC and AIC could be introduced a bit more by adding some information on the motivation of choosing them and their characteristics; for AIC not even the abbreviation is explained

Authors R5: We added the description of the AIC abbreviation in the revised version (line 592). We also added the following text to provide more information and motivation for choosing BIC (lines 309-314): "Specifically, BIC penalizes more complex models (i.e., two regime model here) that inherently increase the model fit to the data, but may not provide more predictability than less parametrized models. For example, the linear model has one additional parameter than the zero-slope model, which is the slope. In order for the linear model to be selected, the additional parameter of a non-zero slope must increase the model fit beyond the penalty of overfitting. Note that information criterion like BIC have been applied to similar model selection applications of water and energy limitation (Feldman et al., 2019; Schwingshackl et al., 2017)."

- line 596: sumary --> summary

Authors R6: This has been corrected.

- it would be helpful to have an overview table for all employed datasets to quickly access information on their native space-time resolutions

Authors R7: We have added the following table:

Variable	Source of data	Spatial resolution	Temporal resolution
Sun-induced chlorophyll fluorescence	Sentinel-5P satellite TROPOM instrument	7 x 3.5 km^2	daily
Soil moisture	SMAP satellite L-band radiometer instrument	36 x 36 km^2	3 days
Normalized Difference Vegetation Index	Terra satellite MODIS instrument	0.05°	16 days
Photosynthetically active radiation	MERRA-2 global reanalysis	0.5° x 0.625°	daily
Precipitation	GPM satellite constellation IMERG product	0.1° x 0.1°	Half-hourly

Table R1. List of datasets used in this study with their respective native spatial and temporal resolution. Note that the datasets were all linearly aggregated to a spatial resolution of 72 x 72 km^2 and 8-day periods.

- color bars in Figure S5b,d should be adapted to avoid the inclusion of negative values

Authors R8: This has been changed accordingly.

- Figure S6b (which is nice!) is not referred to in the text

Authors R9: A reference to the figure (called now Fig. S4b) has now been added (lines 425-426).

Reviewer #2

Jonard et al. presents an observational study to investigate the limitation of light and water on ecosystem photosynthesis across the globe. They consider three types of models to characterize the light and water limitation: water/light-limited, two-regime water/light-limited, and no water/light limitation. Since I received the revised version of manuscript, I found that the authors carefully considered all the comments by two reviewers and addressed most of their comments. They performed several additional analyses to support the robustness of their study, including deseasonalizing the data stream, considering different definitions of growing season, highlighting several sources of uncertainty, testing the difference of BIC and AIC method for model selection, replacing LAI by NDVI, assessing the model thresholds separately for different vegetation types etc. The current manuscript is largely improved compared to the original one. I only have some minor comments. Therefore, I suggest that it can be published in Biogeosciences after addressing the following points.

Authors: Thank you for your constructive comments on our study. We addressed them as described in the responses below.

Minor comments:

1) Figure R2: The spatial pattern of (a) is visually similar to that of Fig. 6 (b). May use a different colorbar for better comparison.

Authors R1: Now, a shorter growing season defined based on an NDVI threshold of 75% is used instead of a 3- or 4-month growing season, as suggested by Reviewer 1. We think that this would allow a better comparison with the Fig. 6 and Fig. 7 of the main manuscript.

2) Figure S4: The two-regime water-limited regions identified by GOME-2 were almost captured by TROPOMI, while TROPOMI identified much more widespread two-regime water-limited regions than GOME-2. As authors mentioned, the fewer data pairs, coarser spatial resolution, higher retrieval noise of GOME-2 SIF could partly account for it. How about other reasons that can also be discussed? I found most of these regions (two-regime by TROPOMI) were classified as no water limitation by GOME-2. Is this also related to the method that characterize different regimes? For example, it's not very clear how to define the 'zero-slope' model: should the slope strictly be zero? or how to distinguish 'zero-slope' model with a very small slope but linear model (water-limited). If I missed these texts, please point it out.

Authors R2: We have added more detailed text with regard to model selection and the specific example difference between selecting the linear model with a non-zero slope and the zero-slope model. See lines 310-314.

3) One other reason may be the difference in overpass time of TROPOMI and GOME-2. The overpass time of TROPOMI is around 1 pm local time while 10:30 am for GOME-2. The ecosystems usually have higher water stress at midday compared to the morning. Please see the highly asymmetrical diurnal cycle of GPP for some dryland sites (Fig. 3c in Qiu et al., 2020 and Fig. 8 in Li et al., 2021). Therefore, this could be another reason why GOME-2 detected less water-limited regions.

Qiu B, Ge J, Guo W, et al. Responses of Australian dryland vegetation to the 2019 heat wave at a subdaily scale. Geophysical Research Letters, 2020, 47(4): e2019GL086569.

Li X, Xiao J, Fisher J B, et al. ECOSTRESS estimates gross primary production with fine spatial resolution for different times of day from the International Space Station. Remote Sensing of Environment, 2021, 258: 112360.

Authors R3: Thank you for the comment and the interesting discussion on the impact of the different timing of observations between TROPOMI and GOME-2. We included the following sentence in the new version of the manuscript: "Another reason could also be related to the different timing of observations, with an overpass time near 13:30 local solar time for TROPOMI and near 9:30 for GOME-2. The higher water stress generally observed around noon compared to the morning could explain the lower detection of water-limited regime (Qiu et al., 2020)." See lines 541-544.

4) I understand the authors do not want to include combinatorial results from multiple SIF, SM, and PAR datasets. Considering that a) SM is one of your most important data; b) even using different SIF data could slightly to moderately change the results, I also agree with reviewer 1' suggestion and prefer to consider at least one more SM data. If do so, may not need to perform all the analyses by a new SM data or present combinatorial results, and I think only one key figure in supplementary material is enough (like Fig. 6b). But for this comment, I respect the authors' own decision.

Authors R4: We confirm that we don't think that the addition of more SM data sets is likely to add physical insight, it will lead towards more of a combinatorial data set comparison study, which is outside the scope of this study.

Lines 561-562: 'not a strong' and 'not greatly' still indicate that your results are (may moderately) affected by the different definition of growing season.

Authors R5: We agree, the different maps do not match perfectly but the general patterns are the same, which suggests a reduced impact of seasonality considerations on results. This has been added to the text (line 554).