Biogeosciences Discussions

Biogeosciences Discuss., author comment AC3
https://doi.org/10.5194/bg-2021-354-AC3, 2022

Reply on RC2

Mark Pickering et al.

Author comment on "Sun-induced fluorescence as a proxy for primary productivity across vegetation types and climates" by Mark Pickering et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-354-AC3, 2022

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> *Thank you for the important comments,and suggestions for improving the manuscript.*
> *Here we present the reviewer's comment in italics, and our response:*
> *Main comment – choice of the reference GPP dataset*
> *The authors have selected FLUXCOM GPP data (8-day & 0.0833º "Remote Sensing" runs) as a benchmark for the evaluation of SIF ability to indicate GPP. I can understand this choice, as the FLUXCOM dataset is well established in the community and has been tested in several projects over the last years.*
> *However, I also have strong concerns about whether the conclusions of the study would hold if a different remote sensing-based global dataset, or tower-based GPP data, were taken as a reference. For example, the values and variability of the SIF:GPP slopes discussed in Section 3 would surely be different if global GPP estimates from e.g. the FLUXSAT https://daac.ornl.gov/VEGETATION/guides/FluxSat_GPP_FPAR.html or the https://data.nal.usda.gov/dataset/global-moderate-resolution-dataset-gross-primary-production-vegetation-2000%E2%80%932016 VPM products had been used as a reference, even if those two GPP products are also based on remote sensing data. Also, recent papers comparing TROPOMI SIF retrievals with tower-based GPP conclude that most of the vegetation types in North America can be grouped in 2-3 statistically-independent SIF:GPP linear models (see Li & Xiao https://doi.org/10.1016/j.rse.2021.112748 and Turner et al. https://doi.org/10.5194/bg-18-6579-2021), as opposed to the 12 independent groups proposed in this study.*
> *It would be great if the authors could provide further evidence of the robustness of their findings by comparing to additional GPP data sets, these being global remote sensing-based, tower-based, or both. For example, the global FLUXSAT GPP data set is provided at 0.05º and a daily time set, so it should not be too difficult to include it in this analysis. Showing that e.g. Table 1 roughly holds for other reference GPP data set are used would be an important proof of consistency for the study.*

Whilst there are many different global GPP products (in addition to many different SIF products), we decided that doing many comparisons of these different datasets was beyond the scope of the paper. The main focus of the paper is to analyse downscaled SIF and thus FLUXCOM is chosen as the comparison GPP dataset as it represents the current state of the art in global GPP: it is a well-known and established reference within the biogeoscience community. Just to note, we will add the reference to the FLUXSAT GPP paper: https://doi.org/10.1016/j.agrformet.2020.108092 in the second paragraph of the introduction in the revised version.

Early on, we did have a look at including fluxnet towers in the analysis, and added the SIF-GPP distribution of fluxnet towers passing certain quality criteria (in order to allow for comparison with our KG-PFT breakdown) to figure 5. Unfortunately, there are simply not enough high quality and comparable globally distributed fluxnet towers over the different vegetation covers to make the analysis worthwhile, though it did serve as a sanity check for the data. We would be happy to provide this figure if it is considered interesting for the reviewers (only a few KG-PFT categories contain data points), but we do not believe it would be a valuable addition to the paper.

Regarding papers grouping the SIF-GPP relationships into a smaller number of categories, I would argue we actually demonstrate a similar thing. We start with 6 different vegetation covers (treating the 4 different climate zones separately) and we argue that these vegetation covers can be reduced to just 2-3 statistically independent linear models in each climate zone. Indeed, in the conclusions, we state that (with noted exceptions) the different species SIF-GPP scaling response (gradient) is similar, but with a distinction in the systematic potential (intercept) between woody/herbaceous:

L567 'For the most part, the gradient of the spatial SIFDS-GPPFX response is similar between differing vegetation types, with the exceptions of temperate deciduous broadleaf forests, continental needleleaf forests and, particularly, equatorial broadleaf forests. However, the GPPFX systematic potential for a given SIFDS observation displays more variation between species, with some divergence between woody and non-woody plants.'
Similarly in the abstract:
L15 'an analysis of covariance (ANCOVA) shows that the spatial response is similar between certain plant traits, with some distinction between herbaceous and woody vegetation, and notable exceptions, such as equatorial broadleaf forests, and continental needleleaf forests.'
See also the conclusions of the ANCOVA results section (the text of which is copied and edited later on in this comment).

The main consideration in our analysis is whether the SIF-GPP relationships hold for different vegetation types in similar conditions, and not whether the different climate groupings should also be reduced. Therefore we don't technically propose 12 groups, we are simply comparing within climate groupings to reflect a study that controls better for climate variation, and propose 2-3 groups within each climate zone. Comparing in similar climate zones reduces the biases/variabiltiy introduced by differences in distribution and climatic conditions by comparing within similar zones. Therefore in reality we consider 6 vegetation covers and combine them into GRA/CRO and woody trees, but we identify in each climate a few exceptions such as EBF (in equatorial climates), DBF (in temperate climates) and in continental climates the woody species behave quite differently to each other depending on what metric and cutoff we use (there is no statistically hard cutoff for these groupings unfortunately). We try to explore the behaviour of these exceptions further in the text. It is important to note that not all vegetation covers exist in sufficient numbers in each climate for a full analysis in each climate (and so combining climate would introduce a bias in our conclusions here). Our choice is trying to separate (as best we can) the effects of distribution and climate on the combination of vegetation covers, as opposed to a global comparison of vegetation cover (which would incorporate, say, tropical and temperate evergreen forests into one unit - which we see from their behaviour in our results would be quite unjustifiable). Section 5.3 contains more details about the nuances and the fact that it is difficult to statistically distinguish groupings - which we think the wider literature supports.

It is also important to note that there is evidence that some vegetation covers can be divided further, for example differences in C3:C4 response https://doi.org/10.1029/2020GL087474 so distinguishing groupings might have a dependence on the scale of the analysis. For example, looking at a global scale there might be so much variation within a vegetation cover that it is difficult to distinguish their relationships, whilst at a scale that controls for this variation, e.g. canopy level, more patterns may emerge.

To make the similarities between vegetation covers clearer, and to emphasise that we are looking within climate zones only, we propose rewording the final paragraph of the ANCOVA section so that instead of listing the individual groupings, we just say herbaceous and woody in each climate zone, with the exception of Eq-EBF, Continental broadleaf, etc, for example rewording line 377+ (with underline denoting changes):

Overall, the ANCOVA analysis suggests that there is a large similarity in the scaling of the SIFDS-GPPFX response (i.e. the slope) between vegetation covers, with the major exceptions of temperate deciduous broadleaf forests, continental needleaf forests, and, particularly, tropical evergreen forests. In terms of the scaling of the SIFDS-GPPFX slope, these three vegetation covers may be treated as being reasonably distinct, with at least around 5% and up to 20% of the difference between slopes being attributable to the vegetation classification. Amongst the other species where the slope does not distinguish between veg etation covers so prominently (with generally less than 3% of the slope variation attributable to the vegetation categorisation), the intercept, and therefore the systemic difference between the linear relationships, loosely depends on whether the species is woody or herbaceous, with higher values for woody species. The difference in the SIFDS-GPPFX response between cropland and grassland is particularly minor. A caveat must be made that there are some exceptions to these generalisations, and there is no statistically concrete global distinction between groupings of vegetation covers.
These results offer loose quantitative support for the larger trends observed in figure 5, and demonstrate that whilst there are broad similarities in the SIFDS-GPPFX response between different vegetation types, there are still distinctions that can be made based on the background climate conditions. A loose, possible grouping of vegetation covers may be suggested within the climate zones, whereby equatorial regions feature: herbaceous (CRO+GRA), EBF and DBF groups; arid regions feature: herbaceous and woody (DBF+ENF) groups; temperate regions feature: herbaceous, woody (ENF+EBF) and DBF groups; and continental regions feature: herbaceous, DBF, ENF, DNF groups. This reduces the climate-vegetation categories for which we expect differing SIFDS-GPPFX responses from 18 groups to 12 overall.
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Overall, **when analysing the the scaling of the SIFDS-GPPFX response (i.e. the slope) between vegetation covers within a climate zone, the ANCOVA analysis suggests that there are large similarities, with three** major exceptions of temperate deciduous broadleaf forests, continental needleaf forests, and, particularly, tropical evergreen forests. In terms of the scaling of the SIFDS-GPPFX slope, these three vegetation covers may be treated as being reasonably distinct from others within that climate zone, with at least around 5% and up to 20% of the difference between the slopes being attributable to the vegetation classification. Amongst the other species where the slope does not distinguish between vegetation covers so prominently (with generally less than 3% of the slope variation attributable to the vegetation categorisation), the intercept, and therefore the systemic difference between the linear relationships, loosely depends on whether the species is woody or herbaceous, with higher values for woody species. The difference in the SIFDS-GPPFX response between cropland and grassland is particularly

minor. A caveat must be made that there are some exceptions to these generalisations, and there is no statistically concrete global distinction between groupings of vegetation covers across all climate zones.
The results demonstrate that within a climate grouping there are broad similarities in the SIF-GPP response of the considered vegetation classifications, excluding three key exceptions. When accounting for differences in the intercept, a loose possible grouping may be suggested of herbaceous and woody vegetation within each climate zones, with the exceptions of equatorial-EBF, temperate DBF, and continental forests (which can be fully distinguished when the difference in the intercept is considered, or split between broadleaf and needleleaf if considering only the scaling). This reduces the climate-vegetation categories for which we expect differing SIFDS-GPPFX responses from 18 groups to 12 overall, **with around three distinct groups in each climate zone, depending on the aggressiveness of the grouping**.

We will additionally add the following lines and references in the 5.3 discussion
L543: 'The universality of the SIF-GPP relationship with respect to vegetation groupings is in area of active debate'.
(Adding the references:
https://www.sciencedirect.com/science/article/pii/S0034425721004685?via%3Dih as an extra reference about the difference between C3/C4 crops SIF-GPP relationship - and showing that there may be cases with more difference within PFTs than between them.
And https://bg.copernicus.org/articles/18/6579/2021/bg-18-6579-2021.html that others find two classes of vegetation)

L546 Indeed it may be the case that there are more differences within certain vegetation covers, than between vegetation covers, and this effect may depend on the scale of the analysis.'

L547 It is important to note however, that vegetation cover in the analysis may partially be a proxy for other factors or regional variables, such as background climate conditions and soil properties \citep{https://www.pnas.org/doi/full/10.1073/pnas.1216065111 a reference to support that some of the variation that cannot be explained by weather or plant function might be related to ecosystem dynamics (this is part of the reason we compare across climate zones)}

Additionally, In answer to a separate question, we reproduced figure 6 to show the difference between FLUXCOM GPP and GPP estimated from the SIF scaling based on vegetation covers, without including climate zones. Whilst we don't go too deep into the specifics (for example re-running the ANCOVA in the absence of climate zones), the fit is noticeably poorer, which suggests that there is some value in distinguishing between different climates. Please see the discussion in response to this request