

Dear Dr. Stoy and Reviewer,

Thank you for the valuable suggestions made during this final stage of our publication process of the manuscript “Unveiling spatial and temporal heterogeneity of a tropical forest canopy using high-resolution NIRv, FCVI, and NIRvrad from UAS observations” for publication in *Biogeosciences*. We appreciate your time and effort and appreciate the improvements suggested for our paper. We have incorporated changes and highlighted those within the manuscript. We also appreciate your patience while we made these changes and for your understanding related to the timeline imposed by me new agency, Naval Research Laboratory, which requires a stringent internal approval process for publishing by its scientists. Please see below for a point-by-point response to the most recent reviewer’s comments.

Please accept our sincerest thanks.

On behalf of all authors,

Trina Merrick

Reviewer comments:

As stated in my previous review, Merrick and coauthors present a novel dataset of remotely sensed vegetation indices (VIs) (NDVI, EVI, NIRv, NIRvrad, FCVI) from an UAS in a tropical forest canopy in Panama. They explore both spatial and temporal variability between indices and highlight potential uses for these indices at those varying scales. Specifically, the authors explore temporal correlations between GPP and VIs over the course of a day, diurnal changes in the spatial variation between VIs, and dominant spatial scales for variability in VI signals.

I continue to be in support of the acceptance and publication of this manuscript and am generally happy with the authors response. However, I have a few more minor comments I feel should be addressed prior to publication. They are outlined as follows:

Lines 24-25: the sentence will be more clear if rephrase it to say “.... these indices and the properties that are presumed to be measured by these indices, such as gross primary productivity (GPP) and absorbed photosynthetically active radiation (APAR).”

Thank you for the suggestion. The wording has been changed.

Line 25: 15cm and greater should just provide the maximum spatial size

Thank you for pointing out this ambiguity. This adjustment has been made.

Line 27: ‘emerging vegetation indicators’ is unclear and not specific enough – better to name them which will also help with the papers longevity when the indicators are no longer

'emerging'. This appears a few other times and I tried to catch all of them but worth doing a read through to double check.

Line 34: same comment as line 27

We have replaced the “emerging indicators” with the names “NIRv, FCVI, and NIRvrad”.

Line 38: the 'are' in 'are not well characterized' refers to 'spatial and temporal heterogeneity' so I believe it should be 'is not well characterized'

We have corrected the grammatical error in this sentence.

Line 40: change to 'forests'

We have changed from “tropical forests” to forests in this instance as you kindly suggest.

Lines 59-64: This section might be clearer to read if you just replace the wording with equations then defining the acronyms

We have replaced this section with appropriate equations.

Line 70: Here you could probably replace 'tropical regions' with a statement about evergreen regions as a whole since the statement still applies and it's a little broader. Keeping it as is also works.

We replaced tropical with evergreen because, as you suggest, this better highlights broader applicability of the work.

Line 79: SIF has not yet been defined – can remove it from this portion entirely or add a separate sentence describing what SIF is (although I think it would be better without)

Thank you for pointing out this oversight. This reference to SIF has now been removed.

Lines 83-86: This sentence is too long and convoluted. Break it up.

We have now changed this one sentence to three shorter sentences.

Line 89: change to 'demonstrated that FCVI tracked GPP...' so you keep the subject and the verb close together – it makes the sentence more straightforward

Thank you for this suggestion. We have rearranged this sentence for clarity.

Lines 96-98: This sentence is also fairly long and convoluted. Consider replacing with an equation then a description or breaking up the sentence.

In this case, we reworded this and the previous sentence to clarify and shorten the sentences.

Line 145: It's unclear what the 'data corresponding to the January 30 flights' is referring to. I think there might be a typo in here.

Thank you, there was a typing error in the sentence that has now been corrected.

Line 156-157: 'A summary of materials...' should go earlier in the section or can be removed entirely

We have removed this statement about the summary of materials.

Line 173: You previously say the GPP data was Jan 30 (Line 145) so one of these must be wrong

Thank you for pointing out the inconsistency. We have now corrected the data collection dates for all data to be on Jan 30 and 31, 2019, except for the EC GPP data, which was only on Jan 31, 2019.

Line 173: I think it would help to reference the figures or sections where these different analysis are done immediately following the statement of what's being done. It will help provide the reader a roadmap to the different sections of analysis.

We have added a sentence for each section and figure for results (Lines 210, 213, 221).

Line 204: 'a joint relationship between...' is vague. Either be more specific or remove this.

We have reworded this sentence to be more specific in our meaning.

Line 216: I'm not so sure about the statement 'NIRvrad is also a more efficient measurement of GPP...' Do the authors mean to say it's more efficient than PAR? I would disagree since here it depends on the scale and the instrumentation used to take the measurements, AND the authors show a stronger agreement between GPP-PAR and NIRvrad-PAR than NIRvrad-GPP. I think the point that NIRvrad tracks APAR should be made more strongly, rather than trying to pitch NIRvrad as an alternative to PAR or APAR measurements.

We have taken this valuable suggestion and rewritten much of (new) lines 252-259 to clarify the points made. We now say "The ability of NIRvrad to track APAR is notable alone. However, our evidence – albeit based on only one day of data – supports the proposed use of NIRvrad as a proxy for changes in GPP on short timescales. In future work, it may also be consequential that NIRvrad is a more practical measurement of GPP than SIF in the sense that a separate instrument to measure PAR is not needed (Wu et al., 2020; Zeng et al., 2019). Also consequential for future work, given that the relationship between NIRvrad and GPP depends on PAR, it is unclear if the association between NIRvrad and GPP would weaken during the wet season when low light or diffuse light conditions are more common (Berry and Goldsmith, 2020)."

Figure 2: The smoothing line is not defined. Please define it in the figure caption.

We added language to the caption defining the smoothing.

Lines 237-238: It might be easier to see the comparison between the two if they are located next to each other in the figure. You could easily switch the locations of NIRv and FCVI since those are also compared with each other.

The reviewer makes a very good point in this suggestion. We changed the figure to realign the distributions in one column each and assigned colors and labels to more easily facilitate comparison. However, the order the plots are presented matches the order in which NIRv, FCVI and NIRvrad were published in the literature and are thus presented in this paper. Respectfully, we feel that keeping the order consistent may prove helpful overall and prevent confusion, but hope our other changes make comparison easier for the reader.

Line 245 (and the following paragraph and Figure 3): stay consistent with time notation. This line starts with 12:00 and 1330 but would be more clear if the time descriptions in the paragraph and figure are all notated the same.

Thank you for pointing out the inconsistency in the time notation. The colon has been removed from times in (new) lines 293 – 295.

Line 248: Is CV defined somewhere? Might need to be defined again or made more clear what this is referring to.

We added the coefficient of variation (CV) explicitly in (new) line 272 as a reminder of the acronym.

Figure 3: I think it would help to have the colors of the distributions be the same for flights at the same time but different days. For example the 15:30 flight times on Jan 30 and 31 could be colored the same to make comparison between the two easier. Further, I think it would help if the times were vertically aligned between days.

Thank you for this valuable suggestion. We changed the figure to reflect these suggestions. Specifically, we realigned the distributions by time (earliest at the top to latest at the bottom), overplotted the times where data were taken at the same time, and re-assigned colors such that day and time matches are more obvious, and color coded labels for each distribution to indicate the day and time.

Line 296: same comment as above about 'emerging vegetation indicators'

We replaced this phrase with "NIRv, FCVI, and NIRvrad".

Line 308: 'which have high reflectance in blue wavelengths compared to fully leaved crowns' deserves a citation

We have added a citation to support this statement (new line 397, Bibliography line 513).

Line 318: remove the statement 'and the scattering of SIF photons'. Since most of this was removed from the results/discussion it seems distracting as the first sentence in the conclusions.

This portion has been removed and we appreciate you catching this oversight.

Line 322-323: remove 'which SIF requires' – I think the framing is better as a 'these can help inform SIF and each other' rather than pitting different RS indices against each other.

Also since you're not presenting SIF data you can't make the argument NIRvrad is a more effective proxy.

Thank you for this suggestion. That phrase has been removed and your suggested framing, 'these can help inform SIF and each other', was used to modify (new) lines 394-396 to strengthen the conclusions.

Line 325: 'which may pave the way to improve our understanding of the relationship between GPP and remote sensing observations' – add a small clarification on HOW it will do this, be more specific.

We added a sentence in (new) lines 377-379 to say, "For instance, by benchmarking changes of vegetation function and structure that underlie a GPP measurement representing the whole EC footprint, fine scale NIRv, FCVI, or NIRvrad measurements may reveal highly differential behaviors of tropical species diurnally to seasonally."