Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2020-41-AC1, 2020

Biogeosciences Discussions
Open Access

Interactive comment on "Decomposing reflectance spectra to track gross primary production in a subalpine evergreen forest" *by* Rui Cheng et al.

Rui Cheng et al.

rui.cheng@caltech.edu

Received and published: 13 April 2020

Printer-friendly version

Discussion paper

Detailed response to referee 1's comments and suggestions

April 13, 2020

General comments: The manuscript "Decomposing reflectance spectra to track gross primary production in a subalpine evergreen forest" aims to investigate the link between seasonal changes in the canopy reflectance (400-900 nm) of a boreal forest and the GPP changes, measured from flux tower measurements. To do so, the authors apply a technique for decomposing the reflectance into independent components (ICA) and derive a PLSR-based factor for explaining the link with the parameter "LUEs/GPPmax".

We thank you for reviewing our work. Please find a point-by-point response below. All the changes will be reflected in the revised draft.

Although the manuscript contains several interesting elements, a clear hypothesis is missing (including novel research questions) and several definitions and underlying mechanisms should be better explained.

Thank you for pointing out the lack of clarity in our hypothesis. We will make sure to clarify our hypothesis in the revised draft. In short, we hypothesized that measuring

Printer-friendly version

Discussion paper

hyperspectral reflectance at the canopy level is able to track the Light Use Efficiency (LUE) at a sub-alpine evergreen forest. For this, we used reflectance as a proxy for the contents of photosynthetic/photoprotective pigments, which was then linked to the photosynthetic LUE.

The first novelty in our study is we continuously measured hyperspectral reflectance at the canopy level. In previous studies, canopy level reflectance was either only simulated with radiative models or observed sparsely and mostly performed at discrete broad spectral bands. Coincident with our year-long reflectance measurements, pigments were sampled across the canopy so that we could track the onset and cessation of photosynthesis, and seek to provide a direct link between changes in canopy reflectance and pigment contents at the canopy scale.

The second novelty is a comprehensive scheme to link the seasonality of photosynthesis at the canopy scale to photoprotective pigments. This exploratory scheme includes empirical methods as well as process-based analysis. Previous studies have used one of the two methods. However, the availability of reflectance observation, pigment samples, and flux measurements allowed us to test our hypothesis both empirically and physically.

Additionally, the PhotoSpec system we used also measures Solar-Induced Fluorescence (SIF), which was shown to track the seasonality of photosynthetic LUE from previous studies. Thus, we included the SIF analysis to our work in order to highlight the different de-excitation pathways of excited chlorophylls by photoprotective pigments and SIF.

For example, the authors are interested in the red-edge region where the chlorophylls absorb but don't present a clear strategy for detecting chlorophyll pigment changes (although they are later retrieved by inversion).

Thank you for asking this question. We will add the measurement of chlorophyll content in the revised section 2.4. We measured the chlorophyll content along with xanthophyll

Printer-friendly version

Discussion paper

content and carotenoid content. The chlorophyll content was used in the calculation of the car/chl ratio and the comparison against the PROSAIL inversion results. In fact, there are changes around the red edge but the absence of clear changes in the peak Chl absorption regions points to small Chl changes throughout the season. However, these changes around the red edge could be related to Chl-a and Chl-b or structural changes.

It is well known that the Car/Chl ratio is the main driver of photosynthetic behaviour on a seasonal scale (L59-61), i.e. altering the ratio between energy dissipation and energy harvesting. Hence, on a seasonal scale the spectral variability would be expected to occur in the pigment absorption regions of those pigments. The authors should highlight which information can be potentially provided by their technique and how it improves (?) the tracking of GPP compared to the standardly used methods (e.g. VIs).

Our empirical methods showed and agreed on the spectral features in the reflectance were attributed to the pigments which are responsible for the photosynthetic seasonality, which was further validated by the process-based analysis using PROSAIL inversion. We will further highlight the link among car/chl, spectral features in the reflectance, and LUE in our revised manuscript.

Although we showed the performance of our empirical methods and well-established Vegetation Indices (VIs), our goal was not to achieve a higher correlation coefficient from our method than the VIs. Instead, our work focuses on mechanistically explaining where, when, and why certain wavelength regions are sensitive to the canopy LUE, which validated the high/low correlation coefficients from the VIs.

Further, the authors aim to evaluate the pigment driven spectral changes (where, when and why). In this regard the authors could further highlight the seasonal dynamics of the detected components in respect to the spring recovery in boreal forests. Does it provide more info compared to the VI dynamics?

Thanks again for pointing out our unclear discussion on comparing our methods with VIs. We will strengthen our discussion in the revision. In section 3.5 comparison across methods, what we really wanted to highlight is the difference between the reflectance change driven by the pigments and SIF. Since the spectral shape and CCI (the representatives of other VIs) both related to the chl:car ratio, the same behavior from the spectral change and CCI are, in fact, expected in Figure 9. Interestingly, the PLSR and ICA decompositions didn't significantly improve (or provide more info) to the ability of existing VIs. This is important because it validates the idea that 'more simple' approaches might be sufficient for tracking the seasonality in evergreen systems.

Finally, there are several jumps in the storyline, use of unclear terminology/method descriptions (L141-143, L190-194) and missing parameters definitions (L187). The presentation of the results is sometimes fragmented (L183-185) or not clear from the graphs (L217-L218, GPPmax is not shown). All these aspects need to be thoroughly reviewed before acceptance of the manuscript.

Thank you for the comment. In the revision, we will correct the definitions, keep the consistency of terminology, and make sure the plots are explanatory to the text.

Specific comments From L43-48 it could be misunderstood that LUE of decidious forests is not affected by biotic factors, while LUE changes due to e.g. pigment composition occur in combination with structural changes, which in fact you can also term a "biotic" factor. The term "biotic" refers to higher-level ecosystem interactions and is less appropriate in the LUE-photosynthesis terminology here. Please rephrase.

Thanks for this comment. We will rephrase carefully in the revised manuscript. We will refer to changes in pigment compositions as 'needle biochemistry.'

What is the link with the “differentiation in NPQ pathways” and SIF, which are suddenly mentioned at L75. Is this relevant for seasonal patterns/this manuscript?

We will add transitional introductions to the revised manuscript and explain the necessity of the comparison of SIF and reflectance spectra. SIF has been shown to track the photosynthetic seasonality in previous studies. However, SIF and the spectral change in reflectance represent different de-excitation pathways of excited chlorophyll. PhotoSpec measures both hyperspectral reflectance and SIF, which enables us to compare the seasonality captured by these pathways.

L77: you are comparing fluorescence radiance with reflectance, which varies strongly in the 400-900 region and is moreover a ratio, not a radiance to compare SIF with.

In the analysis, we used relative SIF, which is SIF normalized by the reflected near-infrared radiation. In the revision, we will rephrase the paragraph and introduce the relative SIF in this section. Relative SIF is used to account for sunlit/shaded fraction within our observation FOV, since it provides an indicator of how ‘bright’ the area of interest is.

L215-216: why would low PAR not drive photosynthesis? Please reformulate this sentence, pointing to the controlling factors in winter/spring.

Thanks. The original sentence was trying to inform the readers that GPP was near zero in winter, although the PAR level in winter. This matches with the strong seasonality of our LUE measurement, GPPmax. And figure S3 shows that instead of PAR, Tair is one of the controlling factors in winter. We will rephrase it in the revision to make it clearer.

L78-81: The mechanisms are not clearly explained here. What about the seasonal radiance budget, i.e. the "abiotic" factors?

Thank you for pointing out the missing part of SIF. In the revised draft, we will elaborate on the explanation of SIF mechanisms and introduce relative SIF. While there is still enough light to drive photochemistry in winter, frozen soils and boles limit water transport as needles must dissipate excess energy as heat. The primary mechanism for increased NPQ is through sustained energy dissipation by photoprotective pigments which co-varies seasonally with SIF (Magney et al., 2019).

Methodology After filtering the data based on light conditions and snow, how many winter days actually remain? Please mention the amount of samples, for both winter and growing season, also in Fig. 1.

We have 96 days of spectral samples between DOY 100-300 and 115 days of spectral samples in the rest of 165 “winter” days.

In the pigment analysis, we have 6 days of both spectral and pigment samples between DOY 100-300 and 4 days in the rest of 165 “winter” days.

In figure 1, there are 39 days in the growing season and 113 days in the dormancy.

We will include these statistics in the revision.

Relative SIF: please elaborate on how the normalization is done (raw data, wavelength range). Since you argued in the introduction that the structural changes are less an issue for coniferous forest, what is the true (or expected) impact of this normalization for SIF? What is the difference with not normalizing? Did you quantify this?

Relative SIF was SIF normalized by the reflected near-infrared radiance at 755nm. This normalization will make SIF more comparable to a ‘SIF yield’, as it is a ratio effectively correcting for incoming irradiance, and sunlit/shaded fraction (see above). The attached fig.1 is similar as we did in Figure 5d but with SIF and relative SIF. The seasonal cycles of relative SIF and SIF are well correlated. Relative SIF is more cor-

Printer-friendly version

Discussion paper

related with the GPPmax in seasonal variations. However, the sub-seasonal change in the growing season is captured more by relative SIF.

LUElightL/LUEtotal: these are supposingly daily values? How APAR was defined/calculated based on the raw data and show a plot of the methodology described in L160. Moreover these parameters are not clearly presented later on and Fig.2 does not give a sufficient visual on the calculation/importance of these parameters. Are they relevant for the story?

GPPmax, LUElightL, and LUEtotal are light use efficiencies (LUE) at different abiotic status: 1) GPPmax: light-saturated LUE; 2) LUElightL: light-limited LUE; 3) LUEtotal: mean status LUE. They are all calculated as daily values. To make the discussion concise and clear in the revised draft, we will only show the results of GPPmax to represent LUE in the main text as it is more representative than LUElightL and more physiology-driven than LUEtotal. We will make sure the terminology of using LUE and GPPmax is consistent through the draft. We will also add sections on how APAR, LUElightL, and LUEtotal were calculated in the appendix with visualized explanations.

APAR was calculated from seven pairs of PAR sensors installed. One pair of sensors was installed above on the same tower where PhotoSpec is located (measuring incoming PAR and reflected PAR). The other six pairs of sensors were installed below the canopy (measuring reflected and transmitted par). The derivation of APAR is shown in the attached fig.2.

The attached fig.3 is a demonstration of how LUElightL and LUEtotal were calculated. Given a day (DOY =278 as an example), we selected the GPP measurements when the PAR level is between 100-500 μmol m^{-2} s^{-1}. Then, we did a linear regression of those GPP measurements with their APAR levels (the cyan dots and dashed line). The slope of this regression is LUElightL. On the same day, all the GPP measurements that happened when the PAR level is above 100 μmol m^{-2} s^{-1} are the orange crosses in

Printer-friendly version

Discussion paper

the plot. We calculate the ratio of GPP and APAR of those orange points, and the daily mean of the ratio is the LUEtotal.

L155: It is claimed that PAR levels between 1000 and 1500 μmol m^{-2} s^{-1} are reached throughout the whole year, but that is not what is seen from Fig. 3, showing PAR values hardly exceeding 1000 μmol m^{-2} s^{-1}. LUEs: this parameter suddenly appears at L187, without any previous definition! Also, what does the reader need to understand from the LUEs/GPPmax parameter? Please, elaborate the choice of this parameter and how it should be interpreted in terms of vegetation dynamics.

In figure 3, PAR is low because it was calculated as the daily averaged PAR of above 100 μmol m^{-2} s^{-1}. In the calculations of GPPmax, LUElightL, and LUEtotal, PAR and APAR are half-hourly data.

Thank you for catching this error. LUEs referred to LUElightL and LUEtotal in the discussion paper. And LUEs/GPPmax refers to GPP and LUEs. GPPmax, LUElightL, and LUEtotal are light use efficiencies (LUE) at different light regimes: 1) GPPmax: light-saturated LUE; 2) LUElightL: light-limited LUE; 3) LUEtotal: mean status LUE. We did all the analysis with these three parameters. The results were quite similar in terms of the seasonal cycle. As we explained in section 3.1 L220-225, GPPmax is a better proxy for LUE as it is more representative than LUElightL and physiology-driven than LUEtotal. Thus, we decided to only keep GPPmax in the main text. In the revision, we will make sure to use GPPmax consistently.

Pigment contents: is there a reason why Chlorophyll content is lacking? This does not follow the line of the objectives.

We didn't show chlorophyll content in figure 7 because Bowling et al (2018) and Magney et al (2019) have shown chlorophyll content didn't vary with the season in our study site. However, we agree with your suggestion that it is important to include it to comprehensively discuss the importance of car and chl:car ratio to the seasonality of photosynthesis. We will redo the plot and add the discussion in the revision.

L190: rephrase this sentence for a better understanding of the final aim. The resulting coefficient is given somewhere or expected later in the results? Which four PLSR components are you referring to?

Four PLSR components we mentioned are the parameters used when we trained the PLSR algorithms. We will rephrase the paragraph to explicitly describe the PLSR coefficient and its role in our analysis. We will also rewrite the implementation of PLSR with clarified terminology.

L203: the raw input reflectance data is unclear here. Also, please further highlight which pigments you are inverting from the reflectance and why.

Thank you for comments. When we calculated the Jacobians, we used the log-scaled daily-averaged canopy-averaged reflectance. In PROSAIL inversion, we used daily-averaged canopy-averaged reflectance without log scaling. The inverted pigments are chlorophylls, carotenoids, and anthocyanin. We compared the inverted pigment contents of chlorophyll and carotenoids as well as their ratio to the measurements from needle samples. We will clarify this in the revised draft and will provide all averaged reflectance data as supporting online material.

Results Section 3.1: this whole section refers to results about GPP max without clearly referring to results on this parameter. Please refer better to the results shown in Fig. 3 and check why LUElighL and LUEtotal are not shown in the graph (but mentioned in the legend).

L226: please refer first to the observations in the figure in the main text, and for further details refer in addition to the supplementary figures.

Thank you for catching the misleading legend. We will remove it. And we will refer to the plots in the section in the revision.

Fig. 4: “Annual mean reflectance”: correct this as the “Annual mean log scaled R”

Thanks. We will correct it in the revision.

Section 3.2: The link between the seasonality of the spectral components and GPP max seems interesting, but there is a clear difference in the onset of the components 1 and 2 (the more dynamic ones) which might be in addition highlighted and of scientific interest.

Thank you for catching this. We are not sure the origin of the abrupt onset near DOY 50 in component 1. This abrupt change happens in all three components in Figure 4. We suspect the change was caused by background noise, such as snow from the ground, given that the PhotoSpec system operated normally during that period. However, we cannot identify the reason and will suggest this as mere speculation in the revisions.

Section 3.3: The explanation of the methodology in this section needs to be improved.

We will elaborate the implementation of PLSR analysis in the revision.

Please be more concrete in terminology (L278: transition period, noise) and what exactly you are referring to.

The transition period refers to the onset and cessation of growing season shown in GPPmax. The noise refers day-to-day fluctuations in winter. GPPmax was consistently near $0\pm1\mu$mol m^{-2} s^{-1} before DOY 100, while PLSR reconstructed GPPmax varies from -2 to 5 μmol m^{-2} s^{-1} in the same period. This large variation is from the noisy input of reflectance, which can be seen in the ICA components. We will rephrase the sentence to be more specific.

L279-L281: What do you mean with that the high-frequency variations are not captured by any method? The PRI captures the variation of the most dominant feature in the PLSR coefficients. So why would these variations not be related to pigment content?

The high-frequency variations refer to the day-to-day fluctuations within growing season. Both PRI and PLSR coefficients are relatively flat during the growing season. They did not follow the day-to-day variations within the season. As both PRI and PLSR use the pigment absorption feature, their invariance suggests these variations are less relevant to pigment.

Section 3.4: L302: Please refer to the graphs.

Thank you for the comment. The sentence will refer to Figure 8(b).

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-41, 2020.

Printer-friendly version

Discussion paper

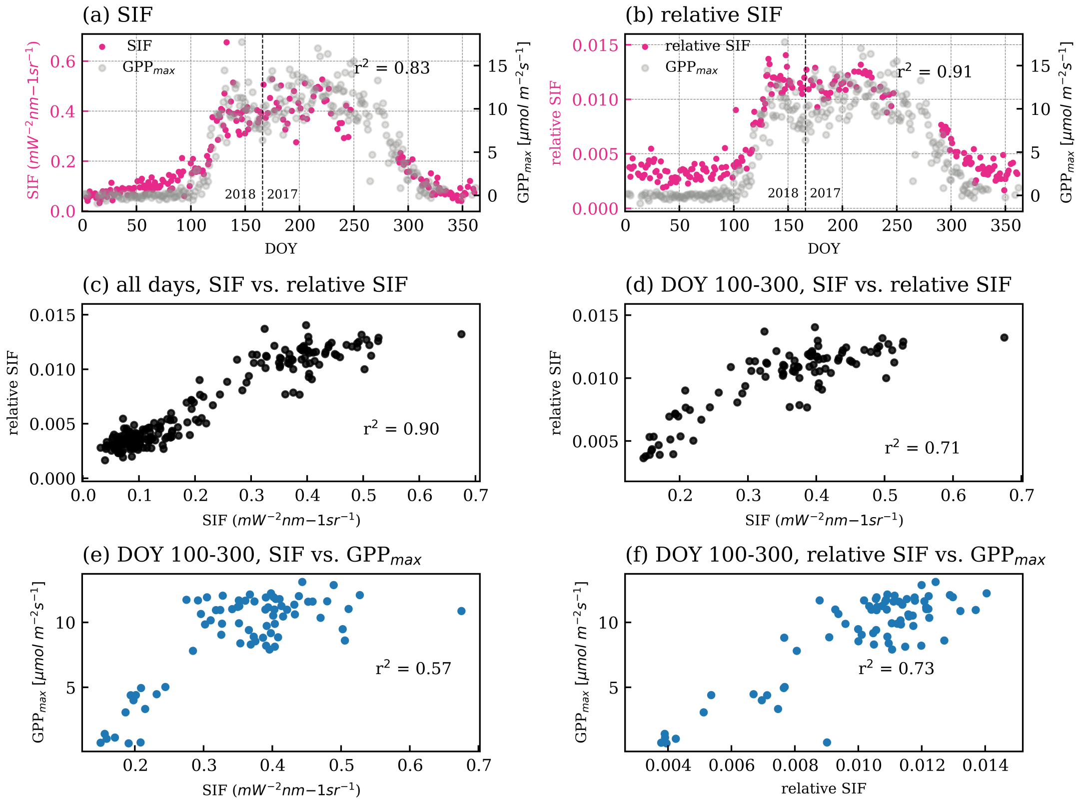
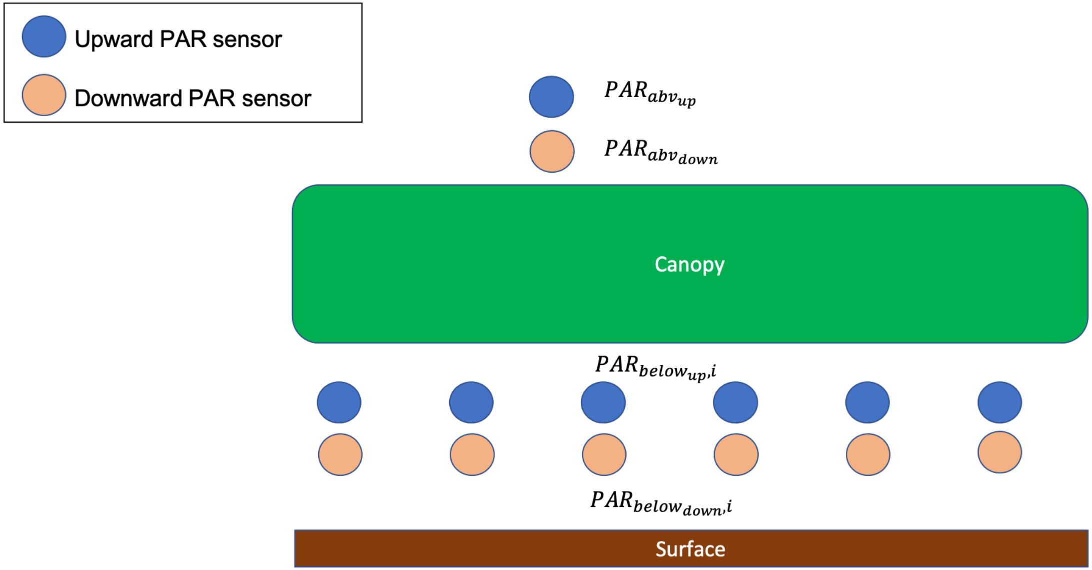


Fig. 1. Comparing SIF and relative SIF

Printer-friendly version

Discussion paper



$$APAR = \left[\left(PAR_{abv_{up}} - PAR_{abv_{down}} \right) - \frac{1}{6} \sum_{i=1}^{6} \left(PAR_{below_{up},i} - PAR_{below_{down},i} \right) \right]$$

Fig. 2. Observing and calculating APAR

Printer-friendly version

Discussion paper

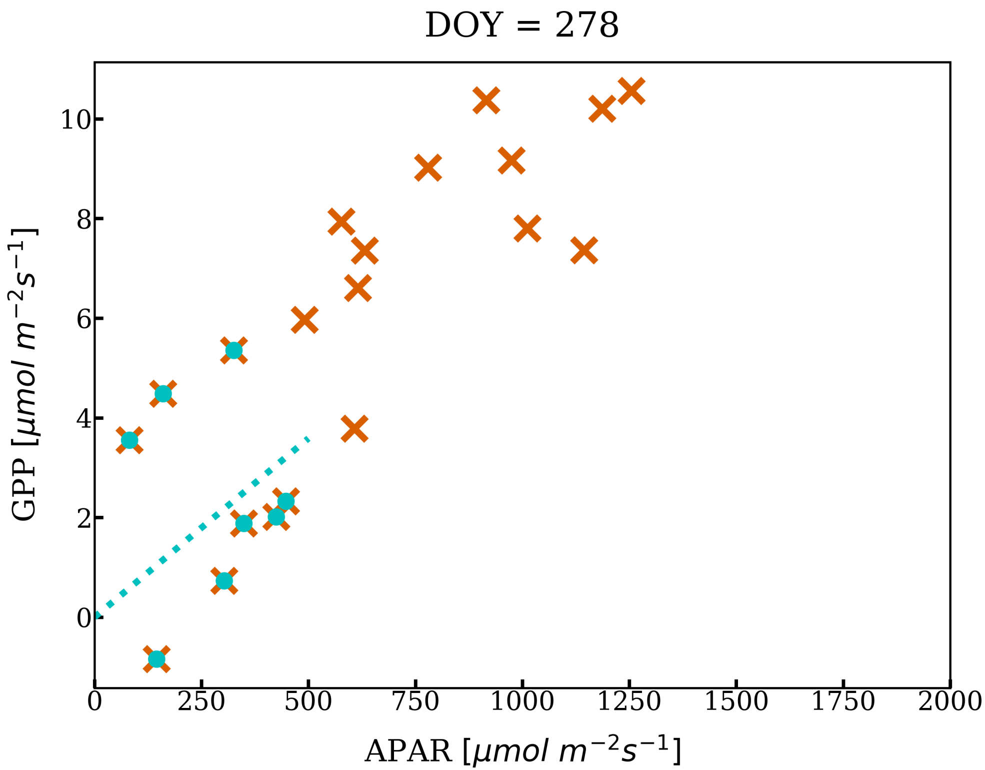


Fig. 3. A demonstration of calculating LUEtotal and LUElightL