Supplement of Biogeosciences, 17, 4523–4544, 2020
https://doi.org/10.5194/bg-17-4523-2020-supplement

Biogeosciences
Open Access

Supplement of

Decomposing reflectance spectra to track gross primary production in a subalpine evergreen forest

Rui Cheng et al.

Correspondence to: Rui Cheng (rui.cheng@caltech.edu) and Christian Frankenberg (cfranken@caltech.edu)

S1. GCC convolution functions

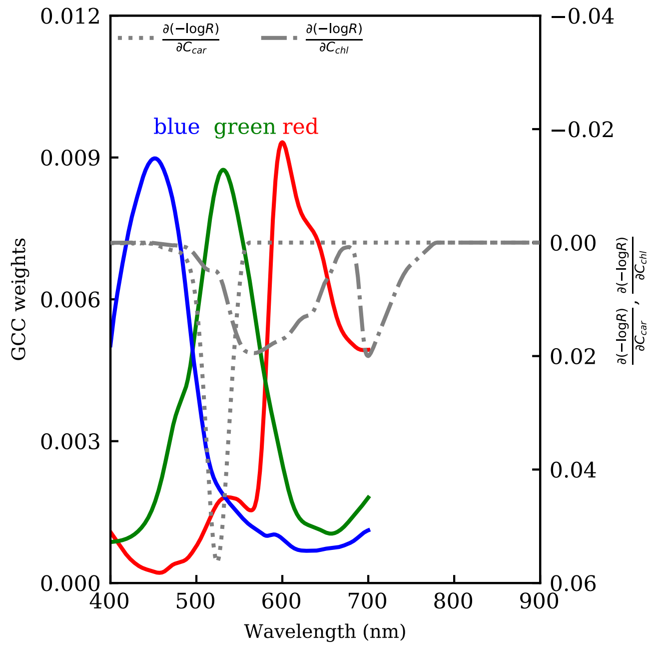

Figure S1. The convolution function of RGB channels used in GCC (Sonnentag et al., 2012) is overlaid with the chlorophyll Jacobian ($\frac{\partial-\log(\mathrm{R})}{\partial\, C_{chl}}$, dashed-dotted) and the carotenoid Jacobian $\frac{\partial-\log(\mathrm{R})}{\partial\, C_{car}}$, dotted)

S2. Three regimes of LUE

S2.1. APAR measurement

Seven pairs of up and down-looking PAR sensors (SQ-500-SS; Apogee Instruments, Utah, US) above and below the canopy was used to calculate fPAR in half-hourly intervals. One pair of sensors was installed above the canopy 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 following graph. fPAR was smoothed with an 8-point (4 hour) running mean and 20-day running mean to remove the noise in the measurements. The first fPAR measurement started on 8 Aug 2017 (DOY 220).

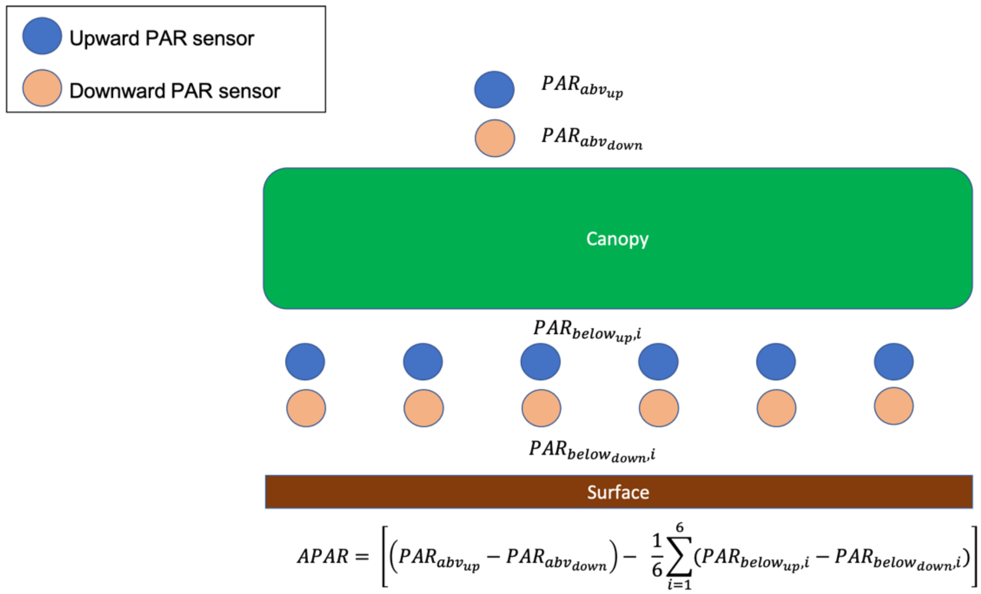

Figure. S2a. A demonstration for APAR calculation.

S2.2. Light limited and daily averaged LUE

At low light intensity, photosynthesis is light limited. We followed the format of Eq. (1) to define light-limited LUE (LUE_{lightL}) as the fitted slope of APAR against GPP at PAR between 100 and 500 µmol m^{-2} s^{-1}. We calculated LUE_{lightL} from half-hourly GPP and APAR for each day. We also defined a more generalized effective daily LUE (LUE_{total}) as the daily averaged ratio of GPP to APAR during the day. This effective daily LUE would be most applicable for empirical LUE models that work on daily time-steps.

LUE_{lightL} is the fitted slope of GPP and APAR when PAR is between 100-500 µmol m^{-2} s^{-1}. The fit was forced to go through the origin as the equation has no intercept.

LUE_{total} is the daily average of $\frac{GPP}{APAR}$ during the day.

Here is a demonstration of how LUE_{lightL} and LUE_{total} 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 LUE_{lightL}. 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 the plot. We calculated the ratio of GPP and APAR of those orange points, and the daily mean of the ratio is the LUE_{total}.

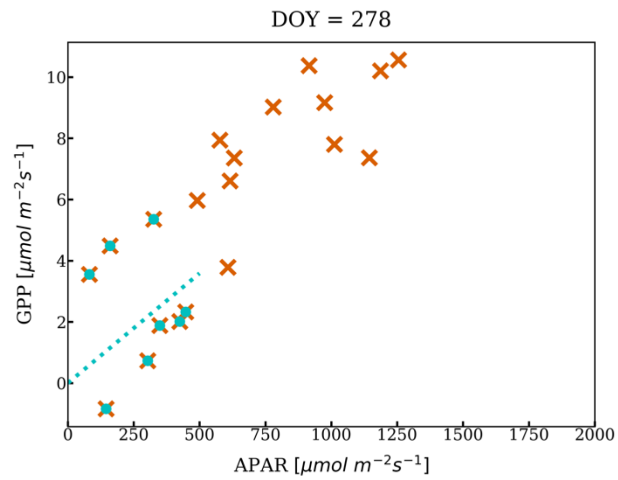

Figure S2b A demonstration of calculating LUE_{lightL} and LUE_{total}.

S2.3. Two ways calculating GPP_{max}

There were only a few days when PAR is so low that LUE did not reach light saturation for most of the day, when LUE_{total} is more comparable to LUE_{lightL}. Also, there is a 26-day gap in APAR measurement in the beginning period of our study. Therefore, we only showed the results of GPP_{max} in the main text as it is more representative than LUE_{lightL} and more physiology-driven than LUE_{total}. Because of the missing APAR, we did not normalize GPP_{max} with APAR. However, the normalized GPP_{max} and unnormalized GPP_{max} are significantly linearly correlated (Fig. S2b). Although GPP normalized by PAR results in the correct unit of LUE, it is easily mistaken as fPAR has been considered. To avoid this confusion, we chose to use mean GPP at PAR between 1000 and 1500 μmol m^{-2} s^{-1}.

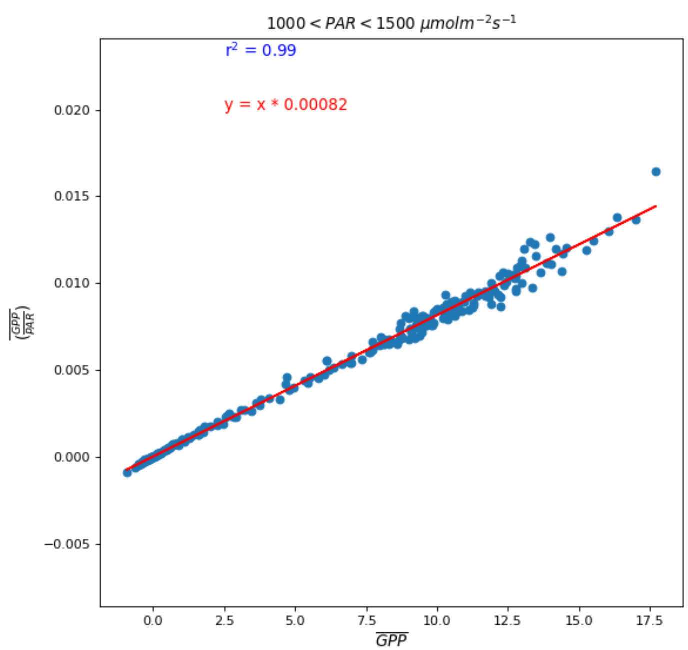

Figure S2c. Normalized GPP_{max} and Unnormalized GPP_{max}

S2.4. Comparing the three regimes of LUE

Needles use light most efficiently at low light levels (LUE_{lightL}) for a fraction of the day. We started to observe a photosynthetic saturation at low PAR values ($\sim$ 500 µmol m^{-2} s^{-1}; Fig. 2), which is represented by GPP_{max}, resulting in low efficiencies under high light conditions. LUE_{total} represents the mean light use scheme throughout the day. Hence, LUE_{lightL} was slightly higher than LUE_{total} during most of the growing season (Fig. S2c).

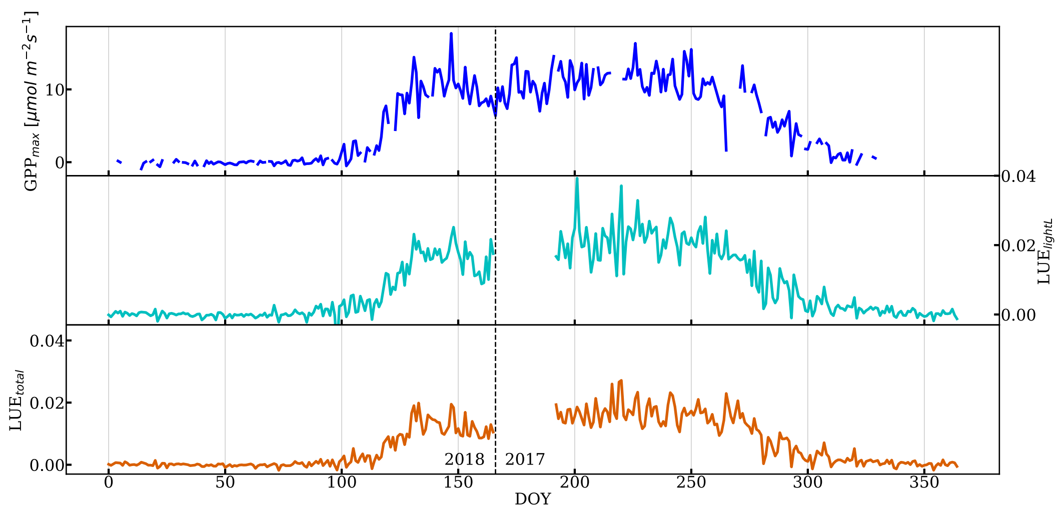

Figure S2d. Time series of GPP_{max}, LUE_{lightL} and LUE_{total}. DOY 166 (2017) is the first day of observation. The vertical dashed line divides the observations from Day of Year (DOY) for year 2017 and 2018.

S3. GPP_{max} and PRI as a function of T_{air} and VPD in different seasons

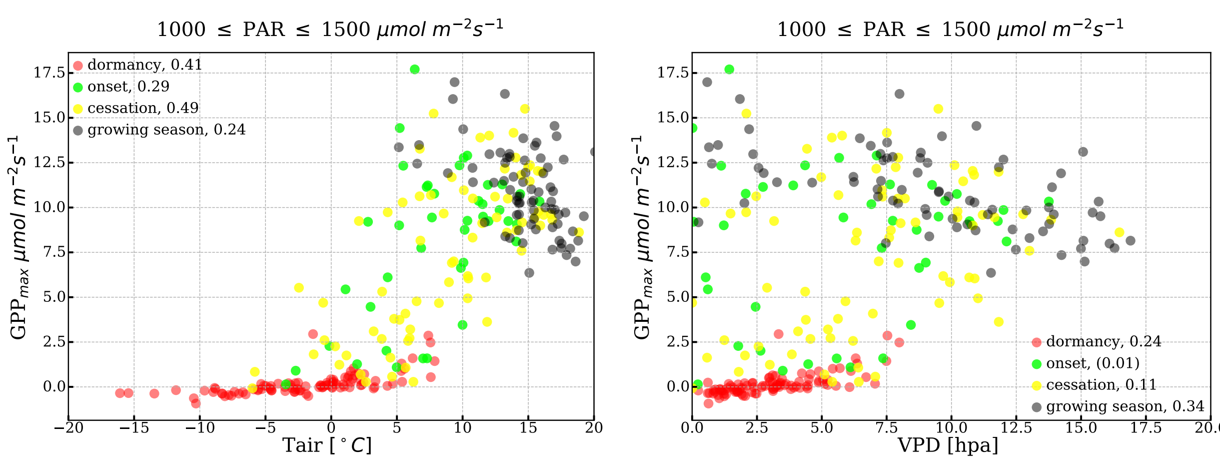

Figure S3a. Scatter plots of GPP_{max} against T_{air} (top left) and VPD (top right). The definition of seasons follows the same convention as in Fig. 1. The onset is the transitioning period from dormancy to the growing season. The cessation is the transitioning period from the growing season to the dormancy. The Pearson-r^2 values are shown in the legend. The statistically insignificant value is in a parenthesis if the p-value is greater than 0.005.

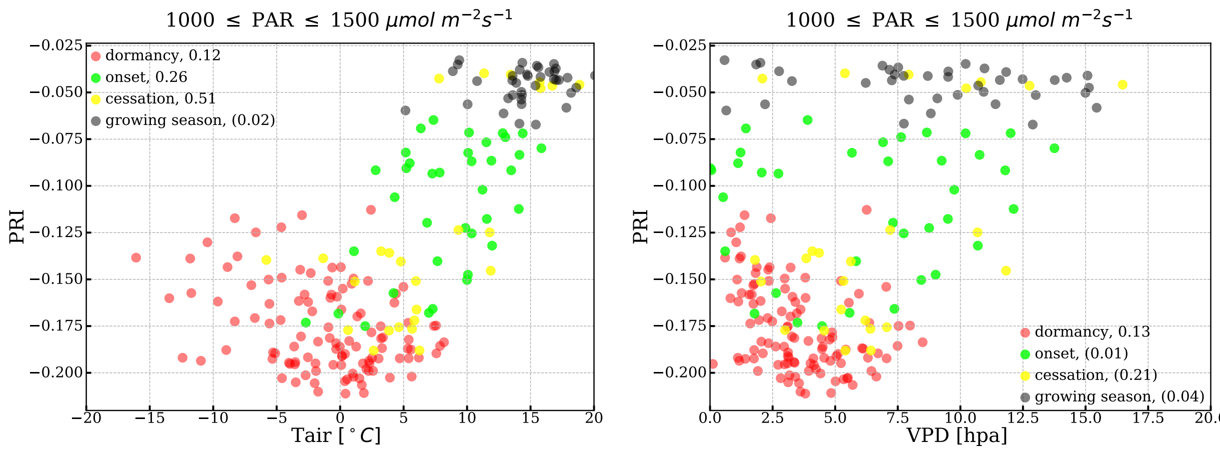

Figure S3b. Scatter plots of PRI against Tair (left) and VPD (right). The definition of seasons follows the same convention as in Fig. (1) and S3a. The onset is the transitioning period from dormancy to the growing season. The cessation is the transitioning period from the growing season to the dormancy. The Pearson-r^2 values are shown in the legend. The statistically insignificant value is in a parenthesis if the p-value is greater than 0.005.

The correlations with Tair and VPD are similar because T_{air} and VPD are significantly correlated.

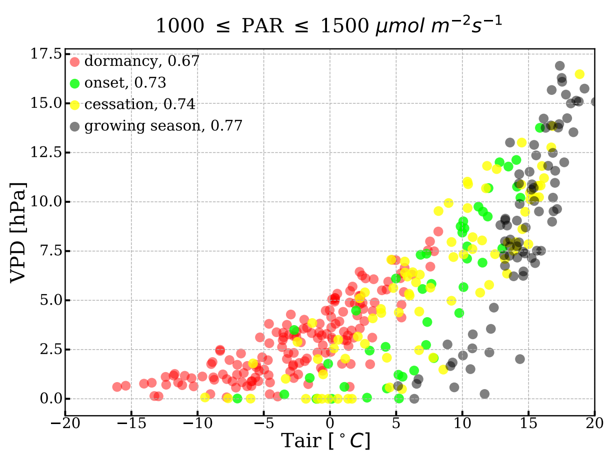

Figure S3c. Scatter plot of VPD and T_{air}. The definition of seasons follows the same convention as in Fig. (1) and S3a. The Pearson-r^2 values are shown in the legend. The statistically insignificant values are in parenthesis if the p-value is greater than 0.005.

S4. ICA algorithm

We used the fastICA algorithm from scikit-learn v0.21.0 (https://scikit-learn.org/stable/modules/generated/sklearn.decomposition.FastICA.html). Because ICA minimizes the dependencies of the second-order moment (variance) and higher, the randomness during the minimization makes the explained variance and order of individual component unclear. In our calculation, the ICA algorithm reduced the dimension of the input matrix by eigenvalue decomposition first, from which the first three second-order independent/orthogonal components yielded 99.99% of the variance. Then, the algorithm extracted the independent components of high-order moments from these orthogonal components.

S5. SIF vs relative SIF

Relative SIF is 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. The attached plot 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 correlated with the GPPmax in seasonal variations. However, the sub-seasonal change in the growing season is captured more by relative SIF.

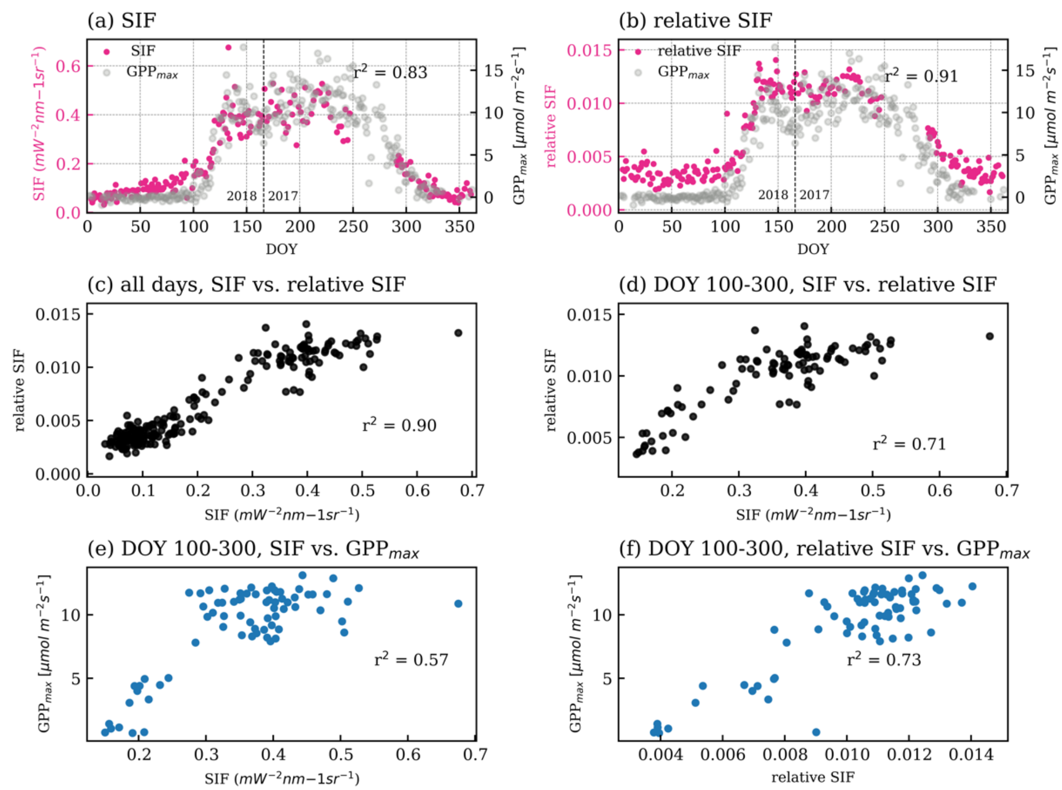

Figure S5. Comparison between SIF and relative SIF, and the correlation of them with GPP_{max} during the growing season.

S6. PLSR analysis

Based on four-fold cross-validations, we set n_components = 4 in the analysis of GPP_{max} and 2 in the analysis of pigment measurements. All the PLSR coefficients are similar (Fig. S4) because LUE_{lightL}, LUE_{total}, and GPP_{max} are similar in terms of the seasonal trend.

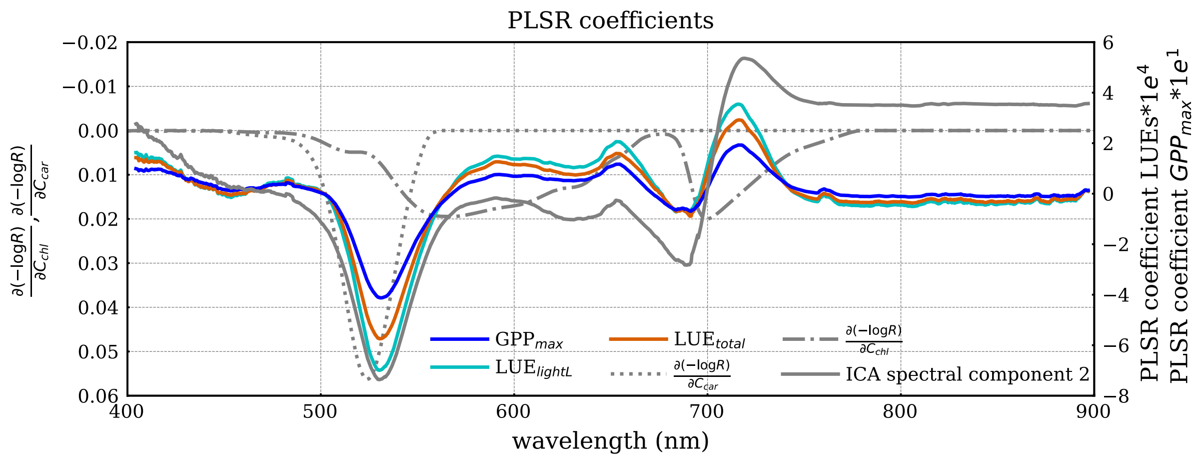

Figure S6. PLSR coefficients of reflectance with GPP_{max}, LUE_{lightL}, and LUE_{total}. The overlaid dash-dotted and dotted lines are chlorophyll and carotenoid Jacobians, respectively. The overlaid solid grey line is the second ICA spectral component. The vertical dashed line divides the observations from DOY for year 2017 and 2018.