Assessment of the diurnal relationship of photochemical reflectance index to forest light use efficiency by accounting for sunlit and shaded foliage

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Sunlit versus Shadowed Foliage

GPP	=	LUE	×	PAR	×	fAPAR
Gross Primary Productivity		Light Use Efficiency		Photo-synthetically Active Radiation		Fraction of Absorbed PAR

Gross primary productivity (GPP) is the total amount of carbon dioxide "fixed" by land plants per unit time through the photosynthetic reduction of CO_2 into organic compounds. GPP is a function of foliage light use efficiency and absorbed sunlight.

$$\mathrm{PRI} = \frac{531\ nm - 570\ nm}{531\ nm + 570\ nm}$$

Spectrometer measurements overestimate the **Photochemical Reflectance Index (PRI),** used to estimate **Light Use Efficiency** (**LUE),** when using large pixels because low-efficiency sunlit foliage and high-efficiency shadowed foliage are mixed together. This overestimation can cause GPP to be overestimated.

- Sunlit leaves have low efficiency because the amount of available light exceeds their ability to fully use it in photosynthesis
- Despite their low efficiency, sunlit leaves contribute a large majority of a canopy's productivity because of their high fraction of absorbed PAR
- Shadowed leaves are more efficient but with less available light their contribution to productivity is significantly lower

Goal: To establish the relationships of Photochemical Reflectance Index (PRI) to diurnal foliage light use efficiency (LUE) in different light environments – sunlit, shadow, and mixed.

Region of Interest: 420m x 420m bounding box around US-NC2 flux tower in Parker Tract, NC Loblolly Pine Plantation.

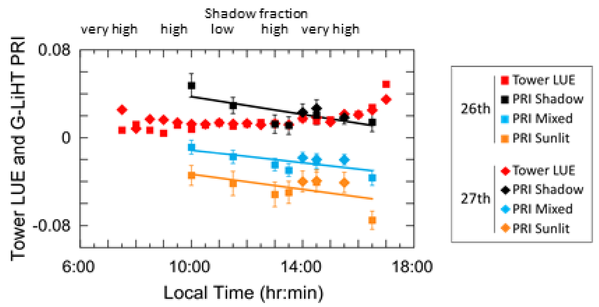
Data: Goddard Lidar, Hyperspectral and Thermal (G-LiHT) FLEX – US Airborne Campaign flights on October 26-27, 2013 and corresponding LUE from US-NC2 flux tower.

Methods: Using MATLAB for data processing including panchromatic band simulation, separation of sunlit and shadowed pixels, spectral indices calculations, and exporting statistics to compare to LUE flux tower data.

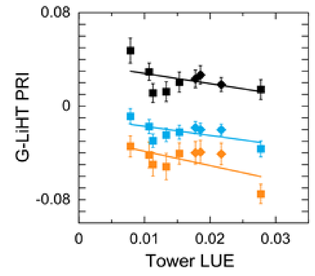
Results: PRI from hyperspectral imagery show negative correlation with LUE during post-growing season when separated into different components of the light environment.

Diurnal Assessment of LUE versus PRI

Six G-LiHT flights covering the flux tower plot were acquired on October 26th spanning the time range from 10:00 am to 4:30 pm and three were flown on the afternoon of the 27th. Because the LUE time series (red squares and triangles) derived from the flux tower was nearly identical on the two days, we chose to create one time series for the nine flights.



The relationship of GLiHT PRI for the different light components (mixed, sunlit, and shadowed) to the flux tower LUE shows a negative correlation in the graph plotted to the right.



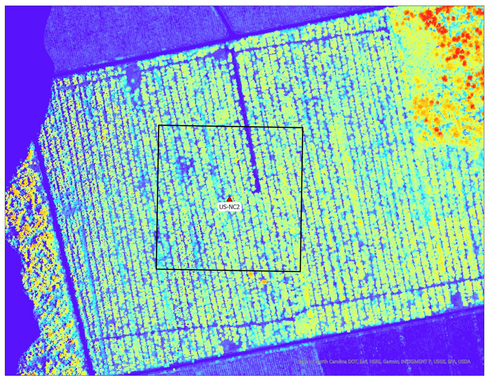
Study Area & Datasets

Goddard Lidar, Hyperspectral and Thermal (G-LiHT)

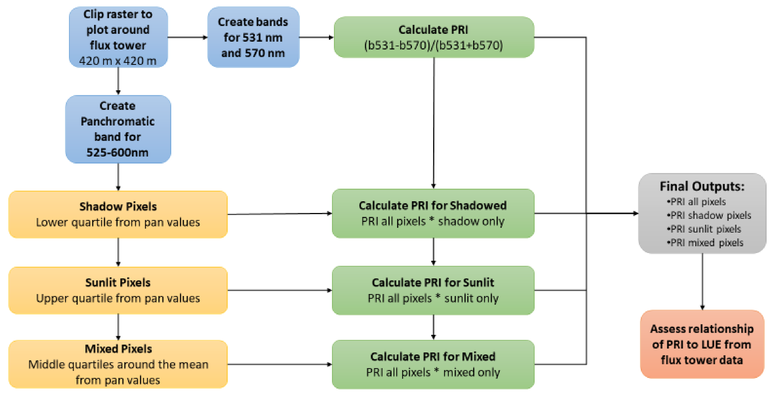
- Multi-sensor airborne campaign conducted in 2013 at Parker Tract, NC experimental forest
- Visible to near-infrared (VNIR) narrow-band hyperspectral imager
- Flights were repeated in the morning, at noon, and the afternoon for diurnal sampling of changing light and environmental conditions
- PRI was calculated from Headwall Hyperspec Imaging Spectrometer in 10 nm bandwidths corrected to at-sensor reflectance with 2m spatial resolution.

US-NC2 Eddy Covariance Flux Tower

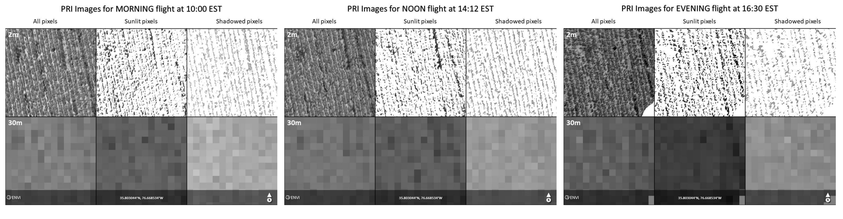
- Derived LUE from flux data every 30 minutes for October 26-27, 2013
- 420 m x 420 m bounding box centered on Ameriflux US-NC2 in a loblolly pine plantation that was planted in 1993 and thinned in 2009.



Data processing workflow



Example Image Results in ENVI



Takeaways

- Over the time range of the G-LiHT flight the LUE shows a gradual increase, indicating an overall increase in the plot efficiency during the day, whereas the mean PRI for all three components decrease.
- The negative correlation between LUE and PRI is shown in the bottom right. Our results are consistent with the work of Nakaji *et al.* (2006) and Nyongesah *et al.* (2016), which show a positive correlation between LUE and PRI during the growing season but a transition to negative correlation at the end of the growing season.
- When upscaled to 30 m, well-defined linear trends show that as the sunlit fraction increases the PRI for the sunlit fraction decreases and as the shadow fraction increases the PRI for the shadow fraction increases. This suggests that, as expected, the foliage efficiency decreases as the intercepted sunlight exceeds the ability of the foliage to fully utilize it in photosynthesis. Whereas, as less light is available due to increased shadowing the foliage efficiency increases.

Future Work

Planned future initiatives will include seasonal and diurnal drone acquisitions at Ameriflux and NEON flux towers in the Mid-Atlantic region shown in the map below. The overall objective is to assess the seasonal variability of the PRI and LUE empirical relationships to forest composition and the diurnal light environment.

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