Inferring Photosynthetic Light-Use Efficiency of Terrestrial Ecosystems from Multi-angular Satellite Observations

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Introduction

Satellite remote sensing provides unique opportunities for spatially continuous observations of plant photosynthesis, however, remote sensing of photosynthetic light use efficiency (ε), is challenging. Some progress has been made using the photochemical reflectance index (PRI) centered at 531 and 570 nm, but the high sensitivity of PRI to extraneous effects has prevented its use at global scales. This poster presents a new, robust algorithm, applicable across space and time.

Methods

Sun-exposed leaves exhibit a lower ε than shaded canopy elements, as sunlit leaves are more likely to be exposed to excess radiation energy (Fig. 1). This relationship disappears under conditions where light is limiting, as in this case, photosynthesis will not be down-regulated in either sunlit or shaded leaves. These considerations have two important implications:

First, stand level LUE cannot be observed from traditional, mono-angle observations, at least not in a robust fashion, because the proportion of shadow fraction observed by the sensor at a given time may not be representative of the overall canopy; thus the contribution of shadow fraction to the photosynthetic down-regulation is unknown. Second, the first derivative of PRI with respect to shadow fractions (PRI') can be used to determine stand-level LUE robustly (Hill et al., 2008, Hilker et al., 2010), as under the assumption of singular leaf scattering a normalized difference reflectance index in the visible bands cannot change its value with the viewing geometry unless the reflectance of one band changes as a physiological response to illumination.

Results and Discussion

The non-linear relationship that was predicted in an earlier theoretical analysis in Hall et al. 2008 was found between EC-derived ε and PRI' obtained from the CHRIS/Proba imagery (r²=0.68, p<0.01). Despite the differences in structure, species composition, climate and location, all observations followed the same non-linear function indicating that this relationship may be insensitive to the unstressed reflectance and structure of the vegetation, including background(RMSE=0.22 gCMJ⁻¹) (Fig. 5).

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REFERENCES


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It can be concluded that

1. It is possible to infer ε across different biomes from space using multi-angle data
2. Canopy ε can be estimated possibly from the same PRI’ function over a broad range of vegetation
3. Data assimilation will allow spatially and temporally continuous modeling of GPP (Fig 6)

Building on these results we propose a new, multi-angular satellite concept that can directly measure gross photosynthesis from PRI and NDVI observations in a spatially continuous mode (Hall et al., 2011)

Figures:

Figure 1: Relationship between PRI and canopy shadow fractions observed at a conifer forest site (DF49). For a time interval during which ε of the canopy is lowest (red curve), PRI shows a large difference between photosynthetically active sunlit and shaded canopy elements. This is because the sunlit leaves are light saturated, whereas the shaded leaves are not. When canopy ε is highest (green curve), photosynthesis is not down-regulated in either sunlit or shaded leaves, hence there is no difference in PRI with shadow fraction. Note that the PRI for non-photosynthetically active sunlit and shaded canopy elements is the same hence they do not contribute to the shape of the curves.

Figure 2: CHRIS/Proba multi-angle sampling scheme.

Figure 3: Structural differences at the 8 research sites presented in this study. The sites are DF49 (A), Harvard Forest (B), HUP1975 (C), HUP2002 (D), Howland Forest (E), NOBS (F), OJP (G) and Tambourba (H).

Figure 4: Multi-angle false color IR images of DF49 from CHRIS during one overpass on June 12, 2005. CHRIS/Proba collects up to 5 images along track. During one overpass, canopy ε can assumed to be constant (Hall et al. 2010)

Figure 5: Relationship between API PRI (PRI) and ε observed from CHRIS/Proba imagery and ε measured ε for eight different research sites. The observations have been taken between 2001 and 2009 (Hilker et al 2011)

Figure 6: Map of ε (in gCMJ⁻¹) as estimated from CHRIS/Proba imagery using the relationship shown in Figure 5. The structural dependency is apparent in both examples.