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 570nm, 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.

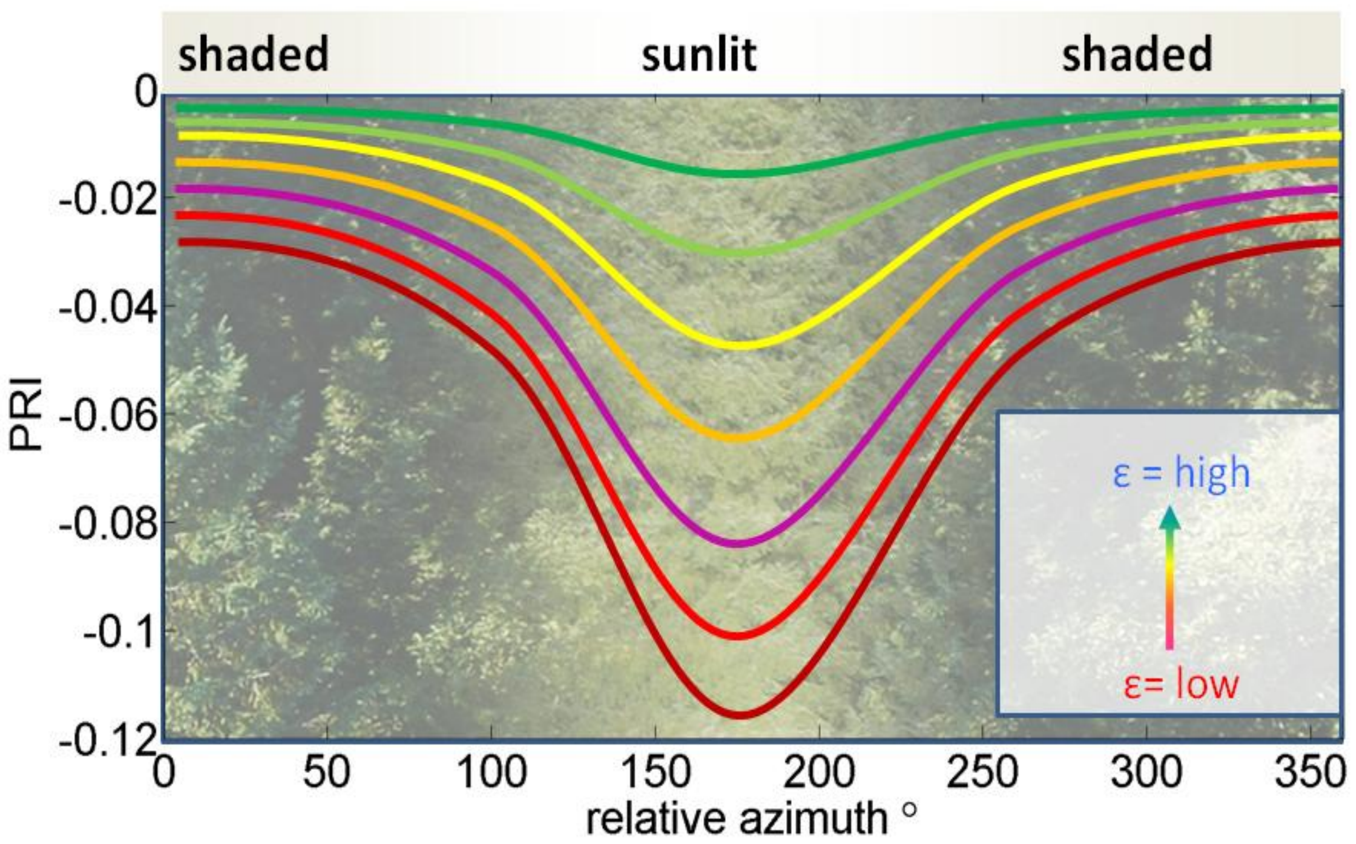


Figure 1: Relationship between PRI and canopy shadow fractions observed at a conifer forest site (DF49). For a time interval during which ε of the canopy is lowest (red curves), PRI shows a large difference between photosynthetically active sunlit and shaded canopy elements. This is because the sunlit leaves are light saturated, whereas the shaded leaves are not. When canopy ε is highest (green curves), 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.

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**, (Hall 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.

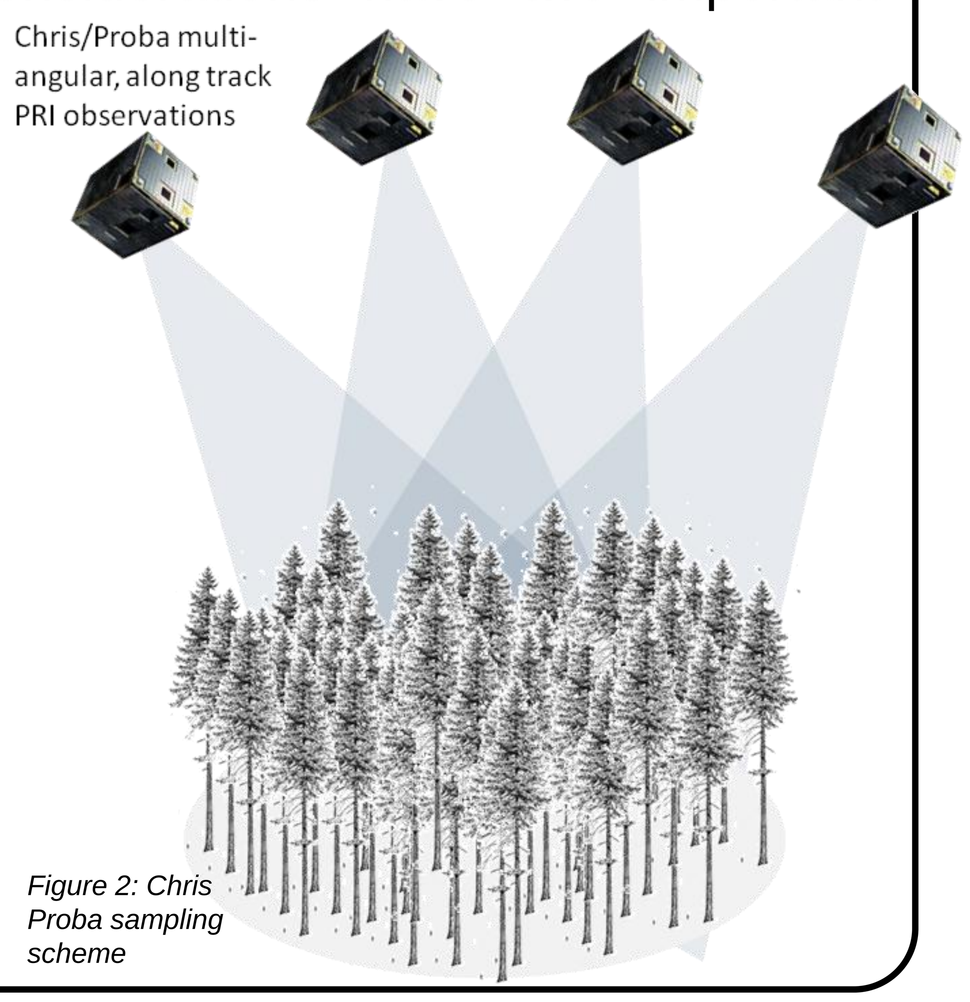


Figure 2: Chris Proba sampling scheme

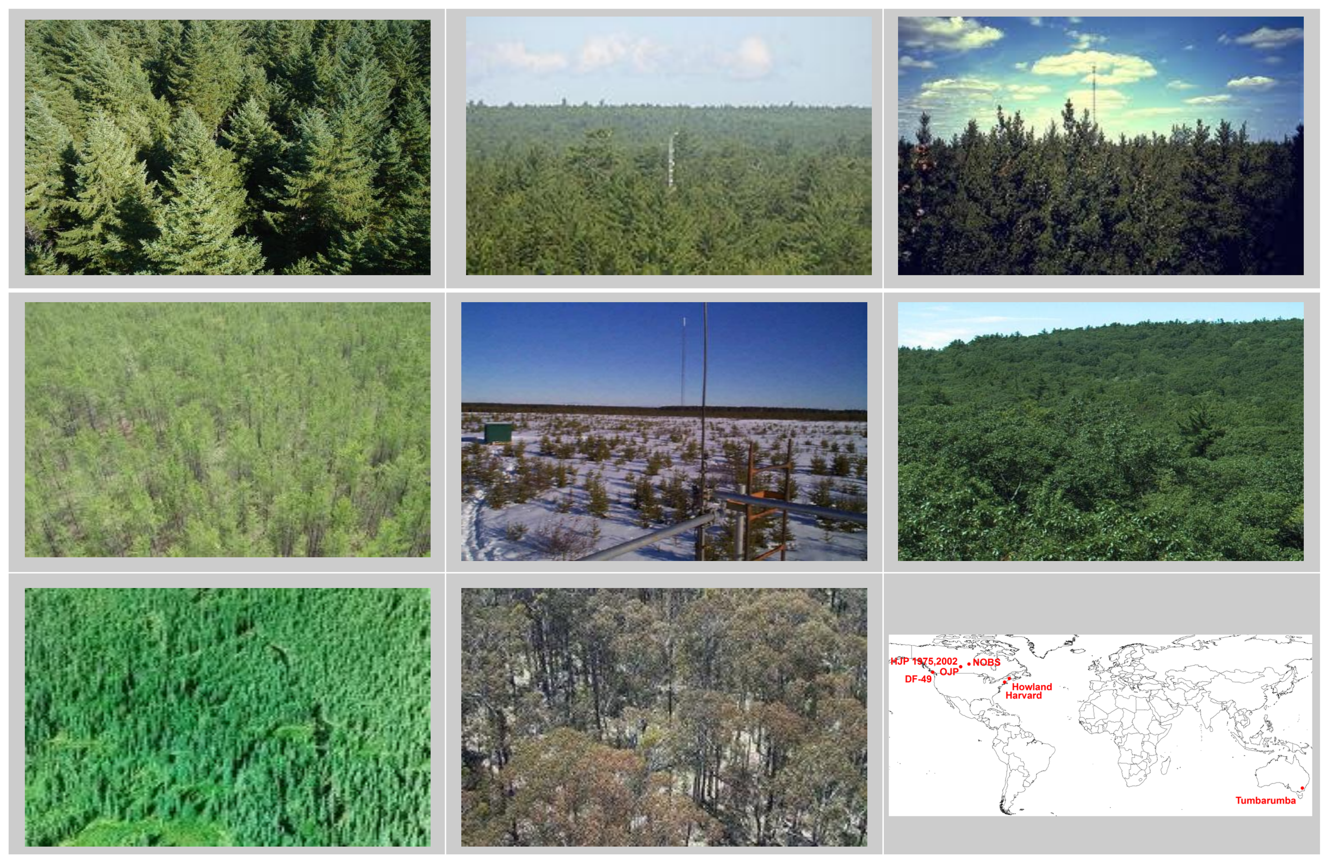


Figure 3: Structural differences at the 8 research sites presented in this study. The sites are DF-49 (A), Harvard Forest (B), HJP1975(C), HJP2002 (D), Howland Forest (E), NOBS (F), OJP (G) and Tumbarumba (H)

Chris/Proba satellite data (Fig. 2) and simultaneous eddy-flux observations were acquired during six growing seasons between 2002 and 2008 at eight different sites from boreal needle-leaf to wet-temperate eucalypt forests (Fig. 3). PRI was computed from CHRIS bands 4 and 6 for images acquired in CHRIS Mode 3 (all sites except for the southern BOREAS region), and band 11 and 15 for images acquired in CHRIS Mode 1. Corresponding canopy shadow fractions for each pixel were estimated using linear mixture decomposition.

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 (r^2=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).

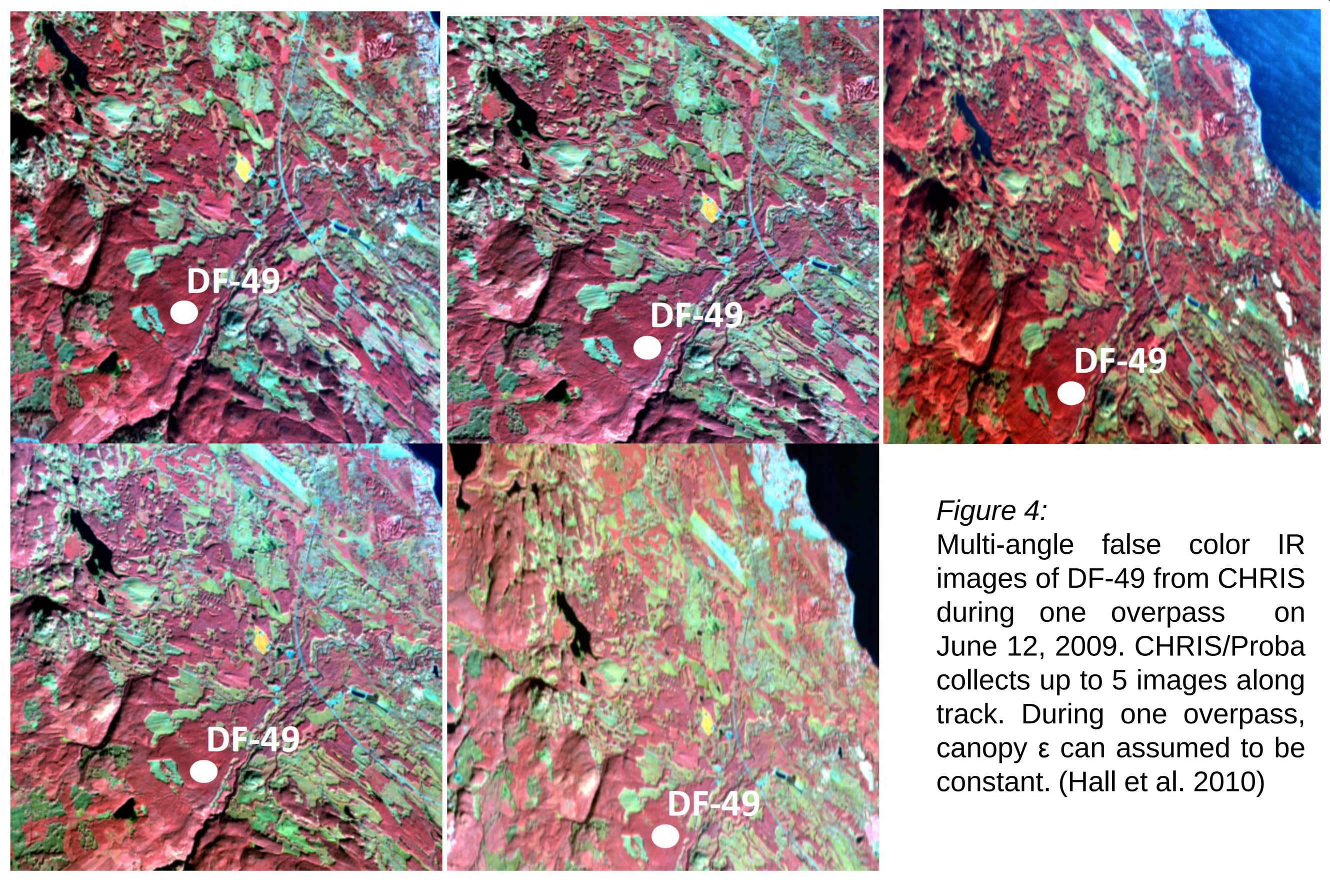
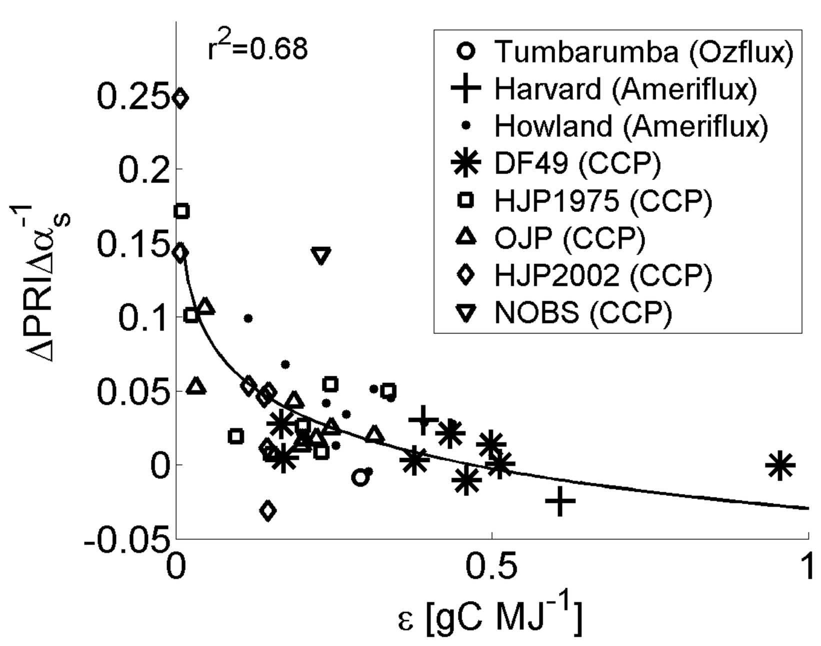


Figure 4: Multi-angle false color IR images of DF-49 from CHRIS during one overpass on June 12, 2009. CHRIS/Proba collects up to 5 images along track. During one overpass, canopy ε can assumed to be constant. (Hall et al. 2010)

It can be concluded that

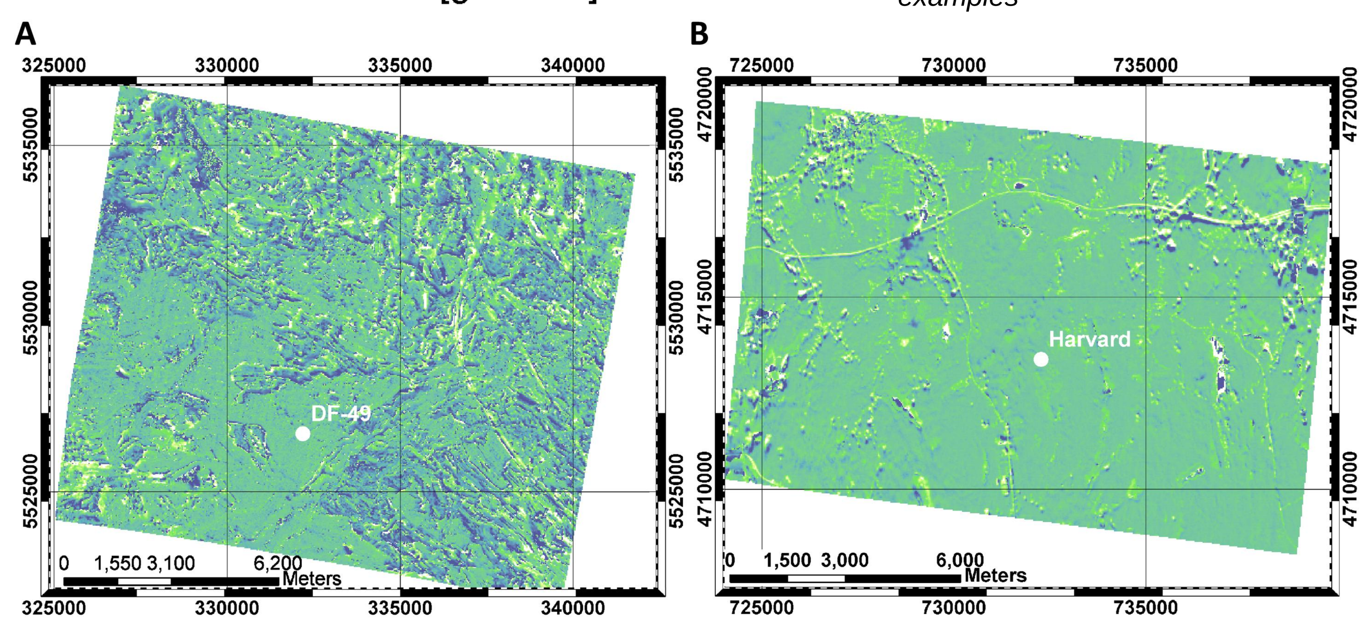
1. **It is possible to infer ε across different biomes from space using multi-angle data**
2. **Canopy ε can be estimated possibly from the same PRI' function over a broad range of vegetation**
3. **Data assimilation will allow spatially and temporally continuous modeling of GPP** (Fig 6)

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)



← *Figure 5* Relationship between ΔPRI $\Delta\alpha_s^{-1}$ (PRI') as observed from CHRIS/Proba imagery and EC measured ε for eight different research sites. The observations have been taken between 2001 and 2009 (*Hilker et al 2011)*

↓*Figure 6 : Maps 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*



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