# INTRODUCTION TO FRACTION OF ABSORBED PAR BY CANOPY CHLOROPHYLL (fAPARchl) AND CANOPY LEAF WATER CONTENT DERIVED FROM Hyperion, SIMULATED HyspIRI and MODIS IMAGES

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## 1. INTRODUCTION

Vegetation photosynthesis produces the oxygen and organic matter to sustain life on Earth. Vegetation absorbs photosynthetically active radiation (PAR) through canopy chlorophyll and uses carbon dioxide ($CO_2$) from the atmosphere for photosynthesis. Understanding the seasonal and annual dynamics for photosynthesis by ecosystems is critical for carbon cycle and climate studies. Satellite remote sensing provides a good opportunity to study global vegetation photosynthesis for terrestrial ecosystems. Vegetation photosynthesis is referred to as gross primary production (GPP) or as gross ecosystem production (GEP). Many production efficiency models (PEMs) based on remote sensing have been developed to estimate GPP [1, 2]. The basic ideas are that GPP is the product of three variables: PAR, the fraction of PAR utilized for vegetation photosynthesis ($fAPAR_{photosynthesis}$), and light use efficiency (LUE):

$$GPP = LUE \bullet fAPAR_{photosynthesis} \bullet PAR \quad (1)$$

The $fAPAR_{photosynthesis}$ is typically assumed to be equal to the fraction of PAR absorbed by a whole canopy or ecosystem (FPAR), and empirically estimated using the Normalized Difference Vegetation Index (NDVI) from NOAA/AVHRR, MODIS and Landsat TM [3-7]:

$$FPAR = 1.24 \bullet NDVI - 0.168 \quad (2)$$

However, a canopy includes both photosynthetic components (primarily chlorophyll pigments) and non-photosynthetic components (e.g., veins, cell walls, senescent leaves, stems, branches, etc) which all absorb some amount of PAR. However, the PAR absorbed by the non-photosynthetic components of the canopy is not used for photosynthesis. So the $fAPAR_{photosynthesis}$ of an ecosystem will be overestimated when based on the use of the parameter, FPAR. Conceptually, $fAPAR_{photosynthesis}$ is linked to the fraction of absorbed PAR by canopy chlorophyll only, or $fAPAR_{chl}$, or:

$$fAPAR_{photosynthesis} = fAPAR_{chl} \tag{3}$$

Temperature, leaf water content (LWC) and other factors may down regulate the optimal light use efficiency, i.e., maximum light use efficiency of vegetation within a canopy or ecosystem. However, there currently is no algorithm using remotely sensing information to derive LWC for PEMs. It should be noted here that, until now, the preliminary version of the vegetation photosynthesis model (VPM) [8] assumes that the Enhanced Vegetation Index (EVI) is a surrogate for $fAPAR_{chl}$ , or $fAPAR_{chl}$ = EVI, but does not actually calculate $fAPAR_{chl}$. In addition, the VPM uses LSWI, not LWC, to calculate LUE [8-10] (see the Table 1 of [11] for definition of the bands):

$$fAPAR_{chl} = EVI \tag{4}$$

$$EVI = 2.5 \times \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + 6.5 \times \rho_{red} - 7.0 \times \rho_{blue} + 1.0} \tag{5}$$

$$LSWI = \frac{\rho_{nir} - \rho_{swir}}{\rho_{nir} + \rho_{swir}} \tag{6}$$

$$LWC = \frac{C_W}{C_W + C_m} \tag{7}$$

where $C_w$ is the leaf water thickness ($g/cm^2$ or cm) and $C_m$ is the leaf dry matter ($g/cm^2$). Here, we examine the use of EVI and LSWI spatially and temporally to prepare for determining ecosystem LUE in the future.

## 2. ALGORITHM DESCRIPTION AND METHODS

Our study [1] at an instrumented aspen forest site in Canada showed that canopy LUE based on the chlorophyll containing sector ($LUE_{chl}$) corresponded well to both the seasonal phase and amplitude of the flux-tower based LUE field measurements, whereas the widely-used canopy LUE ($LUE_{canopy}$) underestimated the field observations, supporting equation (3).

We have developed an algorithm to estimate $fAPAR_{chl}$ and LWC from MODIS observations. The innovative algorithm has been modified to derive $fAPAR_{chl}$ and LWC from high spatial resolution (30 m) images acquired by NASA's Earth Observing One (EO-1) Hyperion satellite, which were also used to simulate future HyspIRI satellite images at 60 m [1, 11]. The major ideas of the algorithm are: (i) coupling the canopy-Soil radiative transfer model SAIL2 with the leaf model PROSPECT; (ii) inverting the coupled PROSAIL2 model with directional reflectance images and the Metropolis algorithm; (iii) obtaining the best estimates for $fAPAR_{chl}$, leaf dry matter Cm and leaf water thickness Cw from the distribution solution; and (iv) producing the $fAPAR_{chl}$ and LWC output images.

## 3. RESULTS AND DISCUSSION

How does $fAPAR_{chl}$ differ from FPAR, NDVI and EVI in spatial distributions across a study site? And how does LWC differ from LSWI? We show some examples here which were derived from MODIS, Hyperion, and simulated HyspIRI images. For un-vegetated areas, $fAPAR_{chl}$ is close to zero while NDVI, EVI and FPAR exhibit values incorrectly associated with sparse vegetation (e.g., ~.2). The examples further demonstrate that $fAPAR_{photosynthesis}$ will be overestimated if based on the parameter FPAR. Spatial distributions across the study site are different for $fAPAR_{chl}$ as compared to either NDVI or EVI, as is the spatial distribution for LWC vs. LSWI, which cannot distinguish vegetation canopy water content from soil wetness.

We propose to replace FPAR with $fAPAR_{chl}$ to estimate GPP using PEMs, climate models, land-atmosphere interaction models and biogenetic emission models, e.g., the MEGAN model - the Model of Emissions of Gases and Aerosols from Nature [12]. In addition, the LWC parameter can be used in estimation of LUE, and for vegetation stress detection and monitoring. We expect that both $fAPAR_{chl}$ and LWC will improve remote sensing of ecosystem phenology.

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