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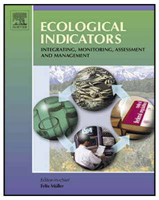

A simple method to simulate diurnal courses of PAR absorbed by grassy canopy

Ruyin Cao [a,b], Miaogen Shen [c], Jin Chen [a,*], Yanhong Tang [b]

[a] State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing 100875, China
[b] National Institute for Environmental Studies, Onogawa 16-2, Tsukuba, Ibaraki 305-8506, Japan
[c] Laboratory of Alpine Ecology and Biodiversity, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China

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ABSTRACT

The fraction of photosynthetically active radiation absorbed by vegetation (FAPAR) quantifies the efficiency of absorbing PAR by plants. Accurate estimation of diurnal variation of FAPAR however remains a challenge because of the dynamic changes of incident light conditions and its interaction with canopy structure. Based on a field experiment, we characterized the effects of solar zenith angle (SZA) and fraction of diffuse light (fdPAR) on diurnal FAPAR in an alpine wetland on the Tibetan plateau. We found an obvious nonlinear change pattern of FAPAR against SZA with a maximum value of FAPAR at the SZA of about 30°, and opposite responses of FAPAR to fdPAR outside of a SZA range between 21° and 30°. A curve fitting (CF) method was proposed to estimate diurnal FAPAR in a rapid and accurate way. The CF method accounting for the interactions of SZA and fdPAR on FAPAR can successfully describe the diurnal dynamics of FAPAR under clear and cloudy sky conditions. The estimation deviation of daily FAPAR was only −0.28% for a period of about eight days with various sky conditions. The new method requires only very simple field measurements, but has higher accuracy than the widely-used light penetration model, which is expected to be widely used in grassy vegetations.

1. Introduction

The fraction of photosynthetically active radiation absorbed by vegetation (FAPAR) describes light absorption efficiency by plants and is a key variable for estimating ecosystem productivity. FAPAR can provide critical information on vegetation state, health condition and other ecological properties, and has been widely used in many ecological models, in particular in models in relation to carbon cycle and climate change (*e.g.*, Monteith, 1972; Sellers et al., 1996; Running et al., 2000). At present, FAPAR over regional or global scales is only available from satellite onboard sensors, such as MODIS (Knyazikhin et al., 1998), SPOT VEGETATION (Baret et al., 2007), and MERIS (Gobron et al., 2006). These satellite-derived FAPAR products have greatly revolutionized our ability to monitor the photosynthesis capacity of ecosystems (Kaminski et al., 2012). Large uncertainties however remain in these FAPAR estimations due to remote sensing data quality and radiative transfer model accuracy, etc., (McCallum et al., 2010; Meroni et al., 2012). Validations and evaluations with ground observations and experiments are necessary for reducing these uncertainties.

The validation of satellite-derived FAPAR is greatly limited due to lack of temporally and spatially compatible *in-situ* FAPAR data sets (FAO, 2007; Li et al., 2010). Yang et al. (2006) and Weiss et al. (2007) found that FAPAR were not collected in most of field measurements. This is because FAPAR may fluctuate dramatically within a day because it is greatly affected by the changing light conditions, including solar zenith angle (SZA) and fraction of diffuse PAR (fdPAR) that determine the interactions between foliage and light (Goward and Huemmrich, 1992). To characterize the dynamic FAPAR during a day, it is necessary to have the FAPAR observations at a high time resolution such as the diurnal courses of FAPAR. Such FAPAR data are also useful for assessing whether a single satellite-derived FAPAR value can represent the canopy absorption during the revisit period for a satellite sensor (*e.g.*, 8 days for MODIS FAPAR). It is impractical to obtain the diurnal FAPAR data conveniently based on the direct measurements in the field (*i.e.*, setting distributed arrays of PAR quantum sensors),

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Abbreviations: CF, curve fitting; CI, sky clearness index; FAPAR, fraction of the PAR absorbed by vegetation; fdPAR, fraction of diffuse to total incident PAR over canopy; LMP, the light penetration model; SZA, solar zenith angle.

[*] Corresponding author. Tel.: +86 13522889711.
E-mail address: chenjin@bnu.edu.cn (J. Chen).

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because a large amount of quantum sensors are usually necessary to be installed at numbers of sampling plots in order to account for the heterogeneity of landscape (Resifsnyder et al., 1971 Shabanov et al., 2003). It is therefore worthy developing an indirect method with simple, rapid, and accurate advantages to simulate the diurnal FAPAR, which is the main motivation of this study.

Indirect methods in the field normally estimate FAPAR by analyzing the information about plant canopy gaps that is derived from hemispherical photographs or some commercially available hemispherical radiation sensors (*e.g.*, Li-Cor, LAI-2000) (Gower et al., 1999; Hanan and Bégué, 1995; Nouvellon et al., 2000). These analyses and computations are often based on the inversions by radiative transfer model. For example, Nouvellon et al. (2000) used the light penetration model to estimate canopy PAR absorption in shortgrass ecosystems based on LAI-2000 measurements, and found that the estimation accuracy greatly improved if clumping index, the parameter describing the dispersion nature of vegetation canopy, is sufficiently described. Improving description of canopy structure such as clumping index and foliage inclination distribution can improve the estimation of FAPAR (Govind et al., 2013; Kim et al., 2011; Nouvellon et al., 2000). However, measuring canopy structure in the field is always laborious and time consuming. A few number of studies suggested that light absorption or extinction by plants can also be described by simple measurements of canopies (*e.g.*, Enríquez and Pantoja-Reyes, 2005).

In this study, we thus aim to develop a simple new method to simulate the dynamic FAPAR. To achieve this objective, we performed diurnal PAR measurements for about one week in a wetland on the Tibetan Plateau. This study site provides us with a valuable base for understanding how SZA and fdPAR affect diurnal courses of FAPAR because of the strong diurnal changes of incident light conditions on the plateau. In this study, we first characterized the effects of SZA and fdPAR on FAPAR. We then presented a curve fitting (CF) method to model diurnal FAPAR, and compared the CF method with the widely-used light penetration model. We finally discussed the effects of canopy structures and soil background on the performances of the CF method.

2. Study site and methods

2.1. Study site

The study site (30°28′09″ N, 91°03′4″ E, 4285 m above sea level) is located in an alpine marsh wetland on the Tibetan Plateau near the southern edge of the Nyainqentanglha Mountains. Alpine wetland covers an area of 0.049×10^6 km^2 and is one of the major ecosystem types on the plateau (Sun and Zheng, 1996). The mean annual air temperature of the study site is 1.3 °C, with the coldest and warmest mean monthly temperatures of −10.4 °C in January and 10.7 °C in July, respectively. The mean annual precipitation is 477 mm and mainly falls between June and August (calculated from records at Damxung weather station (30.48 °N, 91.10 °E) during 1970–2000). The flora in this wetland is dominated by *Kobresia littledalei* (Cyperaceae) and *Carex doniana Spreng* (Cyperaceae), with meadow bog soil underneath (Nanjing Institute of Soil Science, Chinese Academy of Sciences, 1978). The canopy is continuous and reaches heights of approximately 35–40 cm with nearly erect leaves. Moreover, this site is quite flat and roughly homogeneous. Field measurements of PAR were conducted during the period of August 5–14, 2011, when the vegetation was in fully developed with maximum density, with an aboveground dry biomass of 643 gm^{-2} on August 14 (see measurements below). An intensive survey in July 2010 also reported an aboveground dry biomass of 767 gm^{-2} for this wetland (Zhao et al., 2010).

2.2. Measurements of photosynthetically active radiation

Photosynthetically active radiation (PAR, 400 nm to 700 nm) was measured by GaAsp quantum sensors (GaAsP G1118, Hamamatsu Corp., Shizuoka, Japan) within a circular quadrat with approximately 1.25 m in diameter. We installed two sensors upward oriented above the canopy to measure the incident PAR (PAR$_{\mathrm{IN}}$) (Fig. 1); another two downward oriented were placed above the canopy to measure the reflected PAR (PAR$_R$). Eight sensors were installed below the canopy pointing upward to measure the transmitted PAR (PAR$_T$). All sensors were connected to a data collecting device (CR23X, Campbell Scientific Inc., Utah, US) and data were recorded at one minute interval. The voltage values from CR23X were then calibrated against an LI-190 quantum sensor (Campbell Scientific Inc., Utah, US) to obtain PAR (μmol photon m^{-2} s^{-1}). The measurements were taken continuously from about 8:00 to 16:00 local time during August 5 and 8, and on August 10, 12, and 13, 2011. Data were not used for a few hours on August 5 and 7 because of rain. Since the cosine error is very small for SZA smaller than 75° and our data were limited within SZA less than 60°, we did not do the cosine-correction (Pearcy et al., 1990; Posada et al., 2009). The hemispherical view without obstruction in the GaAsP sensor and the high linearity between the sensor and the cosine-corrected LI-190 sensor further guarantee the accuracy in our analysis.

According to the light balance equation (Gallo and Daughtry, 1986), and assuming in and outgoing horizontal fluxes average out, the instantaneous canopy FAPAR was calculated as,

$$\mathrm{FAPAR} = \frac{\mathrm{PAR_{IN}} - \mathrm{PAR}_T - \mathrm{PAR}_R + \mathrm{PAR}_S}{\mathrm{PAR_{IN}}} \quad (1)$$

where PAR$_S$ is the PAR reflected by the soil background and are assumed to be zero because of high vegetation density and the dark-wet soil in the alpine wetland.

2.3. Measurements of plant area index and aboveground biomass

We first measured the canopy using LAI-2000 to estimate its plant area index and mean tilt angle. The measurements were conducted in the morning to satisfy the diffuse light condition, and the canopy gap fractions were determined at five zenith angles centered at 7, 23, 38, 53, and 68 degrees (Welles and Norman, 1991). The plant area index and mean tilt angle were estimated to be 6.26 m^2 m^{-2} and 67°, which indicates a dense and typical erectophile canopy.

After PAR measurements, we further harvested the aboveground vegetation within the plot and measured "plant area" directly using an LI-3100 (Li-Cor, Lincoln, Nebraska US). The plants were then dried at 80 °C for 72 h in an oven to obtain dry biomass.

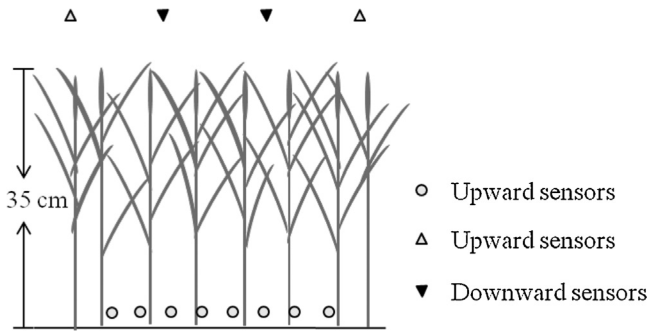

Fig. 1. A sketch indicating the sensor settings for measuring photosynthetically active radiation.