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Mapping diffuse photosynthetically active radiation from satellite data in Thailand

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Abstract

In this paper, calculation of monthly average hourly diffuse photosynthetically active radiation (PAR) using satellite data is proposed. Diffuse PAR was analyzed at four stations in Thailand. A radiative transfer model was used for calculating the diffuse PAR for cloudless sky conditions. Differences between the diffuse PAR under all sky conditions obtained from the ground-based measurements and those from the model are representative of cloud effects. Two models are developed, one describing diffuse PAR only as a function of solar zenith angle, and the second one as a multiple linear regression with solar zenith angle and satellite reflectivity acting linearly and aerosol optical depth acting in logarithmic functions. When tested with an independent data set, the multiple regression model performed best with a higher coefficient of variance R^2 (0.78 vs. 0.70), lower root mean square difference (RMSD) (12.92% vs. 13.05%) and the same mean bias difference (MBD) of −2.20%. Results from the multiple regression model are used to map diffuse PAR throughout the country as monthly averages of hourly data.

Keywords: Mapping; Diffuse photosynthetically active radiation; Model; Satellite

1. Introduction

Photosynthetically active radiation (PAR) forms one part of the solar spectrum with a wavelength range of 400–700 nm. This radiation is the main energy source of photosynthesis which is the start of the food chain. Plants use PAR for the photosynthesis and plant growth. Usually, the amount of PAR is measured as photosynthetic photon flux density, PPFD in mol s^{-1} m^{-2} unit (1 mol = 6.022×10^{23} photons).

Normally, PAR incident at the earth's surface consists of direct PAR and diffuse PAR and the summation of both components is called global PAR. The relative amount of direct and diffuse components of global PAR measured at the earth's surface varies depending on atmospheric parameters and geography. Atmospheric gases such as ozone and water vapor will absorb PAR, while clouds and aerosols are mainly scattering agents. Several researches have examined various depletion agents of PAR (Alados et al., 2000; Grant et al., 1996; Jacovides et al., 1997, 2007; Cho et al., 2003; Tripathy et al., 2015; Tanga et al., 2016), which are different for global and diffuse PAR. Diffuse PAR at the earth's surface mainly depends on cloud, aerosol and solar zenith angle. These parameters are difficult to predict especially for clouds as they vary both spatially and temporally.

Studies on global PAR are well covered in the literatures (López et al., 2001; Hu et al., 2007; Janjai and Wattan, 2011; Wang et al., 2013; Janjai et al., 2013; Janjai et al., 2015a; Yu et al., 2015; Laliberté et al., 2016), but the research on diffuse PAR is very scarce as it is more difficult to measure

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and predict (Alados et al., 2002; Wang et al., 2005; Xiaoli et al., 2014). Diffuse PAR is very important for plant growth in some environments where plants do not receive high intensity of direct beam from the sun. Other environments, such as high latitude polar regions may receive very little direct radiation and practically all the PAR radiation is diffuse. In Thailand, there is a predominance of diffuse PAR during the Southwest monsoon season when cloud depletes most of the direct beam radiation (Janjai et al., 2015b). Productivity is high with ample precipitation, although photosynthesis occurs mostly by diffuse PAR. Given the importance of PAR in photosynthesis, plant growth, and ocean biological productivity (Gates, 1980), it is important to examine how this term behaves, its dependence on external factors, and how it may be modelled.

Towards this objective, we develop two regression models for calculating diffuse PAR using the radiation and related ancillary data from four stations located at four different climate regions of the country. The models are constructed from related data available at the four sites and then tested using an independent PAR data set. The best model is then used for mapping this variable over the entire country on a monthly average hourly basis.

2. Data acquisition

2.1. Ground-based measurements

This analysis has used monthly average hourly data of diffuse PAR and atmospheric parameters. To measure diffuse PAR, quantum photon sensors (EKO, model ML-020P) were used. The sensors are silicon photodiodes which can filter only radiation in the wavelength interval 400–700 nm with a spectral response as shown in Fig. 1.

The instruments were installed at four stations in Thailand, namely Chiang Mai (CM; 18.78°N, 98.98°E), Ubon Ratchathani (UB; 15.25°N, 104.87°E), Nakhon Pathom (NP; 13.82°N, 100.04°E) and Songkhla (SK; 7.20°N, 100.60°E) as shown in Fig. 2. Each photon sensor measuring diffuse PAR was installed on a sun tracker (Kipp&Zonen, model 2AP) on 1.5 m steel pole deployed on a building roof at each station and obstructed from direct solar radiation by a shaded ball. The voltage signals from the instrument was recorded every second by a data logger (Yokogawa, model DX2000). Data conversion to

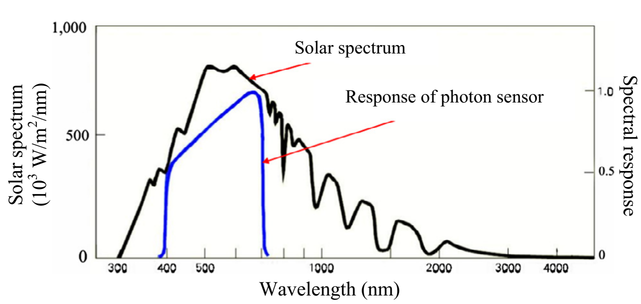

Fig. 1. Spectral response of a photon sensor compared to solar spectrum.

diffuse PAR irradiance used the sensitivity of each instrument. Then values of the irradiance in μmolṡs^{-1}ṡm^{-2} unit were averaged to obtain monthly average hourly data. The data were separated into two groups. The first group (from January 2011 to December 2013) was used for model formulation, while the second group (January–December 2014) was employed for model validation.

Aerosol optical depth at 550 nm is used in this work as it is an important parameter which can both scatter and absorb solar radiation. The measurement of aerosol optical depth is rare in Thailand and as an alternative we use visibility data obtained from 84 meteorological stations around the country to calculate Angstrom's turbidity coefficient using an empirical model developed by Janjai et al. (2003):

$$\beta = 0.589 - 0.068(\mathrm{VIS}) + 0.0019(\mathrm{VIS})^2 \tag{1}$$

where β is Angstrom's turbidity coefficient and VIS is visibility (km).

Afterward, aerosol optical depth at 550 nm is calculated by using a formula of Angstrom (1929).

$$\tau = \beta\lambda^{-\alpha} \tag{2}$$

where τ is aerosol optical depth, α is wavelength exponent and λ is wavelength (μm).

Data of α from 106 sunphotometers of Aerosol Robotic Network (AERONET) located in South, East and Southeast Asia were gathered. Then they were spatially interpolated to cover all areas of Thailand and the values of the interpolated α were used in this work.

Water vapor also has an effect on solar radiation as it can absorb solar radiation above 400 nm. The atmospheric water vapor can be estimated using the method of Janjai et al. (2005) as shown in Eq. (3). Relative humidity, air temperature and saturated vapor pressure data are used in this equation. These data are obtained from the 84 meteorological stations.

$$w = 0.8933\exp\left(0.1715\frac{rh\ p_s}{T}\right) \tag{3}$$

where w is precipitable water in cm, rh is relative humidity in decimal, T is air temperature in K and p_s is saturated vapor pressure in mbar. Those meteorological parameters can be used to obtain precipitable water at each station, and then the data from 84 meteorological stations were spatially interpolated to cover the entire Thailand region.

Solar radiation reaching the earth's surface is absorbed by stratospheric ozone especially in the short wavelengths. Although stratospheric ozone does not influence radiation in the PAR wavelengths much, it will still be considered in this work. Daily total ozone column over the globe can be retrieved from OMI/AURA satellite with spatial resolution of 1°latitude × 1°longitude. These data can be downloaded from http://disc.scu.gsfc.nasa.gov/giovanni during 2006 to 2014, the same period of MTSAT-1R data. For this study, the daily ozone data from OMI/AURA satellite were averaged over individual months to obtain the monthly mean total ozone column. Prior to utilization, the pixels of the