Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 56 (2015) 2356–2364

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Modeling the ratio of photosynthetically active radiation to broadband global solar radiation using ground and satellite-based data in the tropics

S. Janjai [a,*], R. Wattan [a], A. Sripradit [b]

[a] Solar Energy Research Laboratory, Department of Physics, Faculty of Science, Silpakorn University, Nakhon Pathom 73000, Thailand
[b] Faculty of Science and Social Sciences, Burapha University, Sakaeo Campus, Sakaeo 27160, Thailand

Received 6 January 2015; received in revised form 11 September 2015; accepted 12 September 2015
Available online 25 September 2015

Abstract

Data from four stations in Thailand are used to model the ratio of photosynthetically active radiation (PAR) to broadband global solar radiation. The model expresses the ratio of PAR-to-broadband global solar radiation as a function of cloud index, aerosol optical depth, precipitable water, total ozone column and solar zenith angle. Data from the MTSAT-1R and OMI/AURA satellites are used to estimate the cloud index and total ozone column, respectively at each of the four stations, while aerosol optical depth and precipitable water are retrieved from Aerosol Robotic Network (AERONET) sunphotometer measurements, also available at each station. When tested against hourly measurements, the model exhibits a coefficient of variance (R^2) equal to or better than 0.96, and root mean square difference (RMSD) in the range of 7.3–7.9% and mean bias difference (MBD) of −4.5% to 3.5%. The model compares favorably with other existing models.

Keywords: Photosynthetically active radiation; Solar radiation; Ratio; Tropics

1. Introduction

Photosynthetically active radiation (PAR) is a portion of solar radiation in the wavelength band of 400–700 nm. Photons in the PAR range provide energy for photosynthetic process of plants and are thus important in plant growth, biomass production and CO_2 exchange between plants and atmosphere (Olofsson et al., 2007). Climate change studies require a greater understanding of the role of PAR in the earth-atmospheric system. Despite its importance, PAR measurements are still scarce and a modeling approach is required to fill the gap.

Solar radiation spectrum at the earth's surface covers a large range of wavelengths from the ultraviolet to the infrared and the integrated amount of radiant energy over all wavelengths is called broadband radiation. As most of the radiant energy is in the wavelength range from 300 nm to 3000 nm, the measurement of broadband radiation is practically carried out by using pyranometers with their spectral response approximately covering this range (Vignola et al., 2012).

Due to the fact that PAR is part of solar spectrum, a number of authors have proposed relationships between PAR and broadband solar radiation, a more widely measured parameter (Alados et al., 1996; Baranski and Chrzanowska, 1991; Udo and Aro, 1999; Jacovides et al., 2004; Zhang et al., 2000; Gonzalez and Calbo, 2005; Hu et al., 2007; Escobedo et al., 2009; Li et al., 2010). Most

* Corresponding author. Tel.: +66 34 270 761; fax: +66 34 271 189.
E-mail address: serm.janjai@gmail.com (S. Janjai).

http://dx.doi.org/10.1016/j.asr.2015.09.020
0273-1177/

of these studies examined the ratio of PAR to broadband solar radiation as a constant value (Britton and Dodd, 1976; Hansen, 1984; Howell et al., 1983; Udo and Aro, 1999; Papaioannou et al., 1996; Jacovides et al., 2004; Escobedo et al., 2009), or as functions of solar elevation and other meteorological parameters (Alados et al., 1996; Zhang et al., 2000; Alados-Arboledas et al., 2000; Gonzalez and Calbo, 2005; Wang et al., 2006; Hu et al., 2007; Li et al., 2010). It is likely that the PAR-to-broadband radiation ratio is affected by the main depletion agents of solar radiation in the atmosphere, mainly cloud, water vapour, aerosol and ozone (Iqbal, 1983). However, to the best of our knowledge, there is no model which explicitly incorporates all of these parameters. Therefore, the objective of this study is to develop a new model relating the ratio of PAR-to-broadband global radiation using these depletion agents. The radiation and meteorological data used in this work are obtained from four tropical sites in Thailand. This environment is characterized by high humidity during the wet season and high aerosol load from biomass burning in the dry season.

2. Measurements and data

2.1. Ground-based measurements

The model uses data from simultaneous hourly measurements of global PAR and broadband global solar radiation at four stations in Thailand. These are Chiang Mai (18.78°N, 98.98°E), Ubon Ratchathani (15.25°N, 104.87°E), Nakhon Pathom (13.82°N, 100.04°E) and Songkhla (7.20°N, 100.60°E). The station locations are shown in Fig. 1. At each station, a ground-based ultraviolet or GUV radiometer (Biospherical Instrument Inc., model GUV-2511) measures PAR (400–700 nm) plus six bands in the ultraviolet wavelengths which are not used. The measurements of the PAR at the four stations are conducted at a frequency of one minute and averaged every hour. These radiometers are annually calibrated by simultaneous exposure with a newly calibrated radiometer supplied by the manufacturer. All radiometers are also sent back to the manufacturer for hardware check and final calibration at the end of the study. Broadband solar radiation for Chiang Mai, Ubon Ratchathani and Songkhla is measured using Kipp&Zonen pyranometers (model CM21) while a model CM11 from the same company is used at Nakhon Pathom. The voltage signal from the pyranometer is captured every second by a datalogger (Yokogawa, model DC100). The signal is converted into solar irradiance using the sensitivity of the pyranometer. All pyranometers are calibrated annually using a traveling pyranometer recently calibrated at the manufacturer.

The four stations are also equipped with sunphotometers (Cimel, model CE318) which are routinely used to measure solar spectral irradiance at wavelengths of 340, 380, 440, 500, 675, 870 and 1020 nm. These sunphotometers belong to our laboratory and are part of the AERONET of NASA (Holben et al., 1998). The sunphotometers are annually calibrated by AERONET. The spectral data from these sunphotometers are routinely processed by AERONET to provide aerosol optical properties and precipitable water, and are employed in the modeling of the PAR-to-global radiation ratio in this work. The pictorial view of equipment used in this work are shown in Fig. 1.

2.2. Satellite data

To formulate the model of the PAR-to-broadband radiation ratio proposed in this work, other parameters representing cloudiness and ozone are also required. These parameters are derived from satellite data.

Cloudiness is quantified by cloud index (Cano et al., 1986) and it is derived from imagery visible data of MTSAT-1R satellite encompassing the period: 2008–2011. The data are displayed as images covering the entire area of Thailand, with a spatial resolution of 3×3 km^2. The original satellite images are in satellite projection showing the curvature of the earth surface. They are transformed to cylindrical projection, being linear in latitude and longitude. Then, they are navigated using the coastline as a reference. This means that a coastline map of Thailand is superimposed on each image and control points common to both the image and the coastline map are adjusted using a computer program developed by our research group. Nine pixels centered at the position of the four solar radiation measuring stations are selected from the images and averaged to represent the gray level of these stations (Fig. 2). The satellite image consists of a matrix of pixels. Each pixel contains information in the form of gray level, ranging from 0 to 255. The gray level is converted into reflectivity (ρ_{EA}) by using a conversion table supplied by the satellite data agency and this reflectivity is used to derive cloud index. To calculate the cloud index, earth-atmosphere satellite reflectivities (ρ_{EA}) for each pixel covering Thailand are examined and a minimum (ρ_{min}) and maximum (ρ_{max}) values are recorded on a monthly basis. These parameters can then be related to the cloud index n as follows:

$$n = \frac{\rho_{EA} - \rho_{min}}{\rho_{max} - \rho_{min}} \quad (1)$$

The cloud index is derived for each of the four stations and used as a parameter to quantify cloudiness over the stations.

It is noted that the use of cloud index derived from the satellite pixel may cause errors as the position of the station is a point in the satellite pixel. However, this approach gives satisfactory accuracy for PAR estimation to be presented in section 4.

Total ozone column data from OMI/AURA satellite are also acquired for the study area on a daily basis, encompassing the same period as that of MTSAT-1R data. In this study, the level-3 OMI data with the spatial resolution of