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A semi-empirical model for estimating diffuse solar near infrared radiation in Thailand using ground- and satellite-based data for mapping applications

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ABSTRACT

This work has developed a semi-empirical model for estimating monthly average hourly diffuse solar near infrared (NIR) radiation in Thailand. Diffuse NIR radiation data were recorded at four stations in Thailand namely, 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). Our analysis has shown that diffuse NIR radiation is related to cloud, precipitable water and cosine of solar zenith angle in terms of an exponential function. Therefore, the model was formulated with these parameters and validated with independent diffuse NIR measurements. The result showed that diffuse NIR radiation from the model and that from the measurements were in reasonable agreement with root mean square difference and mean bias difference of 16.7% and 1.5%, respectively. The semi-empirical model was used to generate diffuse maps of NIR for the country which displayed both diurnal and seasonal variations.

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1. Introduction

Radiation at the earth's surface consists of solar radiation characterized by short wavelengths covering the region 0.25 μm–3.0 μm, and terrestrial radiation of the region above 3.0 μm called longwave radiation. Shortwave radiation is further subdivided into the ultraviolet (UV), visible and near infrared (NIR) bands. NIR band contributes about 52% of total energy from the sun [1] and is therefore important in global energy studies and climate processes.

In general, the amount of the surface solar radiation depends on latitude, longitude, geography, local climatology as well as atmospheric parameters eg. cloud, aerosol, water vapour. The atmospheric parameters have different effects on the radiation bands. Cloud and aerosol are main parameters which decrease visible radiation by mean of absorption and scattering processes while precipitable water is an important absorption parameter in the NIR band [2].

In biomass production, deterministic plant growth simulation models are usually employed for the prediction of the production [3,4] and these models usually require information on both visible and NIR parts of the solar spectrum.

Similarly to other solar radiation bands, the NIR radiation that reaches the earth's surface is partitioned into direct and diffuse radiation with their sum denoted as global NIR radiation. During the past 20 years, there were some studies on global NIR radiation. For example, Escobedo et al. [5] developed models to estimate hourly and daily global NIR radiation from broadband solar radiation under various sky conditions using solar radiation measured at Botucatu, Brazil. They also carried out the statistical analysis of global NIR radiation at this site in a later study [6].

In general, the penetration of the direct and diffuse components of NIR radiation into the canopy of plants is very different. Naturally, plants utilize the diffuse component more effectively than the direct component. As a result, the accurate plant growth simulation models also require information on the amount of direct and diffuse NIR radiation [7,8]. Global NIR radiation can be obtained from certain measurement stations or from modeling approach [9]. With known global and diffuse NIR radiation, direct NIR radiation can be obtained.

Ideally, diffuse NIR radiation should be obtained from a dense array of solar monitoring stations where diffuse NIR is routinely measured. However, the measurement of diffuse NIR radiation is

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extremely scarce, especially in the developing countries. To overcome this problem, researchers in this field usually use modeling approach to obtain diffuse NIR data. Weiss and Norman [8] have proposed a model to estimate diffuse NIR radiation. According to their model, direct NIR was estimated from atmospheric and geometric parameters and then used as input of a model to calculate diffuse NIR radiation. This model is based on several assumptions such as the portion of diffuse NIR radiation reaching the earth's surface is assumed to be 0.6 of the total diffuse NIR and the effect of cloud is not included in the model, making the model to be applicable only to certain conditions. Therefore, this model is not appropriate to generate NIR maps.

The main objective of this paper is to develop a semi-empirical model for estimating diffuse NIR radiation for diffuse NIR mapping applications using satellite- and ground-based data as input.

2. Data and instruments

2.1. Diffuse near infrared measurement

A precision spectral pyranometer (Eppley, model PSP) with an RG695 filter was used to measure diffuse near infrared radiation in a spectral band covering the region 0.695–2.80 μm. The instrument was installed on a sun tracker (Kipp&Zonen, model 2AP) attached with a shaded ball and therefore providing obstruction from the sun at all times. Uncertainty in the measurement of the radiometer is approximately 9 μV/W.m^{-2}, temperature dependence is 1% in the range −20 °C to +40 °C and the cosine response is about 1% for 0–70° from zenith and 3% from 70 to 80°. Voltage signals from the pyranometer were recorded every second using a Yokogawa data logger, model DX2000. All voltages were converted to diffuse near infrared irradiance using the calibration sensitivity of the pyranometer. Then the data were averaged to hourly data.

The instrument was installed at four sites in Thailand during different periods covering various environments and climatic regimes. The first deployment was in the center of the country at Silpakorn University, Nakhon Pathom (13.82°N, 100.04°E) from May 2012 to January 2014. The second deployment was in the northeast, in Ubon Ratchathani (15.25°N, 104.87°E) from February 2014 to February 2015. The third deployment was in the north, in Chiang Mai (18.78°N, 98.98°E) from March 2015 to February 2016 and the fourth site deployment was in the south, in Songkhla (7.20°N, 100.60°E) from May to November 2016. The locations and instruments at all sites are shown in Fig. 1.

2.2. Satellite data

Geostationary satellite data offers distinct advantages in mapping regional cloud cover as it scans the areas of interest in a timely and regular fashion with a single sensor, therefore avoiding errors arising from use of multiple cloud-observing platforms [10]. In this study, hourly data from the Multifunctional Transport Satellite (Himawari-6) and Himawari-8 in the visible channel were used. The data from Himawari-6 encompassing 2006–2015 and the data from Himawari-8 covering 2016 were employed in this work. Raw images from both satellites were transformed into a cylindrical projection and navigated. The navigation process is as follows.

In the first step, the satellite data were displayed as image using an Interactive Data Language (IDL) computer program. In the second step, a digital map of Thailand was overlayed on each image and this map was adjusted to fit the image using the coastline and islands as references. The fitting was carried out using the IDL program. Finally, the fitted image was sectorized to obtain the navigated image covering Thailand (Fig. 2).

Each navigated image consists of the matrix of 550 pixels × 850 pixels and each pixel contains the information in terms of digital gray levels varying between 0 and 255. This digital gray level was further converted to pseudo-reflectivity by using a calibration table [11] and turned into an earth-atmosphere reflectivity (ρ_{EA}) by division with the cosine of the local solar zenith angle [12]. This parameter was related to cloud cover, with high reflectivity

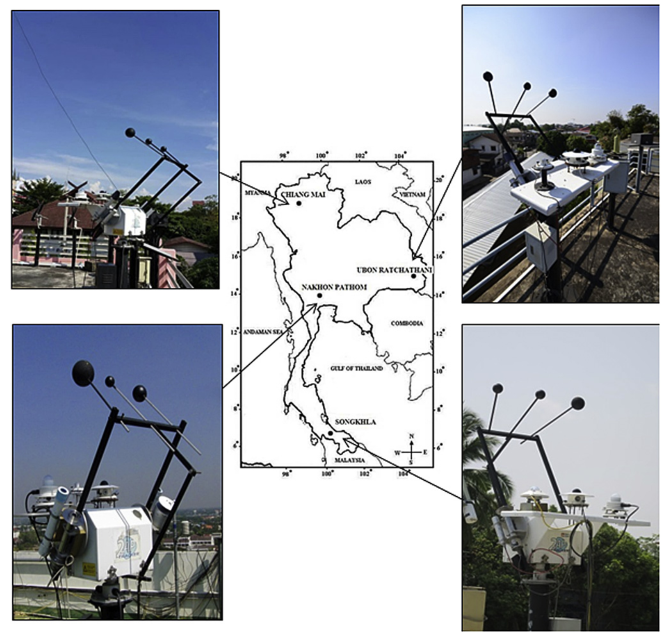

Fig. 1. Installations feature of NIR instruments at the four sites in Thailand.

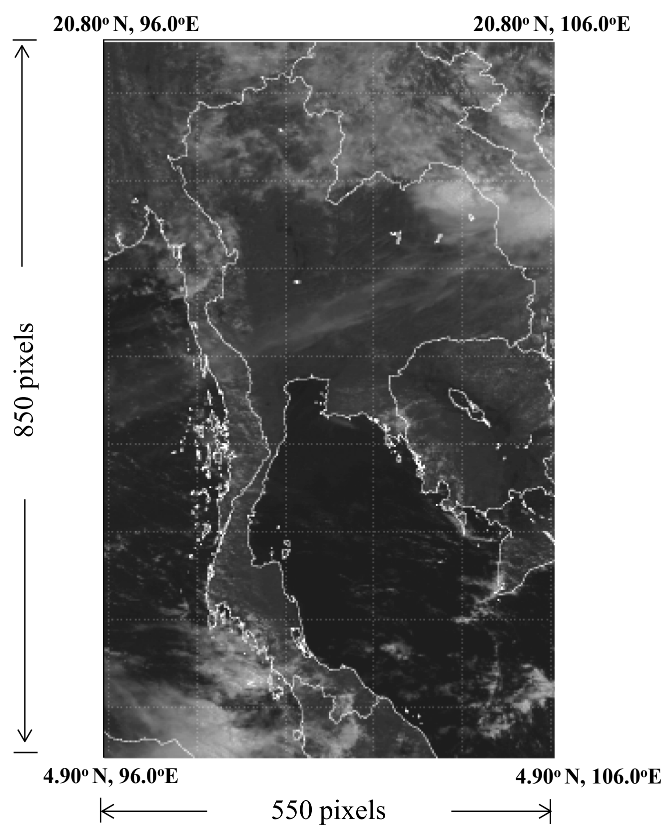

Fig. 2. An example of a rectified image over Thailand.

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