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Estimation of solar radiation over Cambodia from long-term satellite data

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ABSTRACT

In this work, monthly average daily global solar irradiation over Cambodia was estimated from a long-term satellite data. A 14-year period (1995–2008) of visible channel data from GMS5, GOES9 and MTSAT-1R satellites were used to provide earth-atmospheric reflectivity. A satellite-based solar radiation model developed for a tropical environment was used to estimate surface solar radiation. The model relates the satellite-derived earth-atmospheric reflectivity to absorption and scattering coefficients of various atmospheric constituents. The absorption of solar radiation due to water vapour was calculated from precipitable water derived from ambient relative humidity and temperature. Ozone data from the TOMS and OMI satellite data were employed to compute the solar radiation absorption by ozone. The depletion of radiation due to aerosols was estimated from the visibility data. Five new solar radiation measuring stations were established at Cambodian cities, namely Siem Reap (13.87°N, 103.85°E), Kompong Thom (12.68°N, 104.88°E), Phnom Penh (11.55°N, 104.83°E), Sihanouke Ville (10.67°N, 103.63°E) and Kampot (10.70°N, 104.28°E). Global solar radiation measured at these stations was used to validate the model. The validation was also carried out by using solar radiation measured at four Thai meteorological stations. These stations are situated near the Cambodian border. Monthly average daily global irradiation from these stations was compared with that calculated from the model. The measured and calculated irradiation is in good agreement, with the root mean square difference of 6.3%, with respect to the mean values. After the validation, the model was used to calculate monthly average daily global solar irradiation over Cambodia. Based on this satellite-derived irradiation, solar radiation maps for Cambodia were generated. These maps show that solar radiation climate of this country is strongly influenced by the monsoons. A solar radiation database was also generated for solar energy applications in Cambodia.

1. Introduction

The amount of solar radiation incident on the earth's surface is an important information for designing solar energy systems such as solar cells, solar water heaters and solar crop dryers as well as solar passive systems. As solar radiation has diurnal, seasonal and inter-annual variations, long-term solar radiation data are usually required for solar energy system design. Ideally, solar radiation data from the measurements at the site where the systems are intended to build should be used for designing solar energy systems. However, in reality, such data are usually not available and the radiation data from the nearest solar radiation measuring station are employed. An accurate system design is obtained if the density of the measuring stations is high enough to detect the spatial variation of solar radiation. Due to equipment and maintenance costs, the numbers and density of the stations in developing countries are usually far too low to provide sufficient solar radiation data. As an alternative, satellite data can be used to derive solar radiation data, with a reasonable accuracy, especially for a long-term average global radiation. In the past 20 years, a number of satellite-based solar radiation models have been developed with a variety of complexities and accuracies [1–30].

For the case of Cambodia, there is great demand of solar radiation data for solar energy applications, however, there is no systematic solar radiation measurement in this country. Therefore, in this work we proposed to generate solar radiation data from long-term satellite data by using a satellite-based radiation model and five solar radiation measuring stations were established for validation of the model and for long-term systematic radiation measurement in this country.

2. Preparation of satellite data

A 14-year period of 8 bit digital hourly data taken at 8:30, 9:30, 10:30, 11:30, 12:30, 13:30, 14:30 and 15:30 h local time from the

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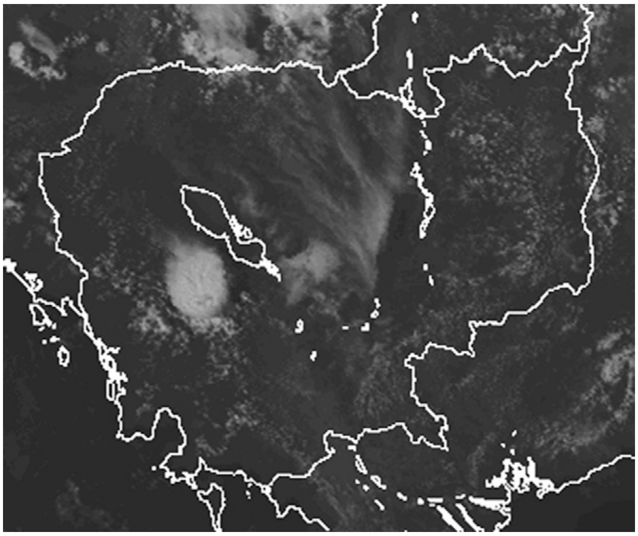

Fig 1. Example of a rectified image.

visible channel of 3 geostationary satellites namely, GMS5 (June, 1995–May, 2003), GOES9 (June, 2003–July, 2005) and MTSAT-1R (August, 2005–December, 2008), were used in this work. These data displayed as image cover the entire area of Cambodia with a spatial resolution of 3×3 km^2. These images originally in satellite projection were transformed to the cylindrical projection and then navigated using coastlines as references. After the navigation, the rectified images which are linear in latitude and longitude are obtained. Each image consists of a matrix of 300×400 pixels. Example of the rectified image is shown in Fig. 1. A calibration table provided by the satellite agencies was used to convert gray levels of all pixels into the earth-atmospheric reflectivity. The values of hourly earth-atmospheric reflectivity were averaged over the day to obtain daily earth-atmospheric reflectivity. Then the values of this daily reflectivity were again averaged over the month to obtain monthly average daily reflectivity (ρ'_{EA}). The values of this parameter were used as the main input of a satellite-based radiation model.

3. Description of the satellite-based radiation model

The model used in this work was originally developed for estimating solar radiation over the tropical western Pacific Ocean [12]. Then it was modified and applied for the tropical environment of Thailand [15]. The model was again improved to account for the upwelling aerosol absorption and effect of the terrain height [29]. This version was selected for this work, because it performed well for several tropical regions especially in South-east Asia. The description of this version is described as follows.

As the wavelength bands of satellite (0.55–0.90 μm of GMS5, 0.55–0.75 μm of GOES9 and 0.55–0.80 μm of MTSAT-1R) and the broadband solar radiation (0.3–3.0 μm) are significantly different, the modeling of solar radiation received by the satellite and solar radiation received by a surface pyranometer are carried out separately. To simplify the modeling, absorption and scattering of solar radiation by aerosols are treated separately, with the absorption coefficient α'_{aer} and scattering coefficient ρ'_{aer}. Rayleigh scattering of air molecules and clouds are represented by scattering coefficient ρ'_A. The absorption of gases (e.g. O_2, CO_2) is represented by α'_g. Although, the visible band of GMS5 includes partly the near infrared wavelengths which are absorbed by clouds, the absorption of solar radiation by clouds was assumed to be negligible.

According to this model, for the satellite band (Fig. 2), when one unit of extraterrestrial solar radiation travels through the earth atmosphere to the earth surface and reflected back from the ground to the outer space, the radiation received by the satellite (ρ'_{EA}) is written as:

$$\rho'_{EA} = \rho'_A + \rho'_{aer} + \left[\left(1 - \rho'_A - \rho'_{aer}\right)\left(1 - \alpha'_w - \alpha'_g - \alpha'_o - \alpha'_{aer}\right)\right]\rho'_G \times \left(1 - \alpha'_{aer}\right)\left(1 - \rho'_A - \rho'_{aer}\right) \quad (1)$$

The first two terms of Eq. (1) are solar radiation reflected back to space by air molecules and clouds (ρ'_A), and by aerosols (ρ'_{aer}), respectively. After these reflections, the rest of radiation $(1 - \rho'_A - \rho'_{aer})$ is absorbed by water vapour (α'_w), ozone (α'_o), gases (α'_g) and aerosols (α'_{aer}). The radiation arrived at the ground is $(1 - \rho'_A - \rho'_{aer})(1 - \alpha'_w - \alpha'_g - \alpha'_o - \alpha'_{aer})$. At the ground, it is reflected back by surface albedo ρ'_G. The reflected radiation: $[(1 - \rho'_A - \rho'_{aer})(1 - \alpha'_w - \alpha'_g - \alpha'_o - \alpha'_{aer})]\rho'_G$ is again depleted by aerosol and clouds in the upwelling path, represented by the last

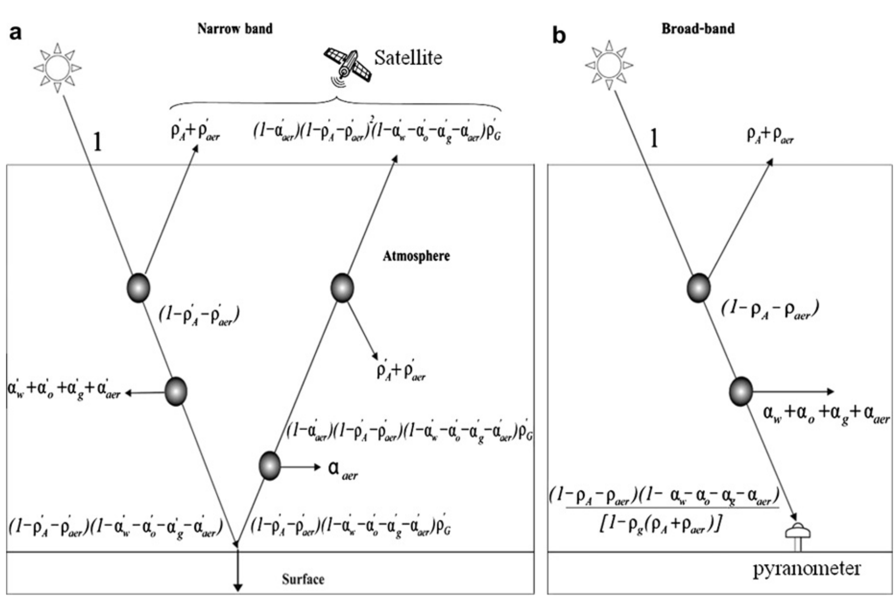

Fig. 2. Schematic diagram of (a) solar radiation modeling for the satellite band and (b) solar radiation as seen by ground pyranometer.