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A method for mapping monthly average hourly diffuse illuminance from satellite data in Thailand

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Abstract

This paper presents a method for mapping monthly average hourly diffuse illuminance from satellite data. The calculation of monthly average hourly diffuse illuminance starts with the estimation of monthly average hourly global illuminance from MTSAT-1R satellite data using an improved satellite-based illuminance model. Next, a diffuse fraction model is developed from ground and satellite-based data which is then used to extract diffuse illuminance from the satellite-derived global illuminance. To assess the performance of the method, modeled diffuse illuminance obtained from this method is compared with that obtained from measurements at four stations in Thailand. There is good agreement between calculated and the measured values of monthly average hourly diffuse illuminance, with the root mean square difference and mean bias difference of 9.7% and −1.4% respectively. The model is used to map monthly average hourly diffuse illuminance for the country. The maps reveal the diurnal and seasonal variations in response to a range of factors including cloud cover, zenith angle and monsoonal effects.

Keywords: Diffuse illuminance; Satellite data; Mapping

1. Introduction

A utilization of daylight for illuminating building interior can provide significant saving in building electricity consumption (Chirarattananon, 2005). For this reason, daylight-integrated buildings and daylight equipment have been developed in many countries (Li and Lam, 2001; Ihm et al., 2009; Zain-Ahmed et al., 2002; Singh and Garg, 2010). Daylight consists of direct sunlight and diffuse sky light. As diffuse sky light does not create glare, it is preferable to use diffuse sky light for illuminating building interior. As a result, the amount of diffuse illuminance available at a location is usually required for assessing the potential use of daylight at that location. Ideally information on diffuse illuminance should be obtained from a dense network of daylight measuring stations where diffuse illuminance is routinely measured. However, in reality the number of the stations is usually scarce and certainly not sufficient to provide reliable data for daylight applications.

As solar illuminance is part of broadband solar spectrum which is derivable from satellite data (Tarpley, 1979; Gautier et al., 1980; Perez et al., 2002; Exell, 1984; Schillings et al., 2004; Vignola et al., 2007; Polo et al., 2011; Ineichen and Perez, 1999; Janjai et al., 2009). Consequently, it is possible to derive illuminance from satellite data. The first attempt to estimate illuminance from satellite data was carried out in the SATEL-LIGHT project (Fontoynont et al., 1997). The estimation technique used in the project consists

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Nomenclature

AOD	aerosol optical depth (–)	α_{aer}	absorption coefficient due to aerosols (–)
d_{aer}	aerosol depletion coefficient (–)	α_g	absorption coefficient due to gases (–)
E_d	diffuse illuminance (lux)	α_o	absorption coefficient due to ozone (–)
E_g	global illuminance (lux)	α_T	total absorption define by Eq. (1b) (–)
$I_{0\lambda}$	extraterrestrial spectral irradiance ($Wm^{-2}\,\mu m^{-1}$)	α_w	absorption coefficient due to water vapor (–)
k_d	diffuse fraction of global illuminance (–)	ρ_{aer}	scattering coefficient of aerosols (–)
k_t	clearness index relative to global illuminance (–)	ρ_A	cloud–atmospheric reflectivity (–)
m_a	air mass (–)	ρ_c	maximum cloud reflectivity (–)
MBD	mean bias difference (%)	ρ_{EA}	earth-atmospheric reflectivity (–)
n	cloud index (–)	ρ_G	surface reflectivity (–)
R	correlation coefficient (–)	ρ_T	total scattering define by Eq. (1a)
RMSD	root mean square difference (%)	τ	illuminance transmission of the atmosphere (–)
T_ρ	total transmission due to scattering (–)	*Superscript*	
T_α	total transmission due to absorption (–)	$'$	quantity in satellite band
VIS	visibility (km)	$''$	quantity in photopic band

of two steps. In the first step, broadband solar radiation is derived from imagery data of METEOSAT satellite. In the second step, it is converted into illuminance by using a luminous efficacy model. For the tropical and subtropical zones, Janjai et al. (2008) and He and Ng (2010) proposed satellite-based methods to estimate global illuminance from geostationary satellite data.

Despite the importance of diffuse illuminance, the derivation of diffuse illuminance from satellite data receives less attention, especially in tropical zone where daylight is abundant. Therefore, the objective of this work is to develop a method for mapping diffuse illuminance from satellite data. The study area of the work is focused on a tropical zone.

At a time scale of an hour, the cloud field is strongly random. This imposes constraints on the ability of satellites to map illuminance with hourly satellite data. By contrast, cloud regional structure emerges after long-term averaging. Therefore in this work, we choose to examine hourly mean illuminance by averaging each hour of the day over the period of one month. Consequently, this procedure averages short time fluctuation of illuminance caused by rapid spatial and temporal variations of cloud structure. Modeling results will present a climatology of diffuse illuminance for daylight applications.

Details of the proposed method are described in the next section. Model performance is assessed in Section 3.1 while Section 3.2 maps diffuse illuminance over Thailand.

2. Description of the proposed method

The main idea of the proposed method is first to derive global illuminance from satellite data. Then diffuse illuminance is extracted from the satellite-derived global illuminance by using a diffuse fraction model from surface-based data. The method can be schematically shown in Fig. 1 and the details of each step are described as follows.

2.1. Processing of satellite data

The satellite data employed in this study are obtained from the visible channel (0.55–0.90 μm) of MTSAT-1R satellite, encompassing a six-year period (2006–2011). The satellite belongs to Japan Meteorological Agency (JMA). In general, the satellite gives hourly data. However, only the data from 8:30 am to 4:30 pm are used in this work. The early morning and late afternoon data are not used due to their low quality resulted from the non-Lambertian reflection. When displayed as images, the satellite data cover the entire area of Thailand with a spatial resolution of 3×3 km^2. These images are transformed into a cylindrical projection and then navigated by using points on the coastlines as reference. Each navigated image comprises 500×800 pixels. Each pixel has a gray level having a value in the range of 0–255. The gray levels of all pixels are converted into earth-atmospheric reflectivity (ρ'_{EA}) using a conversion table provided by the satellite data agency. After correction for incident angle of solar radiation, the satellite data are used as input of a satellite-based illuminance model. All data is grouped and averaged according to hour for each individual month.

2.2. Illuminance measurement

In order to formulate a satellite-based global illuminance model, diffuse fraction model, and validation of the method, it is necessary to have ground-based global and diffuse illuminance data. As Thailand is divided into four geographical regions, our laboratory has stations in each region for monitoring solar radiation in different