Renewable Energy 103 (2017) 171–179

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

A technique for mapping downward longwave radiation using satellite and ground-based data in the tropics

I. Masiri [a, *], S. Janjai [a], M. Nunez [b], P. Anusasananan [a]

[a] Department of Physics, Faculty of Science, Silpakorn University, Nakhon Pathom, 73000, Thailand
[b] School of Land and Food, University of Tasmania, Hobart, 7001, Tasmania, Australia

ARTICLE INFO

Article history:
Received 31 May 2016
Received in revised form
7 October 2016
Accepted 10 November 2016
Available online 10 November 2016

Keywords:
Downward longwave radiation
Satellite data
Tropics

ABSTRACT

This paper presents a technique for mapping monthly average hourly downward longwave ($LW_\downarrow$) irradiance using ground- and satellite-based data. A model relating $LW_\downarrow$ irradiance to a satellite derived-brightness temperature of the earth-atmospheric system, relative humidity and ambient air temperature was formulated. This model was validated against $LW_\downarrow$ irradiance obtained from measurements at 4 sites in the tropics and discrepancy in terms of root mean square errors and mean bias errors was found to be 1.89% and −0.69%, respectively. After the validation, the model was used to calculate monthly average hourly $LW_\downarrow$ irradiance over Thailand and the results were displayed as $LW_\downarrow$ maps. These maps reveal the influence of various factors on $LW_\downarrow$ irradiance.

1. Introduction

An information on the amount of downward longwave ($LW_\downarrow$) irradiance at the earth surface is of importance for many fields including renewable energy and meteorology. In renewable energy, $LW_\downarrow$ irradiance is important for designing radiative cooling equipment. In meteorology, $LW_\downarrow$ irradiance has an influence on the net radiation which affects the stability of the atmosphere.

$LW_\downarrow$ irradiance is emitted by water vapour, carbon dioxide, ozone and cloud water droplets. Under clear sky conditions, $LW_\downarrow$ irradiance can be estimated from several radiative transfer computer codes such as LOWTRAN [1] and MODTRAN [2]. However, an accurate estimate of $LW_\downarrow$ irradiance using a radiative transfer code usually requires accurate profile of atmospheric parameters such as temperature and relative humidity, which are not often available. This makes $LW_\downarrow$ estimate by this approach impractical. The estimation of $LW_\downarrow$ irradiance under cloudy sky conditions using modeling approach is more complicated and needs even more atmospheric data which are usually unavailable on a routine observation.

Although $LW_\downarrow$ irradiance can be measured by a pyrgeometer, routine measurement of $LW_\downarrow$ irradiance using this instrument is costly due to high instrument and maintenance costs. Consequently, the measurement of $LW_\downarrow$ irradiance around the world is sparse, certainly providing insufficient $LW_\downarrow$ irradiance data.

Since the beginning of the last century, atmospheric researchers have attempted to develop simple models relating $LW_\downarrow$ irradiance to wide-spread measured meteorological parameters such as temperature and relative humidity. Ångström [3] is the first researcher who proposed a model relating $LW_\downarrow$ irradiance to a blackbody irradiance estimated from screen-level air temperature (T_a) multiplied by a “bulk” or effective air column emissivity (ε_e). The bulk emissivity is meant to take into account the transparency of the atmosphere, implying for example that when $\varepsilon_e = 1$, the near surface air layer is acting like black body. Conversely, if $\varepsilon_e < 1$, contributions from the colder upper layers of the atmosphere are important.

Numerous authors have attempted to provide expressions for the bulk term ε_e in terms of other screen-level meteorological variables. It consists in essentially relating ratios of measured $LW_\downarrow/\sigma T_a^4$ to relevant variables containing screen-level vapour pressure [3,4], vapour pressure and air temperature [5–7], precipitable water vapour [8], precipitable water vapour and air temperature [9], or air temperature [10,11].

Clouds are efficient emitters of longwave radiation [12] and as a result, a number of models incorporate cloud cover data obtained from surface observations. The exact form of the relationship varies widely depending on the local environment. In the dry sub-Arctic environment of Barrow, Alaska, cloud cover (C) was found to be

* Corresponding author.
E-mail address: iomasiri@gmail.com (I. Masiri).

http://dx.doi.org/10.1016/j.renene.2016.11.018
0960-1481/

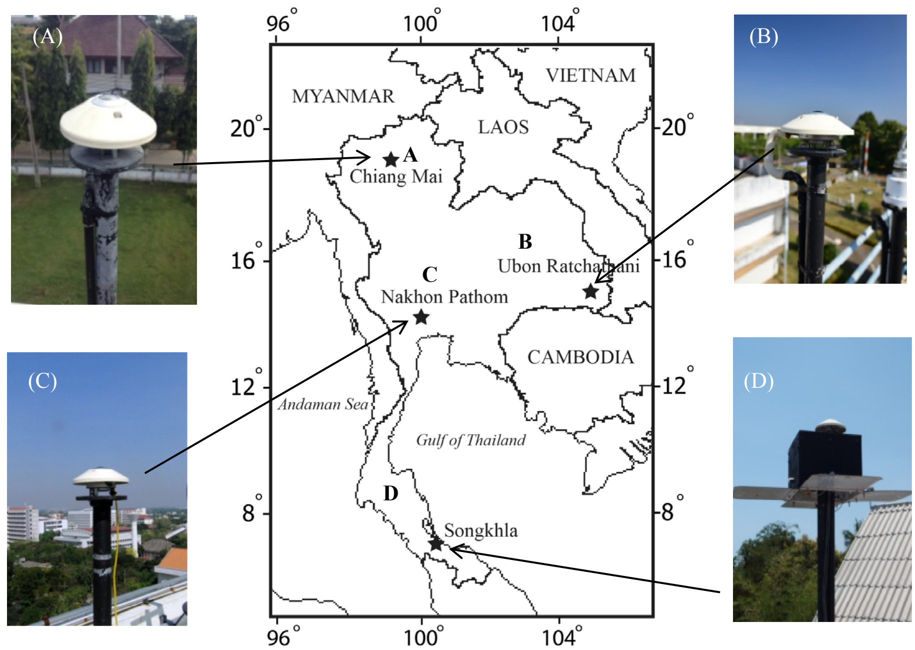

Fig. 1. Pictorial view of the pyrgeometers and positions of the sites (A, B, C and D indicate the northern, northeastern, central and southern regions of Thailand, respectively).

the only good predictor of ε_e [13]. A popular approach is to partition $LW_\downarrow$ irradiance into a cloudless and cloudy portion, and uses a clear sky algorithm to describe the cloudless portion [14–18]. Iziomon et al. [18], describe the cloud term in terms of a quadratic in C that multiplies the cloudless sky ε_e, while in the Andean Altiplano, South America, the correction term is linear in C [19].

In most practical cases, cloud observations are relatively infrequent, so alternative methods involving satellite-derived cloud data are used. Present satellite algorithms provide cloud cover and atmosphere profile information which are then used to estimate $LW_\downarrow$ irradiance via radiative transfer models. Global datasets on $LW_\downarrow$ irradiance may be obtained on-line from the International Satellite Cloud Climatology Program (ISCCP) [20], the CERES Program [21,22] or the Gewex program (GEWEX-SRB) [23]. These are provided at a coarse spatial resolution of around $1^\circ \times 1^\circ$ or more and at a coarse temporal resolution (3 hourly or coarser) as the data is mostly based on sun-synchronous polar-orbiting satellites. This coarse resolution is not sufficient for investigating the $LW_\downarrow$ irradiance over a specific location.

As $LW_\downarrow$ irradiance is strongly influenced by cloud and cloud has a random nature in terms of structure and optical properties, cloud episodes would introduce considerable fluctuation in the $LW_\downarrow$ irradiance. However, cloud regional structure emerges after daily or longer term averaging. In this study, we choose to map monthly average hourly $LW_\downarrow$ irradiance. The resulting maps provide a climatology of $LW_\downarrow$ irradiance which is useful for various renewable energy applications such as the study of potential of nocturnal cooling. Our approach is two-fold. Firstly, we use the existing surface network of $LW_\downarrow$ irradiance, screen-level temperature and relative humidity to construct the model. Given the scarcity of surface-based cloud information, satellite-derived cloud brightness temperature is also used in the model development. Secondly, by using the temperature and relative humidity from high density network and satellite-derived brightness temperature, $LW_\downarrow$ irradiance over the entire area of the country is generated from the model. Merging of these two data should provide detailed distribution of $LW_\downarrow$ irradiance and its changes in the various regions of the country.

2. Methodology

To develop the technique, for calculating $LW_\downarrow$ irradiance, several tasks were carried out as follows.

2.1. Measurement of $LW_\downarrow$ irradiance

Pyrgeometer measurements (Kipp&Zonen, model CGR4) were conducted at four stations in Thailand covering different climatic zones. The instruments were deployed at Chiang Mai (18.78 °N, 98.98 °E) in the mountainous northern region, Ubon Ratchathani (15.25 °N, 104.87 °E) in the dry northeast region, Nakhon Pathom (13.82 °N, 100.04 °E) in the central region, and Songkhla (7.2 °N, 100.60 °E) in the southern maritime region (Fig. 1). For each site, the raw signals and the instrument internal temperature were recorded by a computer every 1 min over 24 h. The voltage signals were converted into $LW_\downarrow$ irradiance using a procedure provided by the manufacturer. The irradiance data were averaged to obtain monthly average of hourly longwave radiation. All pyrgeometers were calibrated by comparing them with a travelling reference pyrgeometer, which was sent to be calibrated at the manufacturer before and after the study period. The pyrgeometers at these sites were maintained by well-trained officers. The input optics of the pyrgeometers were regularly cleaned. The data period of $LW_\downarrow$ irradiance used in this work is shown in Table 1. These data were divided into two groups: the first group for modeling process and

Table 1
Period of data collection used for modeling and validation processes.

Sites	Periods	
	For modeling process	For validation process
Chiang Mai	January 2012 – December 2014	January – December 2015
Ubon Ratchathani	August 2013 – December 2014	January – December 2015
Nakhon Pathom	January 2012 – December 2014	January – December 2015
Songkhla	January 2013 – December 2014	January – December 2015