Comparison of solar spectrum from measurements and that from radiative transfer model under overcast sky condition

K Tohsing*, S Peengam and S Janjai

Laboratory of Tropical Atmospheric Physics, Department of Physics, Faculty of Science, Silpakorn University, Nakhon Pathom 73000, Thailand

*E-mail: korntip.tohsing@gmail.com

Abstract. The solar spectrum under overcast sky condition is of importance for determining the optical properties of cloud by using a radiative transfer model. In this study, solar spectrum under overcast sky condition was measured by employing a spectroradiometer (Instrument System, model SP-320) at Nakhon Pathom station (13.82 °N, 100.04 °E), Thailand. The wavelength range of the measurements is 220-2400 nm, with the resolution of 1 nm in the wavelength range: 220-1700 nm and the resolution of 20 nm in the wavelength range: 1700-2400 nm. The overcast sky condition is determined by using the images of the sky taken by an automatic sky camera. Fifteen datasets of the solar spectrum were compared with those calculated by a radiative transfer model called “LIBRADTRAN”. The input data of the radiative transfer model were obtained from both measurements and literature. As part of the input data, aerosol optical properties were obtained from an AERONET sunphotometer, total ozone column from OMI/AURA satellite and cloud base height from a ceilometer. It was found that the solar spectrum from the measurements and that from the calculation are in reasonable agreement, with the discrepancy in terms of root mean square error (RMSE) of 0.043 W·m⁻²·nm⁻¹. This comparison indicates that this radiative transfer model is accurate enough for use in determining the optical properties of clouds.

1. Introduction

The solar radiation incident at the earth’s surface is an electromagnetic wave which has a wavelength covering mainly from 300 to 3,000 nanometers. It can affect the atmosphere and the global energy balance on the earth’s surface. When the solar radiation passes through the earth’s atmosphere, it was attenuated by atmospheric constituents such as ozone, water vapour, aerosols, gases and cloud via the absorption and scattering processes. Cloud plays an important role in decreasing of surface solar energy. However, it is very difficult to investigate the properties of cloud because they change all the time. Therefore, there were many researchers who determined properties of cloud and its impacts on solar radiation.

Page [1] found that the solar irradiance under overcast sky was changed, depending on the cloud base height, cloud types, and droplet density of clouds. Kasten and Czeplak [2] studied the types of clouds that affect the global solar radiation at Hamburg, Germany. Their results showed that the solar irradiance under overcast sky was changed, depending on solar zenith angle and types of clouds. Matuszko [3] observed that when the solar radiation reaches the earth's surface, it would not be reduced by the high-level clouds such as cirrostratus. On the other hand, the direct solar radiation was reduced by the low-level clouds and mid-level clouds, namely nimbostratus. Moreover, they were also found that different cloud types could cause the difference in solar irradiance about 700 W·m⁻². In case of spectral solar radiation on cloudy sky, Nann and Riordan [4] investigated a spectral transmission of clouds and...
proposed the relationships between cloud thickness and its transmittance in the ultraviolet region of the solar spectrum. Then, they were employed for predicting spectral irradiance. Clouds are a crucial factor affecting the variations of spectral solar irradiance and most studies in the past were carried out under atmospheric conditions in middle and high latitudes and the study in the tropics is very limited [5]. Therefore, this study aims to use a radiative transfer model to estimate spectral solar irradiance under overcast sky by using the input data of cloud and other atmospheric properties in the tropics and then compared the results with those obtained from measurements.

2. The instruments and data

Main instruments used in this work were installed at Silpakorn University (13.82° N, 100.04° E), Nakhon Pathom, Thailand (figure 1) and the data from these instruments encompass a period: August – December 2019. We used the data under overcast sky which was completely covered by a single layer cloud and there was no rain. The sky condition was identified by using sky images taken by a sky camera (PREDE, model: PSV-100). The cloud base height (CBH) was measured by a ceilometer (Campbell Scientific, model: CS135). This ceilometer uses the NIR laser at wavelength of 905 nm which can observe four layers of the cloud base height up to 10 km (figure 1(b)).

Besides the CBH, other inputs for calculating spectral irradiance from a radiative transfer model called “LibRadtran” were solar zenith angle (θz), aerosol optical depth (AOD), single scattering albedo (SSA), asymmetry factor of aerosols, surface albedo, water vapor (W) and total ozone column (O3). The AOD, SSA, asymmetry factor, surface albedo and W were derived from a sunphotometer (Cimel, model: CE318, see figure 1(c)). This instrument is a part of AERONET (Arosol RObotic NETwork) and the data are available on https://aeronet.gsfc.nasa.gov/. Total ozone column was retrieved from OMI/AURA satellite and the data is on the website: https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/.

For the measured solar spectrum, a spectroradiometer (Instrument System, model: SP-320D, see figure 1(d))) was used to collect spectral solar irradiance under overcast sky. The wavelength range of the measurements is 220-2400 nm, with the resolution of 1 nm in the wavelength range: 220-1700 nm and the resolution of 20 nm in the wavelength range: 1700-2400 nm.

![Figure 1](image1.png)

Figure 1. The instruments used in this work (a) sky view, (b) ceilometer, (c) sunphotometer and (d) spectroradiometer and sensor.

3. Methodology

The LibRadtran is a radiative transfer model used to estimate a spectral solar irradiance for entire spectrum from the wavelength of 120 nm to 100 µm. This model based on the DISORT (Discrete Ordinate Radiative Transfer) algorithm applying a plane parallel atmospheric assumption. In this study, we calculated spectral solar irradiance in the range of 300 to 2400 nm under overcast sky with a single layer of clouds and no rain. All inputs of LibRadtran consist of AOD, SSA, asymmetry factor, solar zenith angle, surface albedo, W, O3, CBH, effective radius and liquid water content of cloud. The sources of input data were shown in table 1. These inputs were used in the LibRadtran and the result was the spectral solar irradiance in W·m⁻²·nm⁻¹.
Afterwards, the spectral irradiance obtained from the LibRadtran was compared with that measured by the spectroradiometer. The difference between both datasets was presented in a statistical quantity of root mean square error (RMSE) expressed as follows:

\[
\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X_{\text{model},i} - X_{\text{meas},i})^2} \quad \text{(W·m}^{-2}·\text{nm}^{-1})
\]

where \(X_{\text{model},i}\) is a spectral irradiance calculated from radiative transfer model (W·m\(^{-2}\)·nm\(^{-1}\)) \(X_{\text{meas},i}\) is a spectral irradiance measured from spectroradiometer (W·m\(^{-2}\)·nm\(^{-1}\))

\(N\) is number of data

If the RMSE value approaches zero, it indicates that these two datasets are consistent.

### 4. Results and discussion

Examples of spectral solar irradiance collected by the spectroradiometer at 10.30 AM local time for three days in September, 2019 were presented in figure 2(a) and figure 2(b) presented the spectral irradiance calculated from LibRadtran and that measured by the spectroradiometer on 2 September, 2019. From figure 2(a), the spectral solar irradiance on these days were different due to the cloud’s layer and a path length of the sun. On 2 and 3 September, 2019, the skies were covered by a single layer cloud, whereas on 19 September, 2019, the multi-layer cloud, which attenuated more solar radiation than single layer clouds, were observed.

![Figure 2](image-url)
was found in the range of -0.15 to 0.19 W·m\(^{-2}\)·nm\(^{-1}\). The greatest difference occurred in a near infrared part (700-2400 nm), which was influentially affected by the water droplets inside the clouds.

The comparison between the calculated and measured spectral solar irradiance under overcast sky for the period of August to December, 2019 was shown in figure 3. The result showed that the spectral solar irradiance from both datasets were in reasonable agreement with the discrepancy in terms of RMSE of 0.043 W·m\(^{-2}\)·nm\(^{-1}\). This difference of both data might cause from the variation of actual sky, which leads to the input properties of cloud. In the LibRadtran model, the sky was covered by only single homogeneous layer cloud and water droplet’s properties (liquid water content, cloud effective radius) inside the clouds were set to be constant. Whereas, they might be a multi-layer cloud in the actual sky, which could reduce the spectral irradiance more than the LibRadtran model.

5. Conclusion
In this work, the solar spectrums under overcast sky measured by the spectroradiometer were compared with those calculated by a radiative transfer model called “LIBRADTRAN” applying atmospheric parameters as its inputs during August – December 2019 at Nakhon Pathom, Thailand. It was found that the solar spectrum from the measurements and that from the calculation are in reasonable agreement, with the discrepancy in terms of RMSE of 0.043 W·m\(^{-2}\)·nm\(^{-1}\). This comparing result indicates that this radiative transfer model is accurate enough for determining the optical properties of clouds which affect in surface solar radiation.

References
[1] Page J 2012 Practical Handbook of Photovoltaics (Oxford: Elsevier) pp 573–643
[2] Kasten F and Czeplak G 1980 Solar and terrestrial radiation dependent on the amount and type of cloud Sol. Energy 24 177–89
[3] Matuszko D 2012 Influence of the extent and genera of cloud cover on solar radiation intensity Int. J. Climatol. 32 2403–14
[4] Nann S and Riordan C 1991 Solar spectral irradiance under clear and cloudy skies: Measurements and a semiempirical model J. Appl. Meteor. 30 447–62
[5] Nimnuan P, Janjai S, Nunez M, Pratummasoot N, Buntoong S, Charuchittipan D, Chanyatham T, Chantraket P and Tantiplubthong N 2017 Determination of effective droplet radius and optical depth of liquid water clouds over a tropical site in northern Thailand using passive microwave soundings, aircraft measurements and spectral irradiance data J. Atmos. Sol.-Terr. Phy. 161 8–18
[6] Aufm-Kampe H J 1950 Visibility and liquid water content in clouds in the free atmosphere J. Meteor. 7 54–7