Effect Of Cloudless Sky Parameters On Global Spectral Solar Radiation Within 0.3-1.1 µm Region

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Abstract—The aim of this study is to evaluate the effect of cloudless sky parameters on global spectral solar radiation over the complete solar spectrum (0.3-1.1 µm) in Bangi, Malaysia using SPCTRAL2 parametric model written by MATLAB. The results show that there is a noticeable attenuation in the various spectral global solar irradiance regions when the solar zenith angle becomes larger than 50°. The global solar irradiance at a solar zenith angle 80° has a value of about 146 W m⁻² µm⁻¹ at a wavelength of 0.46 µm but it increases to about 525 W m⁻² µm⁻¹ at a solar zenith angle 10° at the same wavelength. The impact of water vapor on spectral global solar radiation is clear in the visible and near infrared wavelengths between 0.55 and 1.0 µm does not affect the spectral UV. Whereas the ozone effect is especially within the wavelength ranged between (0.3-0.35 µm and 0.49-0.73 µm and there is a strong absorption in monochromatic wavelength 0.469, 0.610 and 0.645 µm. finally the turbidity parameter β has a strong influence on the spectral global solar radiation. The effect of the turbidity parameter β becomes strong when β is equal to 0.20 (turbid) or more and this is due to the increment in the air pollution in the atmosphere. However, the wavelength exponent α has only a minor influence on spectral irradiance. The overall results of this case study show that the spectral global solar radiation is very influenced by an increment or decrement of cloudless sky parameters except the wavelength exponent α.

Keywords—Atmospheric parameters, Spectral solar irradiance (0.3-1.1 nm), Bird and Riordan model, UKM-Malaysia.

I. INTRODUCTION

The functional relationship between intensity and wavelength is called the solar spectral distribution. The spectral distribution of solar radiation outside the earth’s atmosphere, call the extraterrestrial or air mass zero (AM0) spectrum, is well characterized. It roughly resembles the spectrum of a blackbody at 5,900 K [1] with a peak of the spectrum at a wavelength of about 500 nm [2] and the exception of absorption lines caused by attenuation of radiation in the medium surrounding the sun [1]. The exact spectral distribution at the earth’s surface at any time depends on local atmospheric conditions and the path length of solar radiation through the atmosphere (or air mass) [1]; [3].

Many physical, chemical and biological, processes are activated more powerfully at some wavelengths than at others. This is especially true and important in the field of solar energy engineering, where spectrally selective systems such as photovoltaic (PV) devices (to produce electricity), coated glazings, and biological reactors play an increasing role [4].

Usually, these processes cannot be experimentally monitored because of the technical difficulties and prohibitive costs associated with spectral measurements. Moreover, it is often necessary to evaluate or predict the performance of such systems at the design stage, long before they are eventually installed. The only way to perform such predictions is through the use of mathematical models, which must include a description of the spectral characteristics of the incident radiation [5].

A large variety of spectral solar irradiance models have been described or used in the literature, and some of them are reviewed elsewhere. Most solar spectral irradiance models are tailored for a specific application and can generally not be converted to accept other inputs or satisfy other uses [5]. The two main ways generally are used to model the solar spectral irradiance at the ground: first, the simple atmospheric transmittance method (parameterised models, PMs) in which the atmosphere is approximated as a one-layer medium attenuating the extraterrestrial solar irradiance by means of several scattering and absorption processes. The second, the rigorous radiative transfer method (or radiative transfer codes, RTCs), which takes into account the vertical atmospheric inhomogeneity through a series of superimposed scattering and absorbing layers [6].

Examples of the former method are the widely used Bird’s simple spectral model, SPCTRAL2 and simple model for the atmospheric radiative transfer of sunshine (SMARTS2), while an example of the latter method is the well-known LOWTRAN family, which has been supplanted by the even more detailed moderate transmission (MODTRAN) code [6]. Because of the detailed inputs needed, execution time, mathematical and computational complexity, and some output limitations, RTCs...
are not convenient for solar energy or other engineering-type applications. For such uses, two models with different capabilities are recommended: SPCTRAL2 and SMARTS. Even though these models are limited to cloudless sky conditions, they can also be empirically modified to predict spectra under cloudy conditions, at least to some extent [5]; [7]. The main purpose of this paper is to know the influence of cloudless sky parameters on spectral global solar radiation SGSR in Bangi city, 2°55′N latitude and 101°46′E longitude, situated about 35 km south of the capital city of Malaysia, Kuala Lumpur, by using SPCTRAL2 model which written by own MATLAB program.

II. CLOUDLESS SKY PARAMETERS AFFECTING SPECTRAL GLOBAL SOLAR RADIATION

A. Solar Zenith Angle
The air mass is the ratio of the mass of the atmosphere through which beam radiation passes to the mass it would pass through if the sun were at the zenith. It may be expressed as a multiple of the path traversed to a point at sea level with the sun at zenith. By air mass 0 is intended the solar spectral distribution outside the atmosphere. When the sun is directly above a sea-level location the path length is defined as air mass 1. Air mass 1.5 corresponds to a solar elevation of about 42°. When the angle of the sun from zenith increases, the air mass increases approximately by the secant of the zenith angle [9].

B. Water Vapor
Water (H,O) can exist in the atmosphere in three states, as gas, liquid, and ice. Water in gaseous state is called water vapor [10]. Unlike the other gases, water changes state within the range of temperatures observed within the atmosphere; therefore, water vapor derived from the earth’s surface does not accumulate in the air and mix upward thoroughly, but condenses into liquid water and precipitates back to earth before it can rise more than a few kilometers into the atmosphere [11].

Natural concentrations of water vapor in the atmosphere are small but variable between nearly zero and about 5 per cent by volume [12]. Since all water vapor is derived from the earth’s surface [11]. The concentrations are usually higher above oceans, seas and other large water bodies (including large lakes). The concentration of water vapor decreases with altitude, from about 4 per cent close to the ground to more or less zero above about 12 km [12].

C. Ozone
Ozone is natural but unstable molecular. The pure gas has a soft sky-blue colour with a pungent, acrid smell. The molecular is composed of three oxygen atoms (O_3) and the molecular weight, in comparison to the oxygen diatomic molecular (32.00) is of 48.00 [9].

In the upper atmosphere, ozone is created mainly by ultraviolet solar radiation. On the ground, it is formed through decomposition of nitrogen oxide that enters the atmosphere from factory smoke and forest fires for example. The vertical distribution of ozone varies with latitude and season. It is mainly concentrated between a 10- and 35- km altitude. around the equator, total ozone average about 0.24 cm, and the amount increases with latitude: in the polar regions total ozone may be as much as 0.46 cm. at high latitudes, there are distinct variations: in each hemisphere, it is maximum in the spring and minimum in the full [10].

D. Surface Albedo
Albedo is the ratio of the amount of radiation reflected from an object's surface compared to the amount that strikes it. This varies according to the texture, color, and expanse of the object's surface and is reported in percentage. The solar energy community defines albedo as the fraction of solar radiation that is reflected from the ground, ground cover, and bodies of water on the surface of the earth [13].

E. Aerosol
Aerosols are the product of a complicated totality of chemical and physical processes [14]. They are defined in their simplest form as small solid or liquid particles that remain suspended in the air and follow the motion of the air within certain broad limits [15]. An atmosphere containing aerosols is called turbid or hazy. A property of an aerosol-laden atmosphere that depletes direct solar radiation is called atmospheric turbidity, [10]. The presence of aerosols in the earth’s atmosphere has important effects on the transmission of solar radiation and the radiative heat transfers in the atmosphere. This is due to the fact that aerosols absorb and scatter solar radiation as it passes through the atmosphere [16].

III. BIRD AND RIORDAN MODEL (SPCTRAL2 MODEL)
1986
The SPCTRAL2 model was developed in the early 1980s (Bird [17]; Bird and Riordan [18]) but has not been updated ever since. SPCTRAL2 can be useful for very rapid estimates of the clear-sky direct, diffuse and global irradiance on horizontal or tilted surfaces, for 122 wavelengths between 0.3 and 4 μm [5]. The model is based on parameterised models previously developed by Leckner [19]) and by [20]. Bird and Riordan [18] after making comparisons with experimental measurements and accurate spectral codes introduced some corrections to give SPCTRAL2 model its present structure. The model SPCTRAL2 can calculate punctual estimations of spectral irradiances employing as input parameters local geographic coordinates, precipitable atmospheric water vapor content, atmospheric pressure and aerosol optical thickness at 0.5 nm wavelength.
IV. RESULTS AND DISCUSSION

The parameters that have the largest effect on SGSR variations are air mass (solar zenith angle), turbidity (aerosol effects), water vapor thickness and to a lesser extent, ground albedo, amount of ozone and surface pressure.

A. Solar Zenith Angle Effect

The influence of solar zenith angle on SGSR was investigated by using SPCTRAL2 model which has written using the own MATLAB program. Its input parameters as the following; surface albedo was set 0.1, ozone thickness was set at 0.1 cm, aerosol parameters were set at $\beta = 0.05$ and $\alpha = 1.3$ and the month of the year was set as January. The varied parameter in this section is solar zenith angle which is changed from 10° to 80° with an interval of 10° for each run while the other parameters were kept constant at this stage. The result of these studies is shown in Figure 1.

![Fig. 1. The variation of SGSR with wavelength at different solar zenith angles, with other variables held constant](image1)

Figure 1 clarifies that the SGSR varies with wavelength in different values of solar zenith angles. The SGSR decreases with the increase of solar zenith angle. The spectral curves are nearly in the same trend over the course of the year. This is because the atmospheric contents are approximately constant over the year measurement. At solar zenith angle of 10° the SGSR in the range of 0.3-0.39 µm has values between (69 to 367 W m$^{-2}$ µm$^{-1}$). In the wavelength range between 0.4-0.7 µm the SGSR ranged between (526 to 494 W m$^{-2}$ µm$^{-1}$) with a maximum value around 726 W m$^{-2}$ µm$^{-1}$ at wavelength of 0.4 µm.

As the air mass increases, the ultraviolet, visible and near infrared spectrum undergoes much stronger depletion because with longer path lengths of solar beam through the atmosphere (higher Am values) and then there is more opportunity for absorption and scattering of solar radiation by atmospheric constituents.

B. Water Vapor Effect

The effect of water vapor thickness on SGSR was studied by running the SPCTRAL2 model using the following input parameters; surface albedo was set at 0.1, ozone thickness was set at 0.1 cm and solar zenith angle was set at 48.18°, aerosol parameters were set at $\beta = 0.05$ and $\alpha = 1.3$ and the month of the year was set as January. The water vapor was however changed from 0.5 to 9 cm with an interval of 2 cm whereas the other parameters (albedo, solar zenith angle, ozone thickness and month of the year) were kept constant. The result of these studies is demonstrated in Figure 2 which shows how the SGSR varies with wavelength at different values of water vapor thickness.

![Fig. 2. The variation of SGSR with wavelength at different water vapor thickness, with other variables held constant](image2)

It is evident from Figure 2 that there is no any effect of water vapor on the SGSR in the wavelength less than 0.55 µm. In the wavelength range study (0.3-1.1 µm) water vapor causes absorption of solar radiation in absorption bands in the visible and near infrared wavelengths between 0.55 and 1.0 µm does not affect the spectral UV. As water vapor thickness increases, the absorption regions deepen and broaden, and consequently the solar irradiance decreases.

C. Ozone Effect

The impact of ozone thickness on SGSR was studied by running the SPCTRAL2 model using the following input parameters; surface albedo was set at 0.1 and solar zenith angle was set at 48.18° aerosol parameters were set at $\beta = 0.05$ and $\alpha = 1.3$ and the month of the year was set as January. The ozone thickness was however changed from 0.1 to 0.25 at an interval of 0.05 whilst the other parameters (albedo, solar zenith angle and month of the year) were kept constant. Figure 3 shows that there are small disparity of SGSR curves in the wavelength ranged between (0.3-0.35 µm) with a noticeable
absorption in monochromatic wavelength at (0.34 and 0.36 µm).

In the wavelength ranged between (0.35-0.49 µm) the SGSR remains unchanged by a varying amount of ozone. This is because the ozone thickness does not impact on SGSR in this range. Same effect of ozone thickness on SGSR happens in the wavelengths between (0.73-1.04 µm). In the wavelength range between (0.49-0.73 µm) there is noticeable disparity between the SGSR curves with stronger bands centered at 0.469, 0.610 and 0.645 µm. Attenuation by ozone is confined to the ultraviolet and the visible spectrum mainly at the wavelengths between 0.5 and 0.7 µm.

D. Albedo Effect

The influence of surface albedo on SGSR was studied by running the SPCTRAL2 model using the following input parameters; solar zenith angle was set at 48.18°, ozone thickness was set at 0.1 cm, aerosol parameters were set at β = 0.05 and α = 1.3 and the month of the year was set at January. The albedo was changed from 0.1 to 0.9 with interval of 0.2 whilst the other parameters (solar zenith angle, ozone column and month of the year) were kept constant. The result of these studies is shown in Figure 4 which shows how the SGSR varies with wavelength at different values of the surface albedo.

The SGSR increases as the ground albedo increases. This is due to the fact that as the albedo increases, more solar irradiance is reflected from the ground into space. It should be clear that, the influence of ground albedo only affect on diffuse component; this means that for an ideal diffuser surface the radiation reflected is independent from the angle of incidence. The global irradiance at a solar zenith angle 48.18° has a value of about 484 W m⁻² µm⁻¹ at a wavelength of 0.33 nm when the albedo is 0.1 but it increases to about 276 W m⁻² µm⁻¹ at the same wavelength when the albedo is 0.9. The albedo is greater at shorter wavelengths because more energy is scattered in the shorter than in the longer wavelengths.

E. Aerosol Effect

The effect of aerosol on SGSR was studied by running the SPCTRAL2 model using the following input parameters; surface albedo was set at 0.1, ozone thickness was set at 0.1 cm, water vapor was set at 0.5, solar zenith angle was set at 48.18° and the month of the year was set at January. It should be clear that, the spectral effects of aerosol attenuation depend on the properties of the aerosol mainly, the amount of aerosol present in the atmosphere in the vertical direction β and average particle size α. The effects of variation in the turbidity parameter β and of the wavelength exponent α are demonstrated through Figures 5 and 6 respectively.

Figure 5 clarifies that the turbidity parameter β has a strong influence on the spectral reaching the ground. An increase in β diminishes irradiance. Furthermore, irradiance at λ> 0.5 µm remains unchanged by a change in α. The wavelength exponent α, however, has only a minor influence on spectral irradiance. From Figure 6 by keeping total amount of aerosol constant (β = const), the global irradiance remains almost insensitive to changes in α. Small variations that do occur in global irradiance are confined to the near-ultraviolet and the visible portion of the spectrum. Consequently, an increase in α results in slightly lower values of global irradiance.
VI. REFERENCES


V. CONCLUSION

The purpose of this work was to know how the global spectral solar radiation varies due to the variation of the air mass, water vapor, albedo and turbidity using the spectral irradiance model SPCTRAL2 for clear skies on the site of Bangi (Malaysia). The following is a summary of the conclusions:

1. There is a noticeable attenuation in the various SGSR regions when the solar zenith angle becomes larger than 50°.
2. There is a clear impact of water vapor variation on SGSR in the visible and near infrared wavelengths between 0.55 and 1.0 µm does not affect the spectral UV.
3. There is a clear impact of ozone variation on SGSR especially within the wavelength ranged between (0.3-0.35 µm and 0.49-0.73 µm and there is a strong absorption in monochromatic wavelength 0.469, 0.610 and 0.645 µm.
4. An increase in ground albedo increases the amount of global spectral solar irradiance. The global irradiance at a solar zenith angle 40.18° has a value of about 461 W m⁻² µm⁻¹ at a wavelength of 0.46 µm when the albedo is 0.1 but it increases to about 609 W m⁻² µm⁻¹ at the same wavelength when the albedo is 0.9.
5. However, the wavelength exponent α, has only a minor influence on spectral irradiance. The effect of the turbidity parameter β becomes strong when β is equal to 0.20 (turbid) or more and this is due to the increment in the air pollution in the atmosphere.

Fig. 5. The variation of SGSR with wavelength at different amount of aerosol in the vertical direction (β), with other variables held constant

Fig. 6. The variation of SGSR with wavelength at different particle size (α), with other variables held constant