Average Intensity and Wavelength of the Emitted Radiations from Earth Surface with Error Analysis

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ABSTRACT

This research finds the spectrum and the net intensity of the emitted radiations from the earth surface at different temperatures of 273, 283, 293, 303, 313, and 323 K. The intensity of the radiations emitted from the surface varies by 272.013 Wm^{-2} between 273 K and 323 K surface temperatures at emissivity 0.9. The average intensity for emissivity 0.9 is 410.405 Wm^{-2}, with a standard deviation of 101.94 Wm^{-2} and standard error 41.616. The calculated mean emitted flux is found 8.9482 $W/m^2/sr/\mu m$ for 0.9 emissivity. At emissivity of 0.96, the desert emits radiation with an average intensity of 437.77 Wm^{-2} having standard deviation 108.708 Wm^{-2} and standard error 44.379. These large values of standard deviation and standard error are due to the large difference between any two adjacent values of intensity of the emitted radiations. Standard error comparisons between the emissivity calculations of 0.9 and 0.96 show that the intensity in emissivity 0.9 is more appropriate than the intensity in emissivity 0.96 in determining the average value of intensity of emitted radiations. The difference between the calculated and standard values for the average intensity of radiation radiated from the earth's surface is about 17%.

Keywords: Black body emission curve, Emissivity, Irradiance, Intensity, Gaussian Curve

1. INTRODUCTION

Solar radiations are a perpetual source of natural energy. The sun emits electromagnetic radiation and covers a very large range of wavelengths. The range of emitted wavelengths varies from radio waves through the infrared, visible and ultraviolet to X-rays and gamma rays. 99% of the emitted energy of the solar radiations is contained in the wavelength band from 0.15 to 4 µm, consisting of the near ultraviolet, visible and near infrared regions of the solar spectrum. About 40% of the solar radiation received at the earth's surface on clear days is visible radiation within the spectral region 0.4 to 0.7 µm while 51% is infrared radiation in the spectral region 0.7 to 4 µm (Bhatia 2014). The solar disk subtends a solid angle of about 0.5° on average from the earth. The eccentricity of the earth's elliptical orbit is 0.0167. So the distance from the earth to the sun varies throughout the year by ±1.7%, which results in ±3.4% variation in the intensity of the solar radiation at the top of the atmosphere. Earth's reflects about 29% of the incident solar irradiance back to space (Badescu 2008). The depletion layer of solar radiation caused by aerosols is a result of absorption and scattering processes. The water vapors and ozone layer reduces solar radiation energy (Janjai *et al.* 2013). The earth's atmosphere reflects a large amount of the radiation received from the sun. When solar radiation arrives at the top of the earth's atmosphere, it has a peak irradiance value of 1370 Wm^{-2}. This value is known as the solar constant. Similarly, when the solar radiation reaches the earth's surface, it has a peak irradiance value of approximately 1000 Wm^{-2}. The difference between the solar constant and the peak irradiance value at the earth's surface is due to the earth's albedo (Stapleton & Neill 2012). Some solar radiations are absorbed by gases in the atmosphere and some radiations are transmitted (Schmittner 2017). The intensity of the radiation absorbed by the earth's surface is important to calculate the temperature on which the earth surface operates, which is discussed in section 1.1.

1.1. Calculation of the Absorbed Solar Radiation by the Earth Surface

The absorbed solar radiation can be calculated from the total solar irradiance (TSI = 1370 Wm^{-2} at the top of the atmosphere). Earth is a rotating sphere. The amount of radiation received per area is total solar irradiance divided by four. It is because of the area of a sphere is 4 times the area of a disc with the same radius.

$$S = TSI / 4 = 1370 / 4 \approx 342\ Wm^{-2}$$

Fractional part of the incident solar radiation is reflected to space by bright sources such as clouds or snow which is called albedo (a) or reflectivity. The average value of albedo for earth is about 0.3. This means that about 30 percent of the incident solar radiation is reflected to space. This part of energy has no contribution to heating the climate system. So the solar radiation that enters the earth's atmosphere is

$$(1-a)S = (1-0.3)342 \approx 238\ Wm^{-2}$$

In unit m2 area, the energy absorbed per unit area per unit time is 238 J (Stapleton & Neill 2012). This value of energy received by the earth surface varies due to the change in atmospheric conditions and this value of energy is used to estimate the average temperature of the earth surface. The temperature of the earth surface increases by 261 K when it receives 238 J energy. This value may be either greater or lesser depending upon the climate, incident solar radiations, humidity, wind etc. Greenhouse gas also plays a major feedback role in global temperature and hence on temperature of the earth surface (Audi *et al.* 2020). If there is variation of ±3.4% in intensity of the solar radiation, there is an increase or decrease of 47 Wm^{-2}. The total solar irradiance is 1417 Wm^{-2} when intensity of the solar radiation increases by 3.4%, and the total solar irradiance is 1323 Wm^{-2} when intensity of the solar radiation decreases by 3.4%. Since, the area of a sphere is 4 times the area of a disc with the same radius. So, the amount of radiation received per area is the total solar irradiance divided by four,

$$S = TSI / 4 = 1417 / 4 \approx 354\ Wm^{-2}, \text{ if there is variation of } + 3.4\%.$$

The amount of radiation received per area is

$$S = TSI / 4 = 1323 / 4 \approx 331\ Wm^{-2}, \text{ if there is variation of } - 3.4\%.$$

The solar radiation that enters the earth's atmosphere is (1-a) S = (1-0.3)354 ≈ 248 Wm^{-2} when it receives 354 Wm^{-2} by the earth atmosphere. Similarly, the solar radiation that enters the earth's atmosphere is (1-a) S = (1-0.3)331 ≈ 232 Wm^{-2}, when it receives 331 Wm^{-2}.

Using Stefan's Boltzmann law ($P = \varepsilon\sigma AT^4$) the temperature of the earth surface increases by 261 K when it receives 238 joule energy. There is no significant change in the temperature of the earth's surface when there is variation of intensity of the solar radiation by ±3.4%.

About 25–30% solar radiation is removed before it hits the earth's surface. These radiations are removed from the scattering of light and from the absorption by water vapor and ozone (O_3). The most important absorbers in the infrared are water vapor and carbon dioxide. Oxygen/ ozone, methane, and nitrous oxide absorb smaller amounts of ultraviolet radiations (Liang *et al.* 2020). Greenhouse gases absorb infrared radiation. There is only a relatively narrow window around 10 µm through which earth's atmosphere allows radiation to pass without much absorption. Mostly, earth's atmosphere is transparent to solar radiation, whereas it is mostly opaque to terrestrial radiation (Schmittner 2017). The energy's intensity decreases satisfying exponential law when it goes through the atmosphere (Kordun 2015). The radiation emitted from the earth surface depends upon its temperature and this emitted radiations from this earth surface contain a spectrum of wavelength.

1.2. Temperature and Electromagnetic Spectrum

Atmospheric temperature is a measure of temperature at different levels of the earth's atmosphere. It is governed by many factors like the climate, incoming solar radiation, humidity, wind and altitude.

Since the bodies exhibit temperatures in the range 200 K–300 K and terrestrial radiation lies in the infrared portion of the electromagnetic spectrum. At mean surface temperature 288 K, nearly all the emission from a black body occurs between the wavelengths limits of 4 µm and 100 µm, with peak monochromatic emittance at 10 µm (Arnfield 1990). The wavelength and spectral radiance plot for gases O_3, CO_2, H_2O has been discussed by Kiehl *et al.* (Kiehl & Trenberth 1997).

Earth is a black body and the black body emits a spectrum of radiation. Wien's displacement law can also be used to a body (having emissivity) which is not perfectly black (Neupane 2020). The Stefan–Boltzmann law is concerned with the total power of blackbody radiation emitted across the entire spectrum of wavelengths at a given temperature. The area under the black body emission curve represents the total intensity of the emitted radiations from the earth surface. Emissivity is the key parameter to draw the simulated blackbody emission curve. The peak emission wavelength varies due to the variation in the value of emissivity and so the distribution of the emitted radiations depends upon the peak emission wavelength (Li & Chen 2021). The value of earth surface emissivity depends upon its materials and this emissivity and temperature of the surface which are discussed in section 1.3 and 1.3.1.

1.3. Earth Surface Emissivity

The emissivity of a material surface depends on many chemical and physical properties. It is often difficult to estimate. The value of emissivity for the same material on the earth surface keeps on changing. Exact value of earth surface emissivity cannot be known. The earth surface temperature depends upon its emissivity. The increase in earth surface temperature varies due to variation in the value of emissivity of the same surface. Emissivity is important for heat transfer calculations.

1.3.1. Temperature and Emissivity Variation of the Earth Surface with Reference to the Desert

The surface of earth's crust is covered mainly by water, sand (in desert) and other vegetative surfaces. The deserts are made up of a number of abiotic components that includes sand, the lack of moisture and hot temperatures. The range of the emissivity is also found to be between 0.85 and 0.96 (Ogawa & Schmugge 2004).

The Sahara desert (Cloudsley–Thompson 2011) is one of the largest and hottest regions in the world, with mean annual temperatures exceeding 30 °C. In the hottest months, temperatures can rise over 50 °C, and temperatures can fall below freezing in the winter. The minimum surface temperature and the maximum surface temperature are used to calculate the intensity and the wavelength of the emitted radiations from the earth surface. The evaluated wavelengths are used in estimating in season biomass and corn grain yield. Integrated radiation from the earth surface can be determined either by direct measurement or by calculation. Stefan's Boltzmann law can be used to determine the net radiation emitted from the earth surface. The calculated value of the emitted radiations depends on the emissivity of the earth surface. The value of emissivity changes due to the atmospheric conditions like humidity, moisture etc. It changes continuously and so the calculations of the emitted radiations may not be of higher precision. For the direct measurement, Net Radiometer (NR) could be used after calibration. This parameter strongly depended on wind speed and light incidence angle. Emitted radiations changes over time continuously and the measurements can have a high uncertainty (An *et al.* 2017). Indeed, Evett *et al.* (Evett *et al.* 2012) stated that even new radiometers can have an error as high as 10%. Halldin & Lindroth (Halldin & Lindroth 1992) performed comparative measurements using six different types of NR and they observed a difference between 6% and 20%.

Ninomiya & Fu (Ninomiya & Fu 2019) measured the range of emissivity of wavelength from 5 µm to 15 µm for quartz, feldspar, dunite, calcite, water, and ice. The values of emissivity for the same material on the earth surface as reported in different journals were varied but nearly equal. The value of soil emissivity varies in a narrow range, from 0.9 to 0.98. (An *et al.* 2017). Researchers (Ren *et al.* 2017) also measured narrowband emissivities of the land is ranged from 0.95 to 0.99 and the broadband emissivities is ranged from 0.93 to 0.99. Lorenz (Lorenz 1966) obtained emissivity of some common surface materials which ranged from 0.973 for a dense lawn to 0.938 for sand. Idso *et al.* (Idso *et al.* 1969) reported emissivity of a number of plants and the values ranged from 0.938 to 0.995. To summarize over water or surfaces covered with vegetation, emissivity is 0.97 or higher and the assumption that the emissivity is 1.0 can often give satisfactory results for many uses. Since the transmissivity of soils and minerals is zero, measurements of the emissivity can be obtained from measurements of reflectivity (Ninomiya & Fu 2019). Accurate emissivity data are needed as model inputs to better simulate the radiations emitted from the land or earth surface.

Knowledge of the earth's radiative surface temperature is necessary in order to infer air temperature profiles from measurements of spectral radiance made from a satellite. Coll *et al.* (Coll *et al.* 2012) discussed the potential of single channel thermal infrared data measurements for determining atmospheric profiles by knowing the earth surface radiative temperature from other sources. Lohnert *et al.* (Lohnert *et al.* 2009) used an iterative technique to determine a temperature profile, a humidity profile, and surface temperature from measurements of spectral radiance at several wavelengths. An infrared thermometer (IRT) that is used widely to make measurements of surface temperatures which measures radiation in the spectral region from 8 µm to 13 µm. The actual spectral interval varies from model to model. Spectral radiance represents the power flux per wavelength or frequency and per surface area into the hemisphere, which can be seen from the radiating surface element. There are other factors affecting emissivity. Dynamic states of vegetation such as growing crops and idle crops (bare soil) have distinct emissivity. A good review of emissivity and vegetation index was provided by Van de Griend & Owe (Van de Griend & Owe 1993). Emissivity depends on land cover, with high values over dense vegetation regions and apparently low values over desert regions.

The structure on the earth surface has steel, aluminum etc. which are contained in very small amounts in comparison to the area occupied by the water surface (Ocean), the deserts, and the vegetative surface. So the intensity of the radiations emitted from the low value emissivity materials like aluminum, steel are very small which do not affect largely to the average value of the emitted radiations from the earth surface (Youngblood *et al.* 2022). Similarly, the glass (smooth uncoated) covers a very small fraction of the total surface of the earth surface. So the intensity of the radiations emitted from this small fraction surface does not impact largely to the calculated value of the average intensity of the emitted radiations from the earth surface even though the glass (smooth uncoated) has high value of emissivity equal to 0.95. So we have used water, desert, asphalt, brick etc. to calculate the average intensity of the emitted radiations from the earth surface.

In this study, the radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance and band radiance, which are independent upon the lower and upper limit value of the wavelength chosen along with the difference in temperature and emissivity, are going to be determined. Beside this, the average intensity of the emitted radiations is going to be calculated with error analysis. In the previous research, the wavelength range of the radiations emitted from the earth surface has not been determined from the simulated black body emission curve in the range of temperature from 273 K to 323 K in the interval of 10 K, so the wavelength of the emitted radiations is going to be analyzed from the blackbody emission curve. Also, we have performed numerical calculation to determine the intensity of the emitted radiations from the individual objects like silver polished, aluminum foil, copper foil, asphalt, snow, brick, glass (smooth uncoated), water, ice and desert at different temperatures, at which earth surface almost operates.

1.3.2. Materials with their Emissivity

There are different materials in the earth surface and the table 1 shows the materials with their respective emissivity.

Table 1: Emissivity of Materials (Brewster 1992).

Materials	Emissivity
Silver polished	0.02
Aluminum polished	0.03
Copper polished	0.04
Asphalt	0.88
Snow	0.8 – 0.9
Brick	0.93
Glass (Smooth uncoated)	95
Water, pure	0.96
Ice	0.97

The water and ice are almost perfect black bodies (Schmittner 2017).

2. MATERIALS AND METHODS

The main difficulty encountered in this work is the selection of emissivity of the surface. The total power of blackbody radiation emitted across the entire spectrum of wavelengths (i.e. from 0.3μm (lower limit) to 1μm (upper limit)) at a given temperature has been determined and discussed. The model of choosing lower limit value and upper limit value of wavelength is based on the probability distribution of the spectrum of emitted radiations from the soil surface. The total power has been represented by the area under the blackbody radiation curve at a given temperature. The different curves intensity of blackbody radiation versus the wavelength of the emitted radiation has been shown corresponding to a different blackbody temperature starting with a lower temperature at 273 K to a high temperature at 323 K. In this work, earth surface at temperature 273, 283, 293, 303, 313, and 323 K were taken for study. The distribution of the radiation from the earth's surface depends upon peak emission wavelength. Using Stefan's Boltzmann law, the approximate value of emitted intensity by the earth's surface is 238 Wm^{-2} at 261 K. On the basis of this calculated value of total solar irradiance received by the earth, and from the reference of the standard value of the mean surface temperature 288 K of earth, the temperature of the earth's surface were taken 273, 283, 293, 303, 313, and 323 K for study. The blackbody emission curves were drawn at 0.9 value of emissivity and at the given series of temperatures above. The work was carried out to determine the average intensity of the emitted radiations on different surface materials of earth existing as major proportions which are asphalt (0.88), desert (0.9), brick (0.93), and water (0.960). The intensity of the emitted radiations from different materials of section 1.3.2 on earth surface having the lower value of emissivity (Silver polished, Aluminum polished and Copper polished) at different temperatures was also calculated. Which emit a very small value of intensity of the radiations in comparison to the materials having high value of emissivity. So the average intensity of the emitted radiations from the low emissivity materials was not calculated. The normal Gaussian curve was drawn for the average intensity of the emitted radiations from desert at different values of emissivity of 0.9 and 0.96 to compare the standard deviation and standard error. The normal Gaussian curve was also drawn for the average intensity of the emitted radiations from different materials (i.e. asphalt, desert, brick and pure water).

Radiant emittance from the earth's surface was calculated by using Stefan's–Boltzmann law. Peak emission wavelength was obtained by using Wien's displacement law. Peak emission wavelength obtained by using Wien's displacement law was used to investigate the distribution of the emitted radiations from the earth's surface. Stefan-Boltzmann law, Wien's displacement law and simulated blackbody emission curve were taken to carry out and complete our research work. High-resolution spectral modeling (Spectral Calc.com) was used to obtain a simulated black body emission curve when the temperature, emissivity and value of peak emission wavelength (from Wien's displacement law) were given as inputs. The emission curves were drawn to compare the spectral irradiance of the earth surface at the given temperatures. The radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance and band radiance were calculated for each earth surface temperature. The integrated radiance was also calculated for each temperature of the earth surface.

3. RESULTS AND DISCUSSION

In this section, the simulated black body emission curves have been shown in Fig. 1–6 and discussed in terms of radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance, and band radiance. From the Fig. 1 to Fig. 6, the plot between intensity and wavelength at different temperatures at constant value of emissivity (0.9) has been shown. The standard deviation and standard error, and percentage error were also calculated. The normal Gaussian curve were discussed in the Fig. 7(a), 7(b) and 9. Similarly the plot between intensity and temperature at defined different emissivity (Fig. 8(a)) and intensity and emissivity at defined different temperature (Fig. 8(b)) have also been shown and discussed.

3.1 Simulated Black Body Emission Curve at Different Temperatures and at Emissivity 0.9

In this sub-section, black body emission curves have been drawn at different soil temperature 273, 283, 293, 303, 313 and 323 K. For each temperature, radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance, band radiance were calculated. These values were calculated at lower and upper limit wavelength of 0.3 μm and 1 μm respectively, and at emissivity 0.9. The value of spectral radiance shown in Table 2-7 indicates the strength of the emitted wavelength at the specified temperatures.

3.1.1 For 273 K Soil Surface Temperature

Table 2 shows the radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance and band radiance for the soil temperature 273 K. The calculated value of peak emission wavelength at this temperature is 10.6145 μm. Fig. 1 is the black body emission curve for 273 K surface temperature. The intensity of emitted radiation is 283.476 Wm^{-2} and about 5.34321e+19 photons are required for one joule of energy. The radiant flux emitted from a point source in a certain direction per unit solid angle per unit projected area perpendicular to the specified direction is 90.2332 $W/m^2/sr$.

Table 2: Radiant emittance, radiance, peak spectral radiance, spectral radiance and band radiance profile at temperature 273 K

Inputs	Results
	Radiant emittance: 283.476 Wm^{-2}
Emissivity: 0.9	Radiance: 90.2332 $W/m^2/sr$
Temperature: 273K	Peak spectral radiance: 5.58979 $W/m^2/sr/\mu m$
Peak emission wavelength: $1.0614 x 10^{-5}$ m	Wavelength of peak: 10.6145 µm
	Spectral Radiance: 5.58979 $W/m^2/sr/\mu m$
	(5.34321e+19 photons/J)
	Band Radiance: 2.78649e-17 $W/m^2/sr$

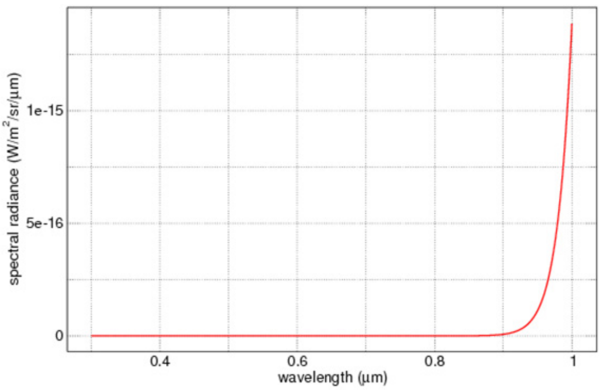

Fig. 1: Variation of spectral radiance curve with wavelength at 273 K soil surface temperature

3.1.2 For 283 K Soil Surface Temperature

Here, radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance, band radiance were calculated for 283 K soil surface temperature which is shown in Table 3. The calculated value of peak emission wavelength at this temperature is 10.2394 µm. The black body emission curve for temperature 283 K surface temperature is shown in Fig. 2. The intensity of emitted radiation is 327.349 Wm^{-2}. About 5.15494e+19 photons are required for one joule of energy. The radiant flux emitted from a point source in a certain direction per unit solid angle per unit projected area perpendicular to the specified direction is 104.199 $W/m^2/sr$.

Table 3: Radiant emittance, radiance, peak spectral radiance, spectral radiance, band radiance profile at temperature 283 K

Inputs	Results
	Radiant emittance: 327.349 W/m^2
Emissivity: 0.9	Radiance: 104.199 $W/m^2/sr$
Temperature: 283 K	Peak spectral radiance: 6.69136 $W/m^2/sr/\mu m$
Peak emission wavelength: 1.024 x 10^{-5} m	Wavelength of Peak: 10.2394 µm
	Spectral Radiance: 6.69136 $W/m^2/sr/\mu m$
	(5.15494e+19 photons/J)
	Band Radiance: 1.8637e-16 $W/m^2/sr$

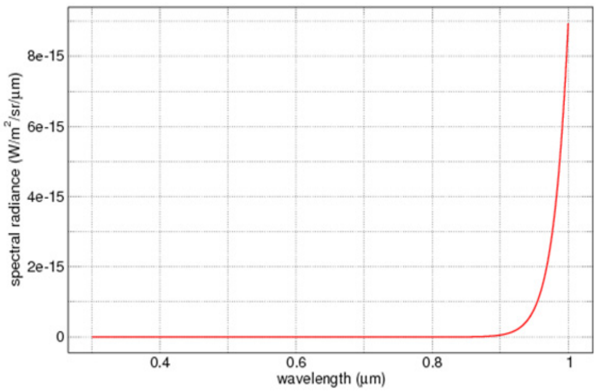

Fig. 2: Variation in spectral radiance curve with wavelength at 283 K

3.1.3 For 293 K Soil Surface Temperature

In this case, radiant emittance, radiance, peak spectral radiance, wavelength of peak spectral radiance and band radiance were obtained using 293 K soil surface temperature and it is shown in Table 4. The calculated value of peak emission wavelength at this temperature is 9.88994 µm. The black body emission curve for temperature 293 K surface temperature is shown in Fig. 3. The intensity of emitted radiation is 376.128 Wm^{-2} and about 4.97824e+19 photons are required for one joule of energy. The radiant flux emitted from a point source in a certain direction per unit solid angle per unit projected area perpendicular to the specified direction is 119.725 $W/m^2/sr$.

Table 4: Radiant emittance, radiance, peak spectral radiance, spectral radiance, band radiance profile at temperature 293 K

Inputs	Results
	Radiant emittance: 376.128 W/m^2
Emissivity: 0.9	Radiance: 119.725 $W/m^2/sr$
Temperature: 293K	Peak spectral radiance: 7.96014 $W/m^2/sr/µm$
Peak emission wavelength: 9.889 x 10^{-6} m	Wavelength of peak: 9.88994 µm
	Spectral Radiance: 7.96013 $W/m^2/sr/µm$
	(4.97824e+19 photons/J)
	Band Radiance: 1.09634e-15 $W/m^2/sr$

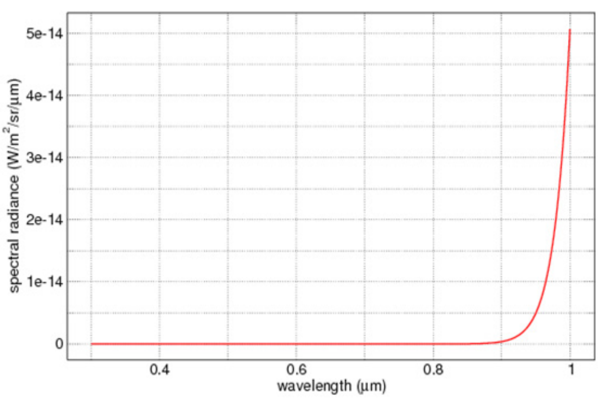

Fig. 3: Variation of spectral radiance curve with wavelength at 293 K soil surface temperature

3.1.4 For 303 K Soil Surface Temperature

In this sub-sub-section, radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance and band radiance were calculated for 303 K soil surface temperature which is shown in Table 5. The calculated value of peak emission wavelength at this temperature is 9.56354 µm. The black body emission curve for temperature 303 K soil surface temperature is shown in Fig. 4. The intensity of emitted radiation is 430.166 Wm^{-2} and about 2.53216e+19 photons are required for one joule of energy. The radiant flux emitted from a point source in a certain direction per unit solid angle per unit projected area perpendicular to the specified direction is 136.926 $W/m^2/sr$.

Table 5: Radiant emittance, radiance, peak spectral radiance, spectral radiance, band radiance profile at temperature 303 K

Inputs	Results
	Radiant emittance: 430.166 W/m^2
Emissivity: 0.9	Radiance: 136.926 $W/m^2/sr$
Temperature: 303K	Peak spectral radiance: 9.41446 $W/m^2/sr/\mu m$
Peak emission wavelength: 9.563 x 10^{-6} m	Wavelength of peak: 9.56354 µm
	Spectral Radiance: 9.41446 $W/m^2/sr/\mu m$
	(2.53216e+19 photons/J)
	Band Radiance: 5.7447e-15 $W/m^2/sr$

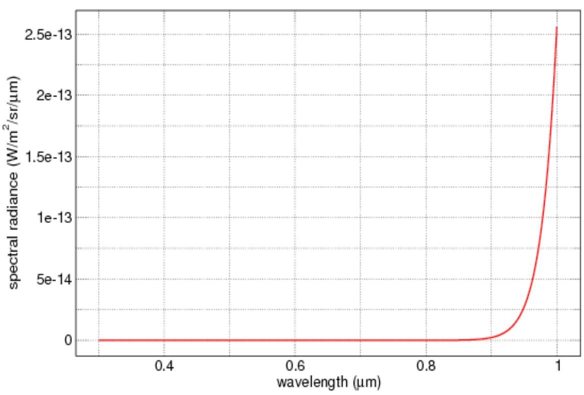

Fig. 4: Variation of spectral radiance curve with wavelength at 303 K soil surface temperature

3.1.5 For 313 K Soil Surface Temperature

In this sub-sub-section, radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance and band radiance were calculated for 313 K soil surface temperature which is shown in Table 6. The calculated value of peak emission wavelength at this temperature is 9.258 µm. The black body emission curve for temperature 313 K surface temperature is shown in Fig. 5. The intensity of emitted radiation is 489.827 $Wm^{-2.}$ About 4.66059e+19 photons are required for one joule of energy. Peak wavelength is obtained at 9.258 µm. The radiant flux emitted from a point source in a certain direction per unit solid angle per unit projected area perpendicular to the specified direction is 155.917 $W/m^2/sr$.

Table 6: Radiant emittance, radiance, peak spectral radiance, spectral radiance, band radiance profile at temperature 313 K

Inputs	Results
	Radiant emittance: 489.827 W/m^2
Emissivity: 0.9	Radiance: 155.917 W/m^2/sr
Temperature: 313 K	Peak spectral radiance: 11.074 W/m^2/sr/µm
Peak emission wavelength: 9.258 x 10^{-6} m	Wavelength of peak: 9.258 µm
	Spectral Radiance: 11.074 W/m^2/sr/µm
	(4.66059e+19 photons/J)
	Band Radiance: 2.7111e-14 W/m^2/sr

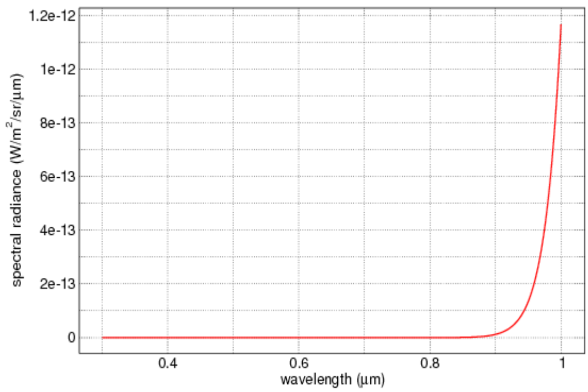

Fig. 5: Variation of spectral radiance curve with wavelength at 313 K soil surface temperature

3.1.6 For 323 K Soil Surface Temperature

In this case, radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance and band radiance were calculated for 323 K soil surface temperature which is shown in Table 7. The calculated value of peak emission wavelength at this temperature is 8.97137 µm. The black body emission curve for temperature 323 K surface temperature is shown in Fig. 6. The intensity of emitted radiation is 555.489 Wm^{-2}. About 4.51107e+19 photons are required for one joule of energy. The radiant flux emitted from a point source in a certain direction per unit solid angle per unit projected area perpendicular to the specified direction is 176.818 W/m^2/sr.

Table 7: Radiant emittance, radiance, peak spectral radiance, spectral radiance, band radiance profile at temperature 323 K

Inputs	Results
	Radiant emittance: 555.489 W/m^2
Emissivity: 0.9	Radiance: 176.818 W/m^2/sr
Temperature: 323 K	Peak spectral radiance: 12.9597 W/m^2/sr/µm
Peak emission wavelength: 8.971 x 10^{-6} m	Wavelength of peak: 8.97137 µm
	Spectral Radiance: 12.9597 W/m^2/sr/µm
	(4.51107e+19 photons/J)
	Band Radiance: 1.16355e-13 W/m^2/sr

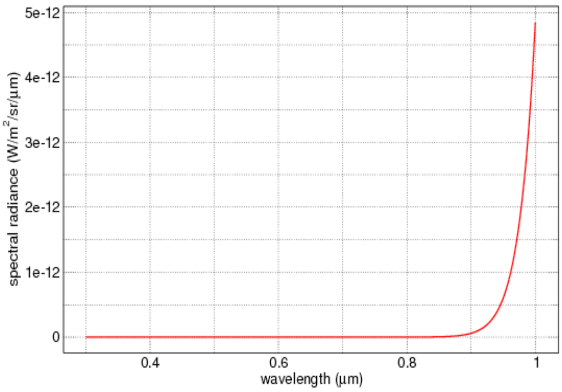

Fig. 6: Variation of spectral radiance curve with wavelength at 303 K soil surface temperature

The total power is represented by the area under the blackbody radiation curve for each given temperature. From Fig. 1 to Fig. 6, the area under the curves are 283.476 Wm^{-2}, 327.349 Wm^{-2}, 376.128 Wm^{-2}, 430.166 Wm^{-2}, 489.827 Wm^{-2} and 555.489 Wm^{-2} at temperature 273K, 283K, 293K, 303K, 313K and 323K respectively. Here, as the temperature increases, the total emitted power (area under the curve) also increases. If the temperature of the earth surface decreases, the intensity of the emitted radiation also decreases. The average intensity of the emitted radiations from the desert (Bare soil at emissivity 0.9) on earth surface due to all different temperatures is 410.405 Wm^{-2}. The standard deviation is 101.94 Wm^{-2} and standard error is 41.616. In all the Fig. from 1 to 6, the spectrum of a blackbody are continuous, so they give off some energy across all wavelengths, but they have a peak value i.e. strength of the wavelength are 10.6145 µm for 273; 10.2394 µm for 283 K; 9.8899 µm for 293 K; 9.5635 µm for 303 K; 9.258 µm for 313 K and 8.971 µm for 323 K. The intensity and distribution of the radiation depends only on its temperature. No power is emitted in the visible and near infrared portions of the spectrum at temperature 273, 283, 293, 303, 313 and 323 K. The earth surface at these given temperatures emits low power radiation which is well outside the visual range of human observation. The strength of the wavelength emitted from the earth's surface goes on increasing on increasing surface temperature of earth (Fig. 1–6). The peak wavelength and the total radiated amount (Fig. 1-6 and Table 2-7) vary with temperature. This concludes that Wien's displacement law holds true for temperature 323 K down to 273 K. The emitted radiations from the earth's surface consist of a spectrum of wavelengths. The radiant energy is not equally distributed among all possible wavelengths. For a particular wavelength, the spectral intensity is maximum. As there is a difference of 272.013 Wm^{-2} in the intensity of the emitted radiations between 273 K and 323 K surface temperature, no significant change is obtained in the wavelength of the emitted radiations. At lower temperature, weaker radiations are produced and at higher temperature comparatively stronger radiations are produced. Wang *et al.* 2006 measured the mean emitted flux 6.4 $W/m^2/sr/µm$ with a probable error of 1.5 $W/m^2/sr/µm$ but we have calculated the mean emitted flux (spectral Radiance) 8.9482 $W/m^2/sr/µm$.

3.2 Calculation of Intensity, Average Intensity of the Emitted Radiations at Different Temperatures and at Emissivity 0.96

Similarly, we have calculated the intensity, average intensity and standard deviation of the emitted radiations from the desert at emissivity 0.96 and at temperatures 273, 283, 293, 303, 313 and 323 K which is shown in Table 8.

Table 8: Temperature, intensity and average intensity profile with standard deviation at emissivity 0.96

Temperature (K)	Intensity (Wm^{-2})	Average Intensity (Wm^{-2})	Standard deviation (Wm^{-2})
273	302.374		
283	349.173		
293	401.204	437.766	108.708
303	458.844		
313	522.483		
323	592.522		

The average intensity of the emitted radiations from desert at emissivity 0.96 is 437.77 $Wm^{-2.}$ The value of standard deviation is 108.708 $Wm^{-2.}$ The standard error is 44.38 Wm^{-2}.

Fig. 7(a) shows the normal Gaussian curve for average intensity value 410.405 Wm^{-2} and standard deviation value 101.94 Wm^{-2} with lower value of intensity and upper value of intensity 283.476 and 555.489 Wm^{-2} respectively for emissivity 0.9. In this case, the standard error is found to be 41.616. Fig. 7(b) shows the normal Gaussian curve for average intensity value 437.766 Wm^{-2} and standard deviation value 108.708 Wm^{-2} with lower value of intensity and upper value of intensity 302.374 and 592.522 Wm^{-2} respectively for emissivity 0.96. The large value of standard deviation (i.e. 108.708 Wm^{-2}) and standard error (i.e. 44.379) found from the table 8 are due to the large difference between any two adjacent values of intensity of the emitted radiations (i.e. 290.148 Wm^{-2} = 592.522 Wm^{-2} – 302.374 Wm^{-2}). The values of standard errors obtained from the calculation of the emissivity 0.9 and 0.96 are 41.616 and 44.379 respectively. On comparing these standard errors, the intensity found in the emissivity 0.9 is comparatively appropriate than intensity found in the emissivity 0.96. This clearly shows that 0.9 emissivity is more reliable to calculate the average value of intensity of emitted radiations which signifies better result.

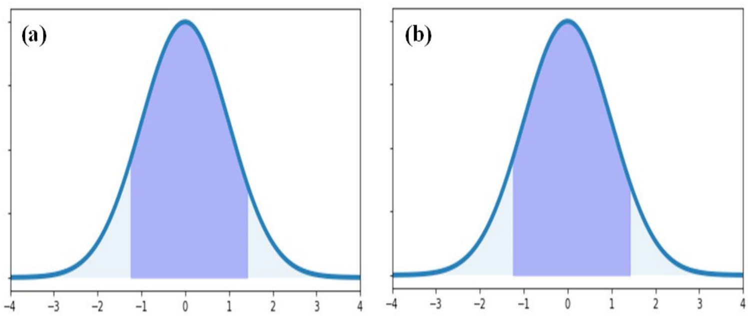

Fig. 7(a): Normal Gaussian curve for 410.4058 Wm^{-2} average intensity value and 101.94 Wm^{-2} standard deviation value with 283.476 and 555.489 Wm^{-2} lower and upper value of intensity respectively (b) Normal Gaussian curve for 437.766 Wm^{-2} average intensity values, 108.708 Wm^{-2} standard deviation values with 302.374 and 592.522 Wm^{-2} lower and upper values of intensity respectively.

Now to find the % error, the standard value of intensity of emitted radiation (i.e. 424.085 Wm^{-2}) is taken from the mean value of both the average intensity of the emitted radiations of emissivity at 0.9 and 0.96. The percentage error between the average intensity of the emitted radiations from the same bare soil surface at two different values of emissivity (i.e. 0.9 and 0.96) is calculated as

% error = (437.766 – 424.085 / 424.085) x 100% = 3.226%
% error = (410.405 – 424.085 / 424.085) x 100% = - 3.225%

The value of percentage error in average intensity of the emitted radiations at two different values of emissivity (0.9 and 0.96) for the same bare soil is about 3%.

3.3 Calculated Value of the Emitted Radiations from Different Objects at Different Temperature

We have also calculated the intensity of various materials given in section 1.3.2 having different value of emissivity at different temperatures. In this case, as the temperature increases the intensity also increases. Along with this, the listing materials from top to down in Table 9 have also increasing value of intensity.

Table 9: Intensity of different materials at different temperatures at different values of emissivity

Objects	Emissivity	Intensity at 273 K (Wm^{-2})	Intensity at 283 K (Wm^{-2})	Intensity at 293 K (Wm^{-2})	Intensity at 303 K (Wm^{-2})	Intensity at 313 K (Wm^{-2})	Intensity at 323 K (Wm^{-2})
Silver polished	0.02	6.299	7.274	8.358	9.559	10.885	12.344
Aluminum polished (Foil)	0.03	9.449	10.911	12.537	14.338	16.327	18.516
Copper polished	0.04	12.598	14.548	16.716	19.118	21.77	24.688
Asphalt	0.88	277.177	320.075	367.77	420.607	478.942	543.145
Brick	0.93	292.925	338.261	388.666	444.505	506.155	574.006
Glass (smooth uncoated)	0.95	299.225	345.535	397.025	454.064	517.04	586.35
Water (pure)	0.96	302.374	349.173	401.204	458.844	522.483	592.522

At mean surface temperature, the intensity of the emitted radiations from asphalt was found to be 380 Wm^{-2} (Shin *et al.* 2019) but we have calculated the mean intensity of emitted radiations from the asphalt as 401.286 Wm^{-2}.

3.4 Graphical Relation Between Temperature and Intensity, and Emissivity and Intensity

The plot between intensity and temperature at different values of emissivity is shown in Fig. 8(a) and the plot between intensity and emissivity at different temperatures is shown in Fig, 8(b). There is a small increase in slope of line in the intensity and emissivity plot. The slope of the curve between the intensity and temperature plot is steeper which indicates that the intensity of the emitted radiations is strongly dependent with temperature than the emissivity which has very small increase in the slope of the line. The change in intensity of the emitted radiations due to the change in value of emissivity is finitely small. So even if there is fluctuation in the value of emissivity of the same surface due to various changeable factors discussed previously, no significant change in the intensity of the emitted radiations is found. This concludes that the intensity of the emitted radiations is affected more by the temperature of the surface than the emissivity.

The temperature and intensity relation in Fig. 8(a) from the table 8 satisfies linear curve fitting with R^2 value of 0.994. The emissivity and average intensity of the emitted radiations relation in Fig. 8(b) from the table 9 satisfies linear curve fitting with R^2 value of 0.991.

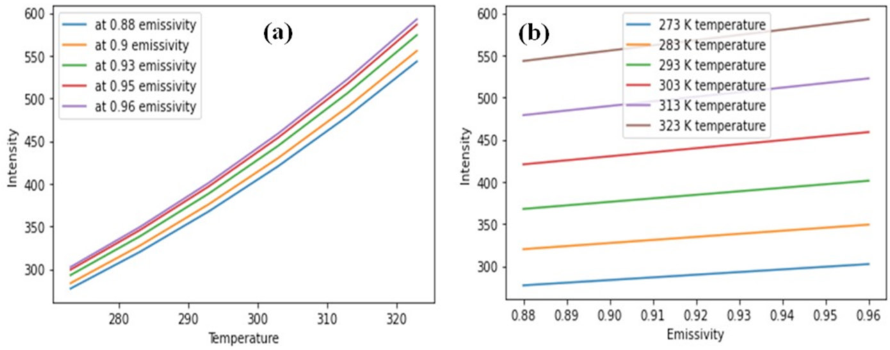

Fig. 8: (a) Temperature and intensity relation at different values of emissivity (b) Emissivity and intensity relation for different materials at different temperature

3.5 Sum and Average of the Emitted Intensity of the Radiations at Varying Temperature of the Bodies

Table 10 contains the calculated values of the sum of intensity and the average intensity for individual particular material at different temperatures 273, 283, 293, 303, 313 and 323 K. Along with these, mean of the intensity of the emitted radiations due to all different materials has also been determined.

Table 10: Sum of intensity, average intensity and mean of intensity of the emitted radiations due to all bodies

Object	Sum of intensity (Wm^{-2})	Average intensity (Wm^{-2})	Mean of intensity of the emitted radiations due to all bodies (Wm^{-2})
Asphalt (0.88)	2407.716	401.286	
Desert (0.9)	2462.435	410.405	418.378
Brick (0.93)	2544.518	424.086	
Water, pure (0.96)	2626.6	437.766	

Due to the small difference between any two adjacent values of intensity of the emitted radiation of individual material, the standard deviation for the average intensity is low and its value is 15.96 Wm^{-2} and the value of standard error is 7.9801.

The Normal Gaussian Curve for mean value of intensity 418.3786 Wm^{-2} with lower and upper value of average intensity 401.286 and 437.766 Wm^{-2} respectively is shown in Fig. 9. The shaded area (region) in the Fig. 9 corresponds to intensity in between the lower and upper bound values.

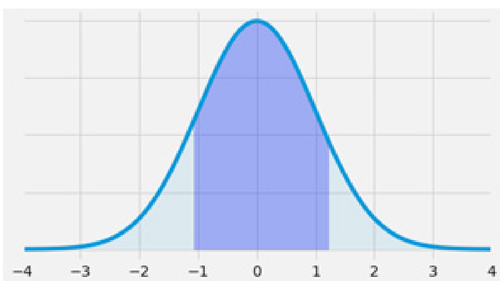

Fig. 9: Normal Gaussian Curve for mean intensity value of 418.378 Wm^{-2} and standard deviation value 15.96 Wm^{-2} with the lower and upper average intensity value of 401.286 and 437.7666 Wm^{-2} respectively

3.6 Error Analysis

The temperatures 273, 283, 293, 303, 313, and 323 K used in this study yields a mean temperature of 298 K which is 10 K far from the standard mean value of 288 K. This shows an error of 3.47%. The mean of the different values of emissivity of asphalt (0.88), desert (0.9), brick (0.93), and Water (0.96) is 0.9175. The peak emission wavelength at 298 K temperature is 9.724 µm while the peak emission wavelength at standard value of 288 K is 10.061 µm which yields an error 3.35% in the value of peak emission wavelength. The average intensity of the emitted radiations from desert (bare soil) at two different values of emissivity of 0.9 and 0.96 is 410.4058 Wm^{-2} and 437.77 Wm^{-2} respectively with their average standard value of 424.085 Wm^{-2} yields an error of about 3%. The value of emissivity for snow varies from 0.8 to 0.9 which is given in section 1.3.2. The difference in the intensity of the emitted radiations from snow at 273 K temperature and at different values of emissivity of 0.8 and 0.9 is 31.497 Wm^{-2}. The error in the intensity of the emitted radiations from snow calculated from its two different values of emissivity of 0.8 and 0.9 is 12.49%. For snow at 273 K surface temperature, the percentage error is 12.49% when there is 0.1 difference in the value of emissivity. The intensity of the emitted radiations from the earth surface of standard mean temperature 288 K is 357.897 Wm^{-2} at the average value of emissivity of 0.9175 [i.e. (0.88+0.9+0.93+0.96)/4]. The average calculated value of the intensity of the emitted radiations due to asphalt, desert, brick and water is 418.3786 Wm^{-2}. The error between the standard value of mean surface temperature and calculated value is about 17%. The percentage error appears large because there is no accurate technique and tool to measure the exact standard value of mean surface temperature of earth. So the standard value itself contains some order of inaccuracy due to the uncertainty in the value of emissivity of the same surface which we have discussed in the introduction. From this, it can be concluded that to find the accurate average intensity of the emitted radiations from the earth surface is a difficult task. The plot between temperature and intensity fits linearly with R^2 value of 0.994. The plot between emissivity of different materials and average intensity of the emitted radiations satisfies linear curve fitting with R^2 value of 0.991. There is a standard deviation of 15.96 Wm^{-2} among the variables of intensity of the emitted radiations from different materials on the earth surface taken for the work. The standard deviation and standard error is less for the average intensity of the emitted radiations obtained from different materials occupied in major proportion on the earth surface but the standard deviation and standard error is greater for the intensity of the emitted radiation obtained from the single material (In this work, it is bare soil). The average intensity of the emitted radiations from low emissivity materials like silver polished (0.02), aluminum polished (0.03) and copper polished (0.04) is very small. So, being low value of average intensity of emitted radiations, all season crops cannot be considered to cultivate. This explains why the earth surface is occupied with materials of high emissivity value in major proportions. This is the beauty of nature. If the earth surface is occupied with low emissivity materials in major proportion, the average intensity of the emitted radiations would be small so that the existence of the living beings would not be possible. All other natural phenomena will not be in favor of the existence of living beings.

4. CONCLUSION

There is difference of 272.013 Wm^{-2} in the intensity of the emitted radiations between 273 and 323 K surface temperature at emissivity 0.9, no significant change in the wavelength of the emitted radiations from the surface is obtained. The strength of the wavelength emitted from the earth's surface goes on increasing on increasing surface temperature of earth. The peak wavelength and the total radiated amount vary with temperature. This concludes that Wien's displacement law holds true for temperature 323 K down to 273K. The peak wavelength of the emitted radiations is 8.9 µm for the maximum value of surface temperature of 323 K. The peak wavelength of the emitted radiations is 10.61 µm for the minimum value of surface temperature of 273 K. For emissivity 0.9, the average intensity value is 410.405 Wm^{-2} and standard deviation value is 101.94 Wm^{-2} with lower value of intensity and upper value of intensity 283.476 and 555.489 Wm^{-2} respectively along with the standard error is 41.616. The average intensity of the emitted radiations from desert at emissivity 0.96 is 437.77 Wm^{-2}. The value of standard deviation is 108.708 Wm^{-2} and the standard error is 44.379. The large value of standard deviation (108.708 Wm^{-2}) and standard error 44.379 are due to the large difference between any two adjacent values of intensity of the emitted radiations. The compared values of standard errors obtained from the calculation of the emissivity 0.9 and 0.96 informs that the intensity in the emissivity 0.9 is comparatively appropriate than intensity found in the emissivity 0.96. This clearly indicates that 0.9 emissivity is more reliable to calculate the average value of intensity of emitted radiations which signifies better result. The mean intensity of the emitted radiations from different materials of earth surface is 418.3786 Wm^{-2}. About 17% of the error is obtained between the standard and calculated value of the average intensity of the emitted radiations from the earth surface. This error arises because the standard value of mean surface temperature itself carries error due to the uncertainty in the value of emissivity. The maximum value of the error in the intensity of the emitted radiations calculated for the different materials does not exceed 17%. The intensity of the emitted radiations is largely affected by the temperature of the surface but not by the emissivity of the surface.

REFERENCES

An, N., Hemmati, S., and Y. J., Cui, 2017. Assessment of the methods for determining net radiation at different time-scales of meteorological variables. Journal of Rock Mechanics and Geotechnical Engineering, 9(2), 239-246. doi.org/10.1016/j.jrmge.2016.10.004

Arnfield, A. J., 1990. Street design and urban canyon solar access. Energy and Buildings, 14(2), 117-131. doi.org/10.1016/0378-7788(90)90031-D

Audi, M., A., Ali, and M., Kassem, 2020. Greenhouse Gases: A Review of Losses and Benefits. International Journal of Energy Economics and Policy. 10(1), 403-418. https://doi.org/10.32479/ijeep.8416

Badescu, V., 2008. Modeling solar radiation at the earth's surface. Springer-Verlag, Berlin/Heidelberg.

Bhatia, S. C., 2014. Advanced renewable energy systems, (Part 1 and 2) (pp. 32-66). First Edition. WPI Publishing, New Delhi, India

Brewster, M. Q., 1992. Thermal Radiative Transfer and Properties. John Wiley and Sons. Inc. New York.

Cloudsley–Thompson, J. L., 2011. Sahara Desert. Terrestrial Ecoregions. World Wildlife Fund. Perhamon Press, Oxford.

Coll, C., V., E., Caselles, Valor, and R., Niclos, 2012. Comparison between different sources of atmospheric profiles for land surface temperature retrieval from single channel thermal infrared data. Remote Sensing of Environment. 117, 199-210. https://doi.org/10.1016/j.rse.2011.09.018

Evett, S. R., J. H., Prueger, J. A., Tolk, and P., Huang, 2012. Water and energy balances in the soil-plant-atmosphere continuum. Second Edition. CRC Press: Boca Raton, FL, USA

Halldin, S., and A., Lindroth, 1992. Errors in net radiometry: comparison and evaluation of six radiometer designs. Journal of Atmospheric and Oceanic Technology, 9(6), 762-783. DOI:20-0426(1992)009<0762:EINRCA>2.0.CO;2

Idso, S. B., R. D., Jackson, W. L., Ehrler, and S. T. Mitchell, 1969. A method for determination of infrared emittance of leaves. Ecology, 50(5), 899-902. doi:10.2307/1933705

Janjai, S., I., Masiri, S., Pattarapanitchai, and J. Laksanaboonsong, 2013. Mapping global solar radiation from long-term satellite data in the tropics using an improved model. International Journal of Photoenergy, 2013, 1-11. doi.org/10.1155/2013/210159

Kiehl, J. T., and K. E. Trenberth, 1997. Earth's annual global mean energy budget. Bulletin of the American meteorological society, 78(2), 197-208. doi:10.1175/1520-0477(1997)078<0197:EAGMEB>2.0.CO;2

Kordun, O. I., 2015. The influence of solar radiation on temperature increment of sheet steel structures. Archives of Civil Engineering, 61(1)., 89-102. DOI 10.1515/ace-2015-0006

Li, Z., and W. Chen, 2021. Progress in dynamic emissivity regulation: control methods, material systems, and applications. Materials Chemistry Frontiers. 5(17), 6315-6332. https://doi.org/10.1039/D1QM00624J

Liang, H., F., Wang, Z., Cheng, C., Xu, G., Li, and Y. Shuai, 2020. Full-Spectrum Solar Energy Utilization and Enhanced Solar Energy Harvesting via Photon Anti-Reflection and Scattering Performance Using Biomimetic Nanophotonic Structure. ES Energy & Environment. 8, 29–41. https://dx.doi.org/10.30919/esee8c456

Lohnert, U., D. D., Turner, and S. Crewell, 2009. Ground-Based Temperature and Humidity Profiling Using Spectral Infrared and Microwave Observations. Part I: Simulated Retrieval Performance in Clear-Sky Conditions. Journal of Applied Meteorology and Climatology, 48(5), 1017–1032. https://doi.org/10.1175/2008JAMC2060.1

Lorenz, D, 1966. The effect of the long-wave reflectivity of natural surfaces on surface temperature measurements using radiometers. Journal of Applied Meteorology and Climatology, 5(4), 421-430. doi:10.1175/1520-0450(1966)005<0421:teotlw>2.0.co;2

Ogawa, K., and T. Schmugge, 2004. Mapping surface broadband emissivity of the Sahara Desert using ASTER and MODIS data. Earth Interactions, 8(7), 1-14. doi:10.1175/1087-3562(2004)008<0001:MSBEOT>2.0.CO;2

Neupane, R, 2020. Study on the Validity of Wien's Displacement Law on Tungsten Bulb. Journal of Nepal Physical Society, 6(2), 85-96. doi.org/10.3126/jnphyssoc.v6i2.34863

Ninomiya, Y., and B. Fu, 2019. Thermal infrared multispectral remote sensing of lithology and mineralogy based on spectral properties of materials. Ore Geology Reviews, 108, 54-72. https://doi.org/10.1016/j.oregeorev.2018.03.012

Ren, H., R., Liu, Q., Qin, W., Fan, L., Yu, and C. Du, 2017. Mapping finer-resolution land surface emissivity using Landsat images in China. Journal of Geophysical Research: Atmospheres, 122(13), 6764-6781. https://doi.org/10.1002/2017JD026910

Schmittner, A. 2017. Introduction to Climate Science. First edition. Oregon State University, USA

Shin, J., H., Park, and T. Kim, 2019. Characteristics of laser backscattering intensity to detect frozen and wet surfaces on roads. Journal of Sensors, 2019, 1-9. https://doi.org/10.1155/2019/8973248

Stapleton, G., and S. Neill, 2012. Grid-connected solar electric systems: the earth scan expert handbook for planning, design and installation. First edition. Routledge, London

Van de Griend, A. A., and M.Owe, 1993. On the relationship between thermal emissivity and the normalized difference vegetation index for natural surfaces. International Journal of remote sensing, 14(6), 1119-1131. doi:10.1080/01431169308904400.

Wang, D., L., He, X., Shi, S., Wei, and X. Feng, 2006. Release flux of mercury from different environmental surfaces in Chongqing, China. Chemosphere, 64(11), 1845-1854. https://doi.org/10.1016/j.chemosphere.2006.01.054

Youngblood, N., C., Talagrand, B. F., Porter, C. G., Galante, S., Kneepkens, G., Triggs, S. G., Sarwat, D., Yarmolich, R. S., Bonilla, P., Hosseini, R. A., Taylor, and H. Bhaskaran, 2022. Reconfigurable Low-

Emissivity Optical Coating Using Ultrathin Phase Change Materials. ACS Photonics, 9(1) 90-100. https://doi.org/10.1021/acsphotonics.1c01128