COMPARISON STUDY ON SOLAR IRRADIANCE SPECTRA FOR COMS MI APPLICATION OF HELIOSAT

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ABSTRACT: Although many research studies have estimated insolation over the Korean Peninsula, most of them employed foreign satellite imagery. In order to provide improved estimates of solar insolation of the Korean peninsula using Koran's first geostationary satellite—the Communication, Ocean and Meteorological Satellite Meteorological Imager (COMS MI)—the Heliosat method was appropriately modified and applied. The algorithm is one of the most popular methods and calculates global horizontal irradiance from images taken in the visible range. Spectral distribution of solar irradiance especially in the visible range plays an important role in the process of converting radiance to reflectance. Although many models measure spectral distribution of solar radiance, the most suitable spectra for the COMS MI sensor response functions have not been confirmed. In this paper, three representative solar irradiance spectra—Wehrli 1985_WMO, ASTM E-490, and ASTM G173-03—were compared and reflectance was estimated using these solar irradiance spectra by the Heliosat method. The results showed that ASTM E-490 had the lowest RMSE value among the reference data. Therefore, ASTM E-490 could be a suitable spectrum to estimate solar irradiance with COMS MI applying the Heliosat method.

1. INTRODUCTION

Solar irradiation is a radiant energy, particularly electromagnetic forms, emitted by the sun. Solar irradiation at the earth's surface is primarily used in many physical, chemical and biological processes; and it has significance for application fields such as industry, architecture and the environment (Wu et al., 2007). Knowledge of solar radiation at a specific region is very important for various fields. However, measuring accurate solar irradiation arrived on the surface is difficult because solar irradiation changes with time as well as location, and atmosphere conditions.

In Korea two institutes, the Korea Meteorological Administration (KMA) and Korea Institute of Energy Research (KIER), have measured solar irradiation as a type of ground data at approximately 20 ground stations (Lee et al., 2014). The ground data had great accuracy and high temporal resolution, but it had limited spatial resolution because solar irradiation was measured only at the stations themselves. When ground stations are separated by more than 30km, the use of estimates obtained from satellite images are considered better than ground measurements. Satellite images could give solar irradiation values at locations where no ground measurements are available. Considering these advantages, several attempts have been made to estimate solar radiation using satellite images over the Korean peninsula. Yeom et al. (2008) and Yeom (2009) estimated solar radiation values using MTSAT IR images with the Kawamura model by adjusting the time disagreement between ground measurements and estimates obtained from MTSAT IR. Choi and Yun (2011) estimated a sub-scale estimation of solar irradiance in North Korea using MODIS. Most approaches to estimate solar irradiance have depended on foreign satellite images, and research based on domestic satellite images has not been conducted. The first Korean multi-mission geostationary satellite—Communication, Ocean and Meteorological Satellite (COMS)—was launched in 2010. COMS MI (Meteorological Imager) has high spatial and temporal resolution and specialized on the Korean peninsula. Therefore, solar irradiance estimates based on COMS MI could be more suitable over the Korean peninsula. Lee et al. (2014) showed that COMS MI could provide improved estimates of solar irradiance based on the Kawamura physical model.

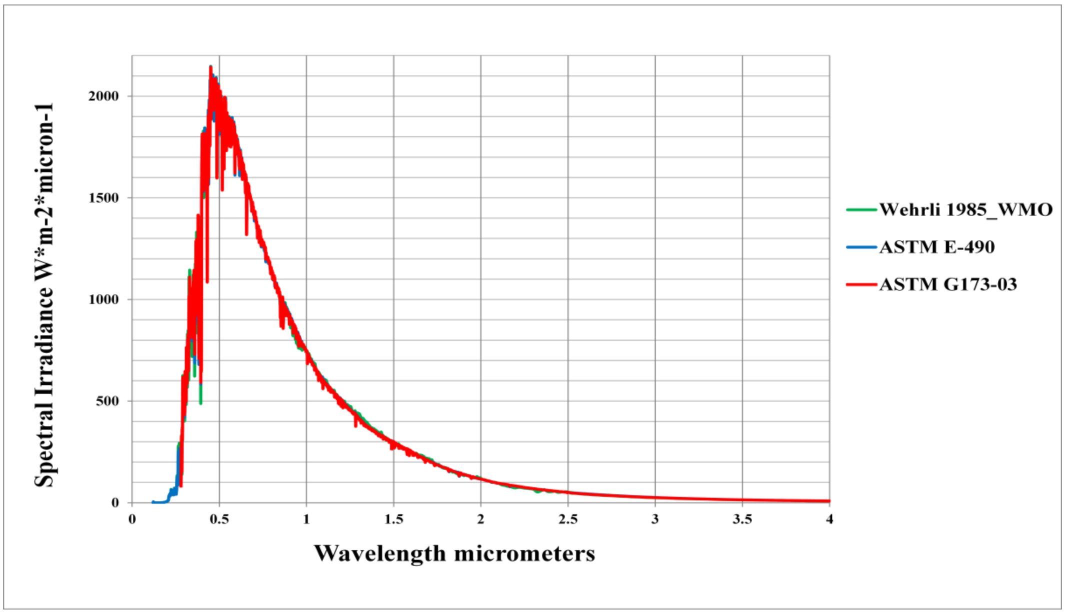
For the estimation of solar irradiance from COMS MI, we used the Heliosat method. It has been modified and still developed (Dagestad, 2004) and is widely used as a solar radiation model. The Heliosat method converts images acquired by the satellite Meteosat into maps of global irradiation. Since the Heliosat method is based on Meteosat, which is a geostationary meteorological satellite operated by EUMESAT, we should modify Heliosat to be applicable with COMS MI. The version used in this paper was the version used by the SatelLight project (www.satel-light.com) and it consists of four steps: 1) the computation of the reflectance, 2) the computation of the atmospheric reflectance, 3) the computation of the cloud index, 4) the computation of the irradiation. As the first step, we should define the reference solar irradiance spectra to convert radiance to reflectance. Accurate spectral distribution of solar irradiance is needed to extract accurate solar irradiance, and there are many different reference solar irradiance spectra for processing the data recorded by various sensors (Shanmugam and Ahn, 2007). In this study, to derive the accurate solar irradiation from COMS-MI based on the Heliosat method, we compared three reference spectra model: Wehrli 1985_WMO, ASTM E-490 and ASTM G173-03, and the results were compared with reference data.

2. SOLAR IRRADIANCE SPECTRA

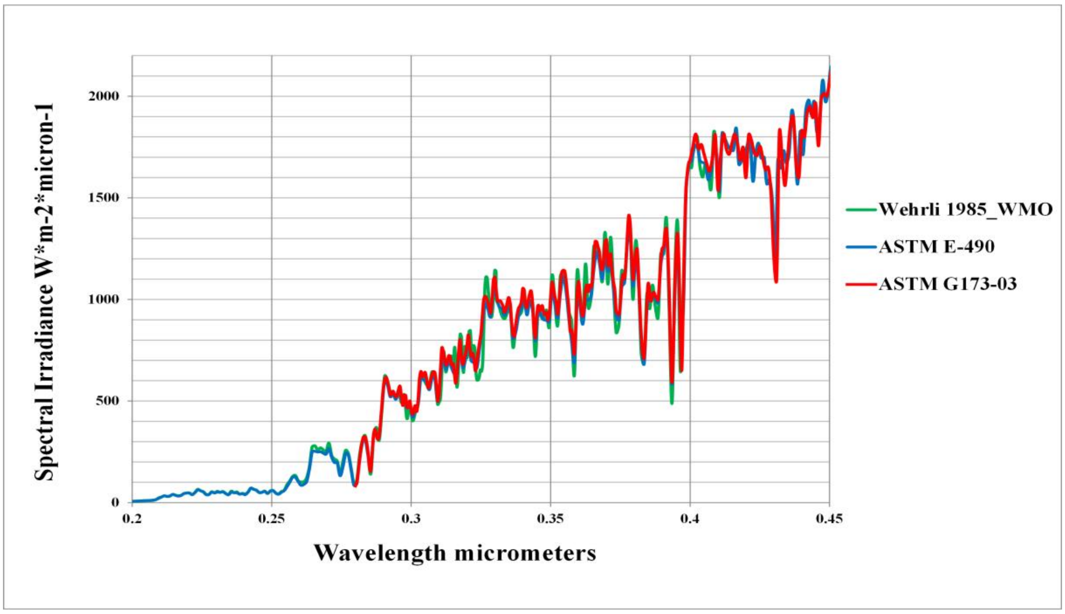
Since it is difficult to define the real instrumental uncertainty at each wavelength and specific time, several different solar irradiance spectra have been adopted. These irradiance spectra were composed by various spectra obtained by different instruments with different resolution and calibration methods, in different spectral bands (Shanmugam and Ahn, 2007). Wehrli 1985_WMO solar irradiance spectrum has been mostly cited as a reference for the MODIS, IKONOS, GOES sensor (Doelling et al., 2001) and uses extraterrestrial solar spectral irradiance distribution. It cited four sources such as rock and balloon data, scaled spectrum of Arvesen et al. (1969), Neckel and Labs (1981) and Smith and Gottlieb (1974). In recent days, the American Society for Testing and Materials developed ASTM E-490 (AM0, air mass zero) and ASTM G173-03 spectra to improve the accuracy over existing spectra. ASTM E-490 is based on satellite data, space shuttle missions, high-altitude aircraft rocket sounding, ground-based solar telescopes and models (Shanmugam and Ahn, 2007). ASTM G173-03 represents spectral irradiance on a surface of specified orientation assuming a specified atmospheric condition. The spectrum used here was solar spectrum at the top of the atmosphere. Table 1 describes some background information on these three irradiance spectra. The solar constant is the total amount of radiation received from the sun on a surface outside the atmosphere at the mean solar distance of the earth (Gates, 1996). Three spectra assumed slightly different solar constants and were defined in different spectral ranges. Figure 1 shows the comparison of Wehrli 1985_WMO, ASTM E-490 and ASTM G173-03. The largest differences are found in ultraviolet and visible blue range (figure 1(b)). In the infrared range two spectra, ASTM E-490 and ASTM G173-03, have similar spectrum; and Wehrli 1985_WMO had slightly different spectral properties from the two spectra (figure 1(c)).

Table 1. Background information on three solar irradiance spectra

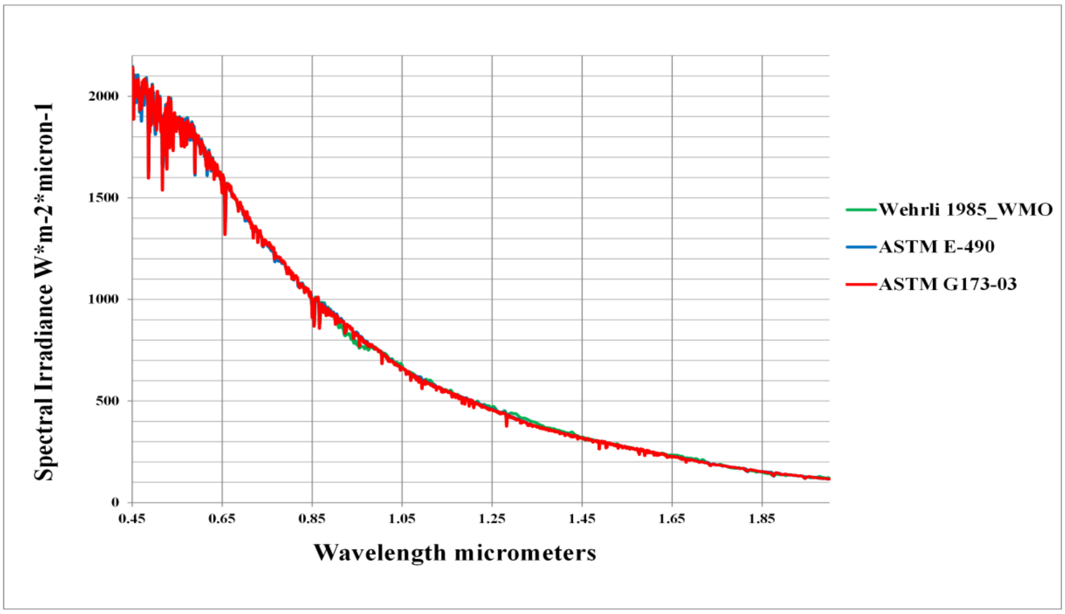
Solar irradiance spectrum	Solar constant	Spectral range(µm)
Wehrli 1985_WMO	1367	0.200 - 100.075
ASTM E-490	1366.1	0.120 - 1000.000
ASTM G173-03	1366.1	0.280 - 4.000



(a)



(b)



(c)

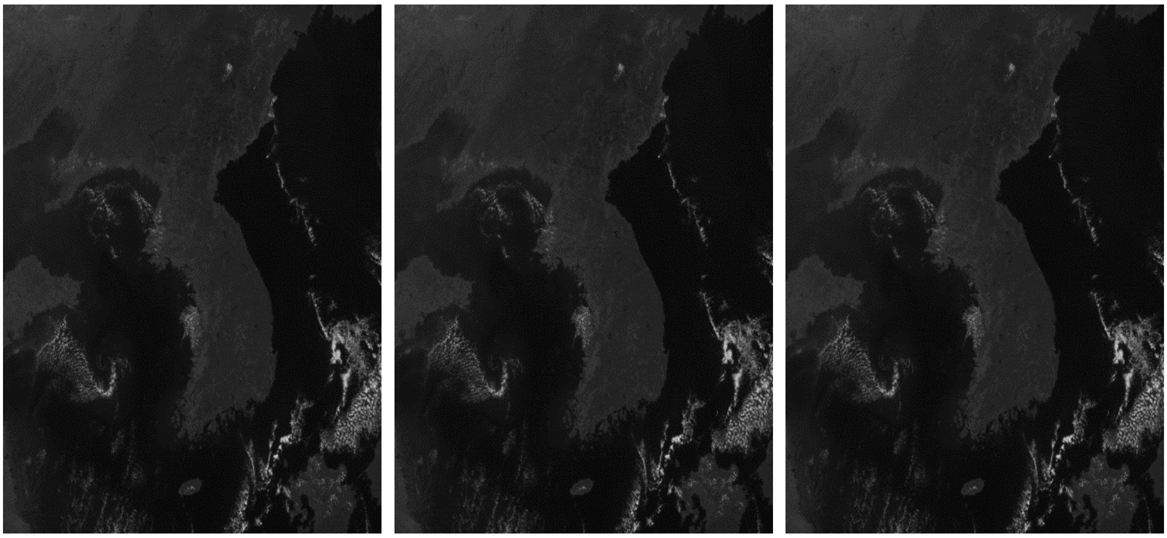
Figure 1. Comparison of three solar spectra: Wehrli 1985_WMO, ASTM E-490 and ASTM G173-03 (a) spectral range from 0.2-4 μm, (b) ultraviolet and visible range (0.2-0.45 μm), (c) visible and infrared range (0.45-2 μm)

3. COMPARISON OF THE SPECTRA

The Heliosat method calculates reflectance to estimate solar irradiance using external information such as the total irradiance in the visible channel and calibration coefficients (Rigollier et al., 2004). The total irradiance in the visible area is calculated as follows:

$$\int_a^b I_{0\lambda} S_\lambda \, d\lambda, in \, Wm^{-2} \qquad (1)$$

Where $I_{0\lambda}$ is the spectral distribution of solar irradiation and S_λ is the sensor spectral response function in the visible range. Each a and b represents the spectral range of visible channels. In order to estimate reflectance from COMS MI, S_λ was defined as the COMS MI spectral response function and a and b were 0.55 and 0.85, respectively, which are the COMS MI visible channels' range. In order to compare the reflectance estimates from different solar irradiance spectra, we assumed other calibration coefficients were the same. Also, since three spectra had different spectral ranges and wavelength intervals with sensor spectral response function, linear interpolation was applied to three spectra to match the spectral range and wavelength intervals. Figure 2 shows the reflectance maps of COMS MI with three different solar irradiance spectra. COMS MI data used here was acquired on Oct. 27, 2013 in the daytime. We selected cloud-free images to exclude the influences of the atmosphere condition. To estimate the accuracy of the reflectance value, we compared the results with reference data. The Korea National Meteorological Satellite Center provided a conversion table of COMS MI. The conversion table represents the relationship between the COMS MI digital count value and the radiance, temperatures of brightness for the infrared channels and albedo for the visible channel. Therefore, the COMS MI image converted by conversion table coefficients was defined as the reference data. Then, the Root Mean Square Error (RMSE) was calculated between reference data and estimates of reflectance with three different solar irradiation spectra (Table 2). ASTM E-490 represented the lowest RSME and ASRM G173-03 had the highest RMSE. The results showed that ASTM E-490 could be suitable for the COMS MI and Heliosat method over the Korean peninsula.



(a) (b) (c)

Figure 2. Reflectance map using different solar irradiance spectra (a) Wehrli 1985_WMO, (b) ASTM E-4940, (c) ASTM G173-03.

Table 2. Background information on solar irradiance spectra

	RMSE		
	Wehrli 1985_WMO	ASTM E-490	ASTM G173-03
Reference map	0.0476	0.0475	0.0485

4. CONCLUSION

In order to estimate solar irradiance over Korea using images from COMS MI, Korea's first geostationary satellite, using the Heliosat method, accurate reflectance should be calculated. In the Heliosat method, reflectance depended on the total irradiance in the visible range and calibration coefficients. Suitable solar irradiance spectrum for the COMS MI should be defined to extract accurate reflectance and solar irradiance. Wehrli 1985_WMO, ASTM E-490 and ASTM G173-03 have been mostly cited as reference solar irradiance spectra. In order to find the best suitable solar irradiance spectra for COMS MI, we estimated reflectance from COMS MI and RMSE was calculated from the reference data. The results showed that ASTM E-490 had the lowest RMSE values and therefore could be the most suitable solar irradiance spectral to estimate solar irradiance over the Korea peninsula.

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