STANDARIZING THE EXTRATERRESTRIAL SOLAR IRRADIANCE SPECTRUM FOR CAL/VAL OF GEOSTATIONARY OCEAN COLOR IMAGER (GOCI)

Palanisamy Shanmugam and Yu-Hwan Ahn

Ocean Satellite Research Group, Korea Ocean Research and Development Institute, Ansan P.O. Box. 29, Seoul, Korea
Emails: spahnmugam@korid.re.kr; yuahn@korid.re.kr

ABSTRACT: Ocean color remote sensing community currently uses the different solar irradiance spectra covering the visible and near-infrared in the calibration/validation and deriving products of ocean color instruments. These spectra derived from single and / or multiple measurements sets or models have significant discrepancies, primarily due to variation of the solar activity and uncertainties in the measurements from various instruments and their different calibration standards. Thus, it is prudent to examine model-to-model differences and select a standard reference spectrum that can be adopted in the future calibration and validation processes, particularly of the first Geostationary Ocean Color Imager (GOCI) onboard its Communication Ocean and Meterological Satellite (COMS) planned to be launched in 2008. From an exhaustive survey that reveals a variety of solar spectra in the literature, only eight spectra are considered here seeing as reference in many remote sensing applications. Several criteria are designed to define the reference spectrum: i.e., minimum spectral range of 350-1200nm, based completely or mostly on direct measurements, possible update of data and less errors. A careful analysis of these spectra reveals that the Thuillier 2004 spectrum seems to be very identical compared to other spectra, primarily because it represents very high spectral resolution and the current state of the art in solar irradiance spectra of exceptionally low uncertainty ~0.1%. This study also suggests use of the Gueymard 2004 spectrum as an alternative for applications of multispectral/multipurpose satellite sensors covering the terrestrial regions of interest, where it provides spectral converge beyond 2400nm of the Thuillier 2004 spectrum. Since the solar-activity induced spectral variation is about less than 0.1% and a large portion of this variability occurs particularly in the ultraviolet portion of the electromagnetic spectrum that is the region of less interest for the ocean color community, we disregard considering this variability in the analysis of solar irradiance spectra, although determine the solar constant 1366.1 Wm^{-2} to be proposed for an improved approximation of the extraterrestrial solar spectrum in the visible and NIR region.

KEY WORDS: Extraterrestrial solar irradiance, ocean color, calibration and validation, GOCI, COMS, Korea

1. INTRODUCTION

The accurate spectral distribution of solar irradiance, produced by sun, on a surface perpendicular to its rays, on the outer limit of our atmosphere, is needed for a variety of remote sensing applications to understand the Earth's natural systems and its atmospheric processes. Obtaining such an accurate and standard solar spectrum imposes difficulty mainly because of two sources of uncertainties in the variation of the solar activity and experimental data. Nevertheless, the variation caused by the solar activity is found much smaller than the discrepancies in the absolute spectral irradiance (Wm-2 µm-1) provided by different instruments that involved to have different calibration standards and degradation histories, thus complicating the overall assessment of screening out a standard spectrum.

This study evaluates eight solar spectra that have been found to be widely used in many remote sensing applications (Dozier and Frew, 1981; Suemnich and Schwarzer, 1998; Delwart, 2001; Nieke and Fukushima, 2001, Barnes and Zalewski, 2003; Doelling et al., 2004; Tayler, 2005). These spectra have been reported by several authors (Thekaekara, 1973; Neckel and Labs, 1984, Wehrli, 1985; Ricchiazzi et al., 1998 (SBDART ETR); ASTM, 2000 (G173-03 and E-490); Gueymard, 2004; Thuillier, 2004). Most of the above solar spectra (from "air mass zero" extrapolation) are not monolithic but rather composites of various spectra recorded by different instruments, in different spectral bands, with different resolution and calibration methods, on different platforms, and at different moments in time. This is the reason why the applied solar irradiance spectra differ substantially depending on the sources of data used in each waveband, resolution, atmospheric corrections and various scaling factors. To select an appropriate solar spectrum to enter into the process of calibration and validation of the first Geostationary Ocean Color Imager (GOCI) onboard its Coomunication Ocean Meterological Satellite (COMS) in 2008 (Table 1), the following criteria are necessary and thus set: i.e., minimum spectral range of 350-1200nm, based completely or mostly on direct measurements, possible update of data and less errors. The results of this evaluation and recommendation are presented in what follows.

Table 1. Comparison of the spectral characteristics of GOCI with the polar orbiting SeaWiFS, MERIS

Centre Wavelength ± Bandwidth (nm) SeaWiFS	MERIS	GOCI	Application/mission objectives
412 ±20	412.5 ±10	412 ±20	Yellow substance and detrital matter
443 ±20	442.5 ±10	443 ±20	Chlorophyll absorption maximum
490 ±20	490 ±10	490 ±20	Chlorophyll and other pigments
510 ±20	510 ±10		Suspended sediment, red tides
555 ±20	560 ±10	555 ±20	Chlorophyll reference, suspended sediments
	620 ±10		Suspended sediments
670 ±20	665 ±10	660 ±10	Chlorophyll absorption and fluorescence base 1
	681.25 ±7.5	680 ±10	Chlorophyll fluorescence peak
	708.7 5±10		Atmospheric correction, fluorescence base 2
	753.75 ±7.5		Vegetation, cloud
765 ±40	760.625 ±3.75	745 ±20	Chlorophyll fluorescence base 2, Oxygen absorption (in case of MERIS)
	778.75 ±15		Atmospheric correction, vegetation
865 ±40	865 ±20	865 ±40	Water vapour reference, vegetation
	885 ±10		Atmospheric correction
	900 ±10		Water vapour, land

Table 2. Background of the eight solar irradiance spectra.

Solar Irradiance Spectrum	Solar constant	Spectral range (nm)	Step size / Increment (nm)	Satellite Sensor	References
Thekaekara 1973	1352.5	115-400000	5 (visible), 10 (NIR), >10 (others)	MSS	Dozier and Frew (1981)
Neckel and Labs 1984	1365	380-1250	1	IRS-P3 MOS, SeaWiFS,	Suemnich and Schwarzer (1998); Barnes and Zalewski (2003)
Wehrli 1985_WMO	1367	199.5-10075	1-2 (visible, NIR), <2 (others)	MODIS, SEVIRI, GOES	Doelling et al. (2004)
ASTM E-490	1366.1	119.5-1000000	1 (visible), 1-2 (visible-MIR), <20 (others)	IKONOS	Taylor (2005)
ASTM G173-03	1366.1	280-4000	0.5 (ultraviolet), 1 (visible-NIR), >5 (others)		
SBDART ETR		250-4000	0.5-1		
Gueymard 2004	1366.1	0.5-1000000	0.5 (ultraviolet), 1 (visible, IR), >1 (others)	*To be proposed	
Thuillier 2004	1366.7	0.5-2397	0.05-0.1	MERIS, GLI, (old version of Thuillier)	Delwart (2001) Nieke and Fukushima (2001)

2. RESULTS AND DISCUSSION

Fig. 3 displays those eight spectra of Thuillier 2004, Neckel and Labs 1984, Wehrli 1985_WMO, ASTM E-490, ASTM G173-03, Gueymard 2004, SBDART ETR, and Thekaekara 1973. It appears that the solar irradiance varies with wavelength, raising near green and dropping gradually toward NIR and abruptly toward UV part of the spectrum. This figure enables us to identify four types of problems in these spectra that include localized inaccuracy around a specific wavelength, large-band underestimations or overestimations, sharp underestimation structure corresponding to atmospheric absorption interference in uncorrected data, particularly in

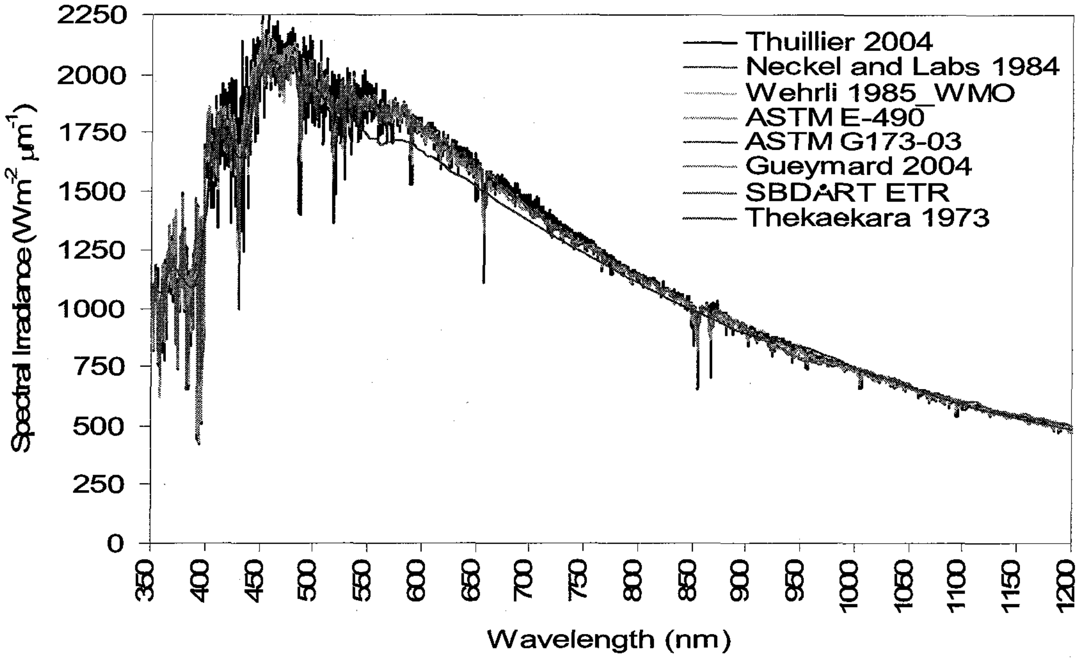

Figure 1. Solar irradiance spectra from 8 models

the NIR, rapid wavelength-to-wavelength fluctuations close to solar Fraunhofer lines or other solar absorption features, particularly in the UV, VIS and NIR caused by slight spectra shift between spectra.

To better illustrate the magnitude of the differences, the irradiance values of each reference spectrum are averaged for the wavelengths ranges UV (375-425nm), VIS (450-500nm) and NIR (825-875nm) (large differences occur in these regions) and the differences (from Thuillier 2004 because it represents very high spectral resolution and the current state of the art in solar irradiance spectra of exceptionally low uncertainty ~0.1% (Rottman et al., 2004)) are calculated. In both absolute and band-averaged terms (W m^{-2} µm^{-1}), the Thuillier 2004 spectrum shows significantly higher values in the UV and VIS and nearly consistent values with those of other spectra in the NIR (except Fraunhofer lines). While taking the difference from Thuillier 2004 spectrum and comparing with other spectra, the Gueymard 2004 spectrum closely agrees with the Thuillier 2004 spectrum at 450-500nm , but seems to differ by -213.30 and -8.71 W m^{-2} µm^{-1} at 375-425nm and 825-875nm respectively. The Thekaekara 1973 spectrum though exhibiting relatively less difference at UV and VIS (blue) yields a large negative bias at NIR (absolute term also explains this difference from 500-900nm).

The differences in the Wehrli 1985_WMO, ASTM E-490 and SBDART ETR spectra are generally less at 825-875nm (0.18, -1.14 and 0.79 W m^{-2} µm^{-1}), but they show remarkably large differences with Thuillier 2004 spectrum at 450-500nm (-56.50, -58.50 and -51.17 W m^{-2} µm^{-1}) and 375-425nm (-150.97, -151.85 and -151.85 W m^{-2} µm^{-1}). On the other hand, the ASTM G173-03 spectrum tends to have slightly smaller values than those of Neckel and Labs 1984 spectrum at 825-875nm and 450-500nm. However, at 375-425 the situation becomes reversed, i.e., ASTM G173-03 spectrum differs by a factor of -240.38 W m^{-2} µm^{-1} larger than -133.01 W m^{-2} µm^{-1} of Neckel and Labs 1984.

Because the GOCI has similar characteristics with those of SeaWiFS and MERIS (Table 1), the model-to-model differences have been also examined in the in-band irradiances of these sensors using their spectral response functions (see Table 3). It appears that the differences between Thuillier 2004 and Gueymard 2004 are radically small compared to other irradiance spectra. Among the older spectra, the Neckel and Labs 1984 and SBDART ERT closely respect each other and Wehrli 1985_WMO shows slightly larger, but is still reasonable while comparing with ASTM G173-03 and ASTM E-490. On the whole, the Thekaekara 1973 claims inaccuracy and

Table 3. Band-averaged percent difference from Thuillier 2004.

Sensor	Neckel and Labs 1984	Wehrli 1985_WMO	ASTM E-490	ASTM G173-03	Gueymard 2004	SBDART ETR	Thekaekara 1973
MERIS	0.987845	1.112088	1.272651	1.198229	0.677517	0.97962	4.416144

SeaWiFS	0.719042	0.886044	0.975329	0.870834	-0.21814	0.728499	2.221714

the large difference associated with this spectrum could be attributable to aircraft measurements that were affected by terrestrial absorption features (and atmospheric interferences by ozone and water vapour) and inefficient calibration methods and experimental problems and conflicting determinations of solar constant (1352.5 W m^{-2}) (Frohlich, 1983).

3. CONCLUSION

Several earlier solar irradiance spectra were constructed from many different sources of data from different instruments that used different calibration standards and atmospheric correction schemes. This imposes difficulty to assess them because of the need of the accurate radiometric data. This study concludes that for ocean color observations the Thuillier 2004 spectrum seems to be more appropriate than other spectra. This composite spectrum is from the most recent experiments (SOLSPEC) promising the desired updates of the former standards and spanning a wavelength range of 0.1 to 2400 nm with the highest spectral interval of 0.05-0.1nm, ideal for use in the process of calibration and validation of GOCI and its related bio-optical algorithms development. The Gueymard spectrum is an alternative to Thuillier 2004, for multispectral/multipurpose satellite sensors (e.g., KOMPSAT-II MSC) that observe the land where the former is capable of providing spectral data beyond 2400nm of the later.

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