Estimating Ultraviolet Radiation from Total Radiation

Aron Habte,[1] Manajit Sengupta,[1] Christian A. Gueymard,[2] Ranganath Narasappa,[1] Olivier Rosseler,[3] David M. Burns[4]

[1]National Renewable Energy Laboratory, Golden, CO, USA, [2]Solar Consulting Services, Colebrook, NH, USA

[3]Saint-Gobain Research North America, Northboro, MA, USA, [4]3M Weathering Research Center, St. Paul, MN, USA

Abstract

- Terrestrial ultraviolet (UV) radiation is a primary factor contributing to the weathering of materials over time.
- Measured and/or modeled total solar irradiance (TS) data are relatively abundant; however; availability of UV measurements is limited.
- Estimate terrestrial UV irradiance (~280–400 nm and ~285-385 nm) from total irradiance data (280–4000 nm).
- Develop a model of the UV/TS ratio using simulations obtained with the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) [1], [2] and examine the influences of atmospheric constituents—such as aerosols, precipitable water vapor, or ozone—and of the local surface characteristics (albedo) on the predicted ratios.
- The goal is to provide reliable estimates of the UV received by samples as a function of location, orientation, and airmass, thus representing various climate conditions.

Method

- This study investigates the total UV irradiance on horizontal surface by developing a model of the UV/TS ratio using simulations obtained using SMARTS [1], [2] for various locations around the world.

Fig. 1. Selected locations included in the study

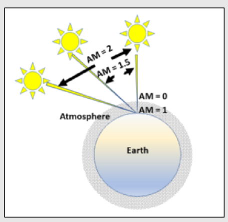

Fig. 2. Illustration of airmass

- Using SMARTS, a handful of airmass-dependent irradiance simulations were generated for the locations under study.

$$UV_m = TS_m * R_{uv}$$

$$R_{uv} = \frac{UV_S}{TS_S}$$

where UV_S and TS_S are the total UV irradiance and total shortwave irradiance estimated with SMARTS, respectively (W/m^2).

$$UV_m = TS_m(\sum_0^4 m_i\, AM^i)$$

where TS_m (W/m^2) is the measured or modeled total solar irradiance, AM_i are airmasses, and mi are numerical coefficients obtained by least-squares fitting (Table 1 and Fig. 3).

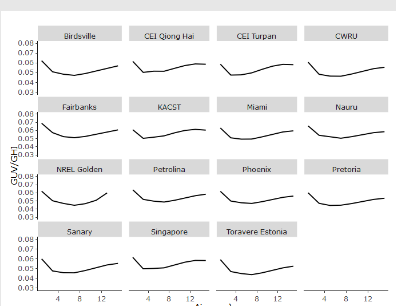

Fig. 3. (Right) R_{uv} (GUV/GHI) as a function of airmass for mean annual fixed atmospheric conditions (prevailing conditions) of 15 locations for the range 280–400 nm.

A fourth-order polynomial function was developed using Fig. 3 for 280 – 400 nm. Similar relationships for other spectral wavebands were also developed (295–400 nm, 285–385 nm, and 295–385 nm).

Results

Table1. Comparison of Results Using Different Definitions of UV Spectral Range

Station	NREL Model (280–400 nm) MJ/m²*	NREL Model (295–400 nm) MJ/m²*	Poliskie, 2011 (295–400 nm) MJ/m²	NREL Model (285–385 nm) MJ/m²	NREL Model (295–385 nm) MJ/m²*	White et al., 2011 (295–385 nm) MJ/m²
Case Western Reserve Univ., Ohio, USA	291 (0° tilt) 285 (5° tilt) 269 (41° tilt)	288 (0° tilt) 285 (5° tilt) 269 (41° tilt)	—	227 (0° tilt) 221 (5° tilt) 208 (41° tilt)	224 (0° tilt) 221 (5° tilt) 208 (41° tilt)	—
Miami, Florida, USA	422 (0° tilt) 410 (5° tilt) 400 (26° tilt) 369 (45° tilt)	416 (0° tilt) 410 (5° tilt) **400 (26° tilt)** 369 (45° tilt)	**390 (26° tilt)**	330 (0° tilt) 320 (5° tilt) 304 (26° tilt) 295 (45° tilt)	325 (0° tilt) **320 (5° tilt)** 311 (26° tilt) **288 (45° tilt)**	**338 (5° tilt)** **320 (45° tilt)**
NREL, Golden, Colorado, USA	341 (0° tilt) 341 (5° tilt) 337 (40° tilt)	339 (0° tilt) 341 (5° tilt) 337 (40° tilt)	—	266 (0° tilt) 265 (5° tilt) 260 (40° tilt)	264 (0° tilt) 265 (5° tilt) 260 (40° tilt)	—
Phoenix, Arizona, USA	439 (0° tilt) 435 (5° tilt) 432 (34° tilt)	436 (0° tilt) 435 (5° tilt) **432 (34° tilt)**	**440(34° tilt)**	343 (0° tilt) 339 (5° tilt) 361 (34° tilt)	340 (0° tilt) **339 (5° tilt)** **336 (34° tilt)**	**359 (5° tilt)** **363 (34° tilt)**

* Values are obtained using the NREL TMY data set (Physical Solar Model V3).
Note: Orientation is south facing

- With the assumption that cloudiness does not affect R_{uv}, the method described here can be used with conventional typical meteorological (TMY) data converted to desired tilt angle to obtain a representative estimate of annual UV irradiation at hourly intervals. As an example, Table 1 shows four U.S. locations in varied climates. For each site, the TMY global horizontal irradiance (GHI) (TS_m) data set is used to obtain the modeled UV over various wavebands and tilt angles. The result was compared with results provided in other studies based on actual measurements on near-horizontal or tilted surfaces.

Validation

- The modeled UV_m results for 1 year (August 2016 to August 2017) are compared to average measurements of UV from two different UV radiometers (Eppley Lab TUVR and Kipp & Zonen CUV4) deployed at NREL.
- Most of the hourly differences are within ±2 W/m^2, as shown in Fig. 4 and Fig. 5. There are a few outliers outside of the ±4 W/m^2 range, but these could be related to snow events or radiometer maintenance issues.

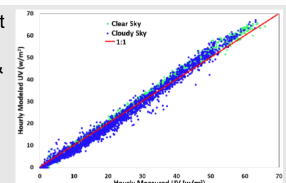

Fig. 4. Hourly modeled vs. measured global UV irradiance under clear-sky and cloudy-sky conditions at the SRRL

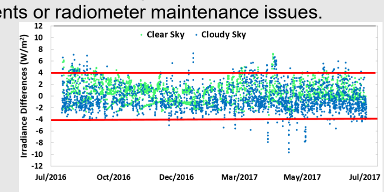

Fig. 5. Hourly modeled vs. measured global UV irradiance differences under clear-sky and cloudy-sky conditions at the SRRL

The measured albedo larger than 0.5 are identified separately and indeed demonstrate different behavior (Fig.6).

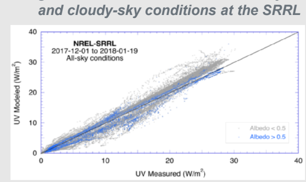

Fig. 6. Modeled vs. measured 1-minute UV global irradiance under all-sky conditions at the SRRL for low and high surface albedo conditions

Conclusions and Future Work

- The proposed model can be applied to estimate the total UV irradiance from total solar irradiance (e.g., GHI) under all-sky conditions, tilt, and location.
- Input data can be obtained from, e.g., actual measurements, satellite-derived modeled time series, or TMY data files.
- The preliminary tests conducted here show that the modeled UV results are in good agreement with actual measurements at different timescales, which provides confidence about the accuracy of the model.
- The model typically under- or overestimates the measured UV irradiance by only ±2W/m^2 during the course of 1 year.
- Based on this approach, a new ASTM standard (on the estimation of UV irradiance received by samples as a function of location, orientation, and tilt) is under development.

References

1. C.A. Gueymard, *Simple Model of the Atmospheric Radiative Transfer of Sunshine, Version 2 (SMARTS2): Algorithm Description and Performance Assessment* (FSEC-PF-270-95) (Cocoa, FL: Florida Solar Energy Center, 1995).
2. C.A. Gueymard, "Parameterized Transmittance Model for Direct Beam and Circumsolar Spectral Irradiance," *Solar Energy* 71 (2001): 325–346.
3. M. Poliskie, *Solar Module Packaging: Polymeric Requirements and Selection* (Boca Raton, FL: CRC Press, 2011).
4. C.C. White. *Service Life Prediction of Polymers and Plastics Exposed to Outdoor Weathering* (Saint Louis, MO: William Andrew, 2017). http://lib.myilibrary.com?id=1039678.

This work was authored by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

Solar Power International 2018
Anaheim, CA
September 24-27, 2018
NREL/PO-5D00-72429