Modeling of Ultraviolet Irradiance from Total Irradiance: A Simplified Approach

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Abstract

- Terrestrial ultraviolet (UV) irradiance is a small portion of the solar spectrum. However, the high energy contained within those wavelengths can cause degradation of materials, such as photovoltaic (PV) modules.
- Measured terrestrial UV data is limited and is prone to high measurement uncertainty resulting from calibration error and directional response.
- Measured or modeled total irradiance data of relatively low uncertainty is relatively abundant for many locations.
- In this poster, we demonstrate and validate a method [1] to estimate terrestrial UV using a model that provides ratio of terrestrial UV to total irradiance spectra.
- This study examines the total UV irradiance on a horizontal surface derived from a model of the UV/GHI ratio developed using simulations obtained using Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) [1], [2] with observed atmospheric parameters.
- The model demonstrates good agreement with measurements.

Method

Fig. 1. Selected locations included in the study

- At the earth surface, the irradiance is strongly affected by the airmass factor, which depends on solar geometry.
- Using the SMARTS model, airmass-dependent irradiance simulations were generated for the locations under study (Fig 1).

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

$$R_{uv} = \frac{UV_s}{TS_s}$$

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

The result of UV:TS ratios were then multiplied with available TS to obtain modeled UV for these locations.

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

where TS_m (W/m^2) is the measured or modeled total solar irradiance, AM_i are airmasses, and m_i are numerical coefficients obtained by least-squares fitting (Fig. 2). A fourth-order polynomial function was fitted to Fig. 2 for 280 – 400 nm and 285–385 nm. Similar relationships for other spectral wavebands were also developed (295–400 nm, and 295–385 nm).

However, for locations with limited meteorological information an average of the 15 location lines (black thick line in Fig. 2) can be used to develop the R_{uv}.

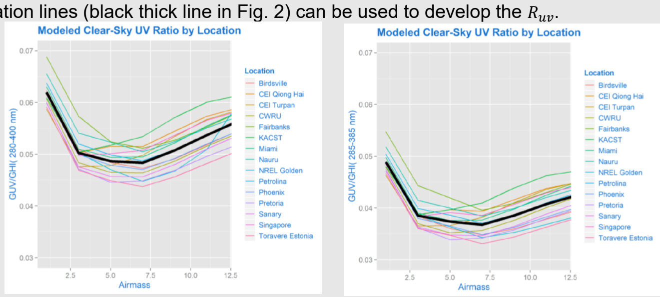

Fig. 2. (Right) R_{uv} (GUV/GHI) as a function of airmass for mean annual fixed atmospheric conditions (prevailing conditions) of 15 locations for the range 280–400 nm and (Left) for 285–385 nm . The black thick line is the average of all 15 lines.

Results

- The model demonstrated good agreement with the measured UV (Fig.3 and 4)
- Cloudiness did not affect the agreement between model and observations (Fig 3 and 4).

Validation using Individual Polynomial Function

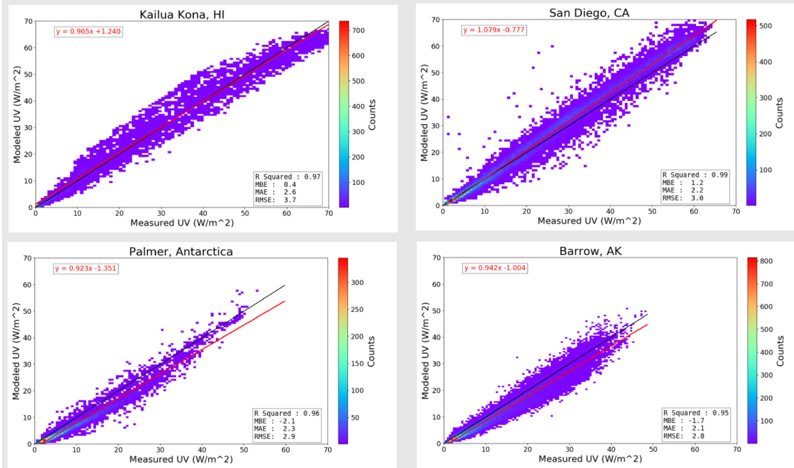

Fig. 3. Modeled vs. measured global UV irradiance under all sky conditions and zero tilt for multiple locations. Black line is 1:1 line and red line is a regression fit (obtained from [1]).

Validation using Average Polynomial Function

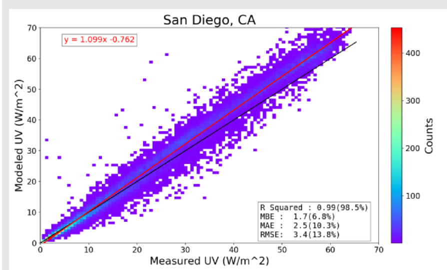

Fig. 4. The same as Fig. 3 but using average polynomial coefficients (Fig. 2)

- Fig. 4 demonstrates insignificant difference (see statistics from Fig. 4 and top right panel of Fig. 3 for comparison) between using individual polynomial coefficients and an average of the 15 polynomial functions from Fig. 2 (right panel).

Conclusions and Future Work

- NREL in collaboration with industry partners, published a journal article [1], and the model can be applied to estimate the total UV irradiance from measured or modeled total solar irradiance under all-sky conditions.
- The validation of both individual and average functions shows good agreement with measurement and provides confidence about the accuracy of the model.
- The model bias on average is only $\pm 2 W/m^2$ when validated for multiple locations.
- Based on this approach, a new ASTM standard on the estimation of UV irradiance received by samples as a function of location has been drafted and balloted.

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