Assessment of Error Sources in the Modeling of POA Irradiance Under Clear-Sky Conditions

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Assessment of Error Sources in the Modeling of POA Irradiance under Clear-sky Conditions

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ABSTRACT: A new physics-based model, the Fast All-sky Radiation Model for Solar applications with Narrowband Irradiances on Tilted surfaces (FARMS-NIT), accurately computes plane-of-array (POA) irradiances in both narrow- and broad wavelength bands within the solar region. The evaluation studies suggest the new model provide more accuracy than a model assuming isotropic diffuse solar radiation and an empirical model linking the POA irradiances with long-term surface observations at selected locations. This study anlyzes the surface observations used by FARMS-NIT and is intended to understand the error sources under clear-sky conditions as well as their impact to the performance of FARMS-NIT.

Keywords: solar radiation, resource assessment, POA irradiance

1 INTRODUCTION

Conventional models that estimate the production of solar energy conversion systems compute or measure solar radiation on a horizontal surface and convert it to plane-of-array (POA) irradiance [1, 2]. To improve the accuracy and efficiency of those models, Xie et al. [1] and Xie and Sengupta [3] developed the Fast All-sky Radiation Model for Solar applications with Narrowband Irradiances on Tilted surfaces (FARMS-NIT) to provide physics-based solutions of spectral irradiance in the POA. This new model employs the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) [4] to efficiently compute clear-sky atmospheric properties, e.g. the optical thickness of the atmosphere, in 2,002 wavelength bands from 0.28-4.0 µm.

Following the Rayleigh scattering correction technique, FARMS-NIT considers five independent events where photons (1) directly transmit through the aerosol/cloud, (2) are scattered by gas molecules in the upper clear sky and scattered by the aerosol/cloud, (3) are scattered by gas molecules in the upper clear sky and directly transmit through the aerosol/cloud, (4) are scattered by the aerosol/cloud and scattered by gas molecules in the lower clear sky, and (5) directly transmit through the aerosol/cloud and are scattered by gas molecules in the lower clear sky. Then surface radiances from all spacial directions are computed by considering the possible paths for individual photon transmission, and the relevant absorption, scattering and reflection by aerosols, clouds and land surface. For clear-sky conditions, the computation is simplified using the assumption of single scattering within aerosols and the single-scattering phase functions. For cloudy-sky conditions, we developed a lookup table (LUT) of cloud bi-directional transmittance distribution functions (BTDFs) for 97 wavelengths, 39 optical thicknesses, 28 effective particle sizes, 50 solar zenith angles, 25 viewing zenith angles and 18 relative azimuth angles. The POA irradiances are then accurately computed by integrating radiances over inclined surfaces with any tilt angles. The broadband POA irradiance is calculated by integrating the spectral irradiances over the 2,002 wavelength bands.

The FARMS-NIT will be used to provide spectral irradiances in the POA using satellite observations and the estimation of cloud microphysical and optical properties [5-16]. The simulations will be dissiminated by the National Renewable Energy Laboratory's (NREL's) National Solar Radiation Data Base (NSRDB) [17]. The operational application of FARMS-NIT requires reliable validations in various scenes to understand the magnitude of the model uncertainties. An analysis is also required to understand the error sources associated with the uncertainty in FARMS-NIT.

2 EVALUATION OF POA IRRADIANCE

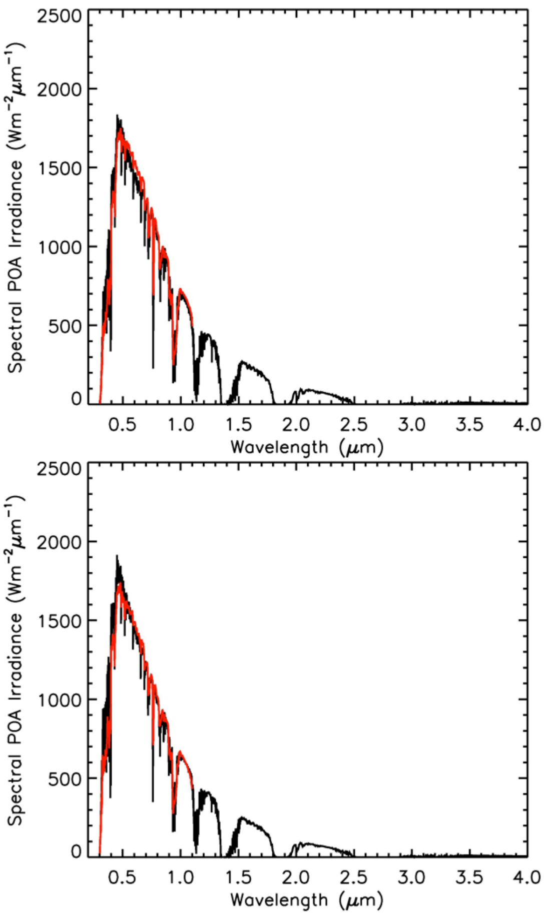

Figure 1 Spectral POA irradiance on a one-axis tracker measured by a LI-1800 (red line) and simulated by FARMS-NIT (black line) at 8:30 am (upper panel) and 12:05 pm (lower panel) on June 18, 2017.

We utilize the surface-based observations at the NREL's Solar Radiation Research Loboratory (SRRL) to

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validate FARMS-NIT in clear-sky conditions [1]. An EKO WISER spectroradiometer on a one-axis tracker is used to measure spectral POA irradianes from 0.3 to 1.1 µm for every 5 minutes. The aerosol optical depth (AOD), surface albedo, surface air pressure, and solar and PV orientations are measured for every 1 minute. The precipitable water vapor (PWV) is measured for every 30 minutes by a Zephyr Geodetic GPS antenna. The surface observations are collocated to the time steps of the spectral POA irradiance measurements for each 5 minutes, and they are applied to FARMS-NIT to compute spectral POA irradiances from 0.28 to 4.0 µm. The model simulations are compared with the surface observations at NREL's SRRL.

Our results suggest that the percentage error (PE) and absolute percentage error (APE) of FARMS-NIT are 0.615% and 4.93%, respectively, over the 121 5-min intervals on June 18, 2017. These errors are significantly lower than models assuming isotropic diffuse solar radiation [18] and an empirical model linking the POA irradiances with long-term surface observations at selected locations [2].

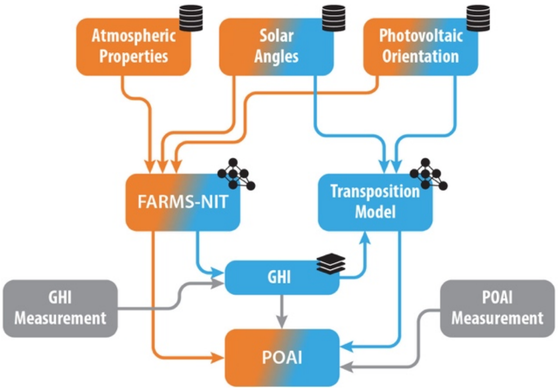

Figure 2 A flowchart of evaluating POA irradiances using surface measurements.

Current model evaluation efforts use measurements of global horizontal irradiance (GHI) to compute POA irradiances and compare them with surface observations [19-22]. To reduce the restriction by the availability, consistency, and accuracy of the GHI measurements, we use a new algorithm based on FARMS-NIT, and surface observations of AOD, precipitable water vapor (PWV), cloud fraction, surface pressure, surface albedo and solar angles. Figure 2 is a flowchart of evaluating POA irradiance computed by FARMS-NIT and transposition models. We first collocated the surface observations to 5-min intervals, input them to FARMS-NIT, and computed broadband GHI and POA irradiance. The computed GHI is decomposed to direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI) and used by transposition models to compute POA irradiances. The computations by FARMS-NIT and the transposition models are finally compared with surface observations.

3 ASSESSMENT OF ERROR SOURCES IN FARMS-NIT AND TRANSPOSITION MODELS

Our analysis indicates the uncertainty of the transposition models comes from the inherent limitations of the models, e.g. limitation of directions and locations of GHI and POA irradiance measurements. The uncertainty of the transposition models may also come from the computed GHI by FARMS-NIT as well as measurements of the atmospheric properties to compute GHI. It is thus important to assess the uncertainty sources of FARMS-NIT for the optimal employment of the models and to further improve their performance.

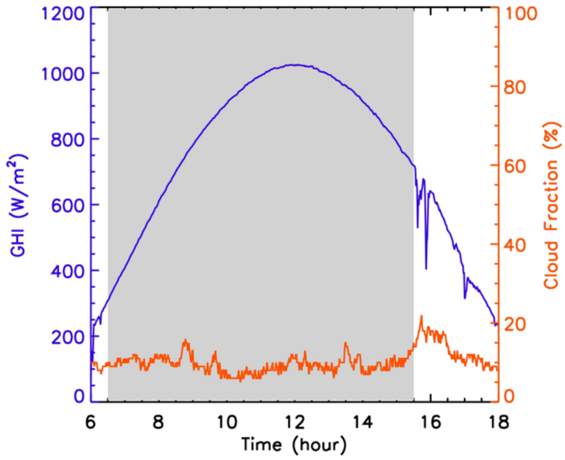

Figure 3 Observation of GHI and cloud fraction at NREL's SRRL on June 18, 2017.

Because FARMS-NIT directly solves POA irradiance from the computed radiances, the error sources come from the uncertainty and limitation of the atmospheric properties used to compute solar radiances. To evaluate FARMS-NIT in clear-sky conditions, we selected relatively clear days at NERL's SRRL based on measured GHI by a Kipp and Zonene CM Pyranometer 22 (CMP22) and cloud fraction by a Yankee Total Sky Imager at NREL's SRRL. Figure 3 shows the GHI and cloud fraction on June 18, 2017 that is selected because the average cloudy fraction is less than 15%. However, the 100% clear-sky condition assumed by FARMS-NIT leads to uncertainties because of the partially covered cloud conditions.

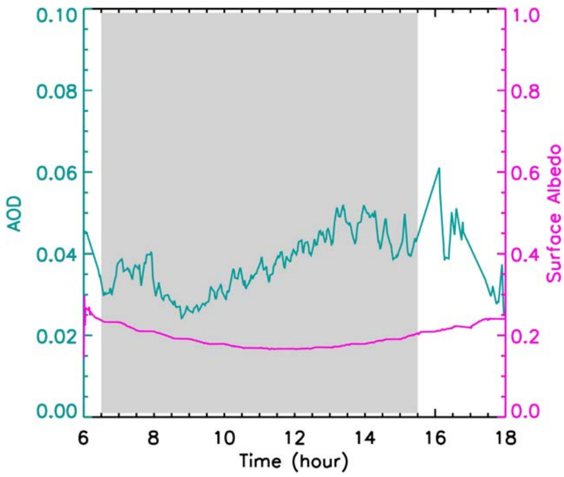

Figure 4 Observation of AOD and surface albedo at NREL's SRRL on June 18, 2017.

Other important error sources include measurements of AOD and land-surface albedo. Figure 4 shows the daily variation of AOD, which indicates the use of daily averaged AOD may lead to significantly bias in a day. FARMS-NIT uses measurements of broadband surface albedo because those in spectral bands are unavailable at NREL's SRRL. Following previous studies by McKenzie and Kotkamp [23], spectral surface albedo of green grass

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tends to be smaller and greater than broadband albedo in visible and near-infrared regions, respectively. Therefore, the land-surface albedo may lead to significantly bias when used by FARMS-NIT to compute spectral irradiances. Their impact on the simulation of broadband irradiance requires further sensitivity studies.

4 CONCLUSIONS

FARMS-NIT solves POA irradiance from the optical and physical properties of the atmosphere, and it thus reduces the inherence limitation in the transposition models that relies on long-term observations of GHI and POA irradiance. FARMS-NIT has less than 5% uncertainties as evaluated by the surface observations at NREL's SRRL. Our study suggests that the error sources in FARMS-NIT come from the use of the clear-sky model when a small fraction of cloud exists. The error sources in FARMS-NIT can also be related to infrequent observations of AOD and the representation of spectral surface albedo by observations in the broadband region.

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