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Advances in the Modeling of All-Sky Radiative Transfer for Solar Energy Applications

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I. Unique Requirements from Radiative Transfer Models for Solar Energy

Radiative transfer models for climate and weather studies provide only shortwave irradiances in direct and downwelling directions or radiances in narrow spectrums.

In contrast, solar energy applications require:

1. Fast and efficient computation because irradiance changes rapidly over time and space and it needs to be computed quickly for large areas at high resolution
2. Irradiances in multiple wavelength bands because different photovoltaic (PV) panels have different spectral response
3. Solar irradiances over inclined surfaces because solar systems track the sun on multiple axes.

This poster introduces NREL's rapid broadband and spectral radiative transfer models for solar energy applications.

Figure 1. A solar panel on the NREL campus. Photo by Dennis Schroeder, NREL 40805.

II. Rapid Simulation of Shortwave Irradiances Over Horizontal Surfaces

FARMS: A New Model

NREL developed the Fast All-sky Radiation Model for Solar applications (FARMS).

FARMS rapidly computes global horizontal irradiance (GHI) and direct normal irradiance (DNI) for all sky conditions [1].

What Is FARMS?

- FARMS computes solar radiation using REST2 and a parameterization of cloud transmittance and reflectance (Fig. 2).
- The model was implemented in the Weather Research and Forecasting model for solar energy applications (WRF-Solar) [2].

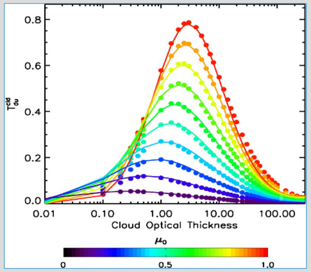

Figure 2. Transmittance of diffuse radiation through water clouds

How Good Is FARMS?

FARMS was tested using Atmospheric Radiation Measurement (ARM) data from the Southern Great Plains site (SGP, Fig. 3) and demonstrated:

- Accuracy comparable to two-stream approximation (Fig. 3)
- A speed about 1,000 times faster than other radiative transfer models utilized in solar energy applications (Fig. 4).

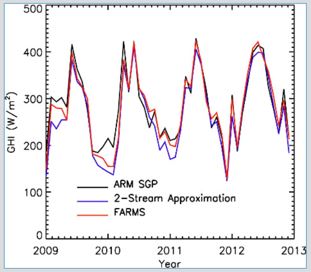

Figure 3. Simulated and measured monthly mean GHIs at the ARM SGP site

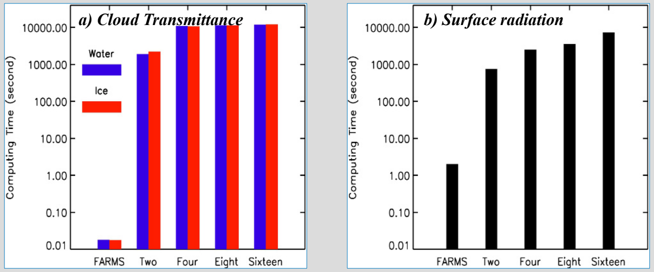

Figure 4. Computing time of a) cloud transmittance and b) surface radiation using FARMS and 2- to 16-stream approximation.

III. Narrowband Irradiances Over Inclined Surfaces

The need for narrowband irradiances on inclined surfaces

Solar energy needs irradiances over both horizontal and inclined surfaces (Fig. 5).

Due to the spectral response of PV panels, the solar energy industry needs irradiances in both broad and narrow wavelength bands.

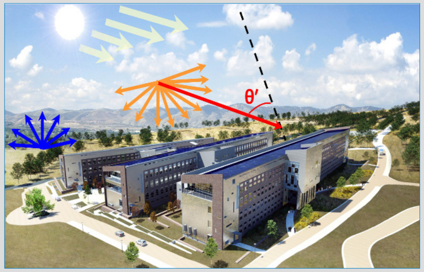

Figure 5. Solar irradiance over an inclined surface. Illustration by RNL Design, NREL 18471.

What's FARMS-NIT?

NREL developed the computationally efficient FARMS-Narrowband Irradiance over Tilted surfaces (FARMS-NIT) for spectral GHI, DNI, and plane-of-array irradiance in 2002 wavelength bins from 0.3 to 4 μm.

An example output from FARMS-NIT is shown in Figure 6.

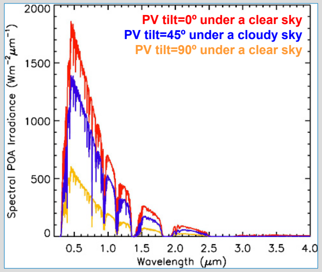

Figure 6. Spectral plane of array irradiance for θ_0=15º.

IV. Observations Lead the Way

The theme of the 2017 AMS Annual Meeting is "Observations Lead the Way." In our experience:

Observations and networks that are needed include:

- Resource and production summaries for solar plants at subhourly scales
- Simplified data discovery and extraction.

Instruments needed to make these observations include:

- Research-grade solar radiation measurements with metadata
- GHI and DNI.

The greatest observational needs for solar energy deployment include:

- A way to share data but protect commercial interests, such as sharing delays through aggregation
- More demonstrations to industry that show the value of data sharing.

The information in this panel is in response to a request from the AMS and is based on the authors' experiences.

V. Conclusions

Radiative transfer models used for solar energy applications must meet demands beyond those required by most weather and climate studies.

FARMS and FARMS-NIT rapidly compute broad- and narrowband irradiances over horizontal and inclined surfaces under all sky conditions.

FARMS is used in NREL's National Solar Radiation Data Base (NSRDB) and is now included in WRF-Solar as well.

References and More Information

References

1. Y. Xie, M. Sengupta, and J. Dudhia, "A Fast All-Sky Radiation Model for Solar Applications (FARMS): Algorithm and Performance Evaluation," *Solar Energy* (2016): 435–445.
2. P. A. Jiminez, J.P. Hacker, J. Dudhia, S.E. Haupt, J.A. Ruiz-Arias, C.A. Gueymard, G. Thompson, T. Eidhammer, and A. Deng, "WRF-Solar: Description and Clear-Sky Assessment of an Augmented NWP Model for Solar Power Prediction," *Bulletin of the American Meteorological Society* 97 (2016): 1,249–1264.

Access solar irradiance data for the United States and beyond:

- National Solar Radiation Database: https://nsrdb.nrel.gov

For more information about solar energy applications:

- A. Clifton, B.-M. Hodge, C. Draxl, and M. Sengupta, "Wind And Solar Resource Mapping," *Wiley Interdisciplinary Reviews Energy and Environment* (forthcoming).
- M. Sengupta, Y. Xie, A. Habte, A. Lopez, and A. Clifton, *The National Solar Radiation Data Base* (forthcoming).

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