NATIONAL RENEWABLE ENERGY LABORATORY

Modeling Spectral Solar Irradiance for Solar Energy Applications

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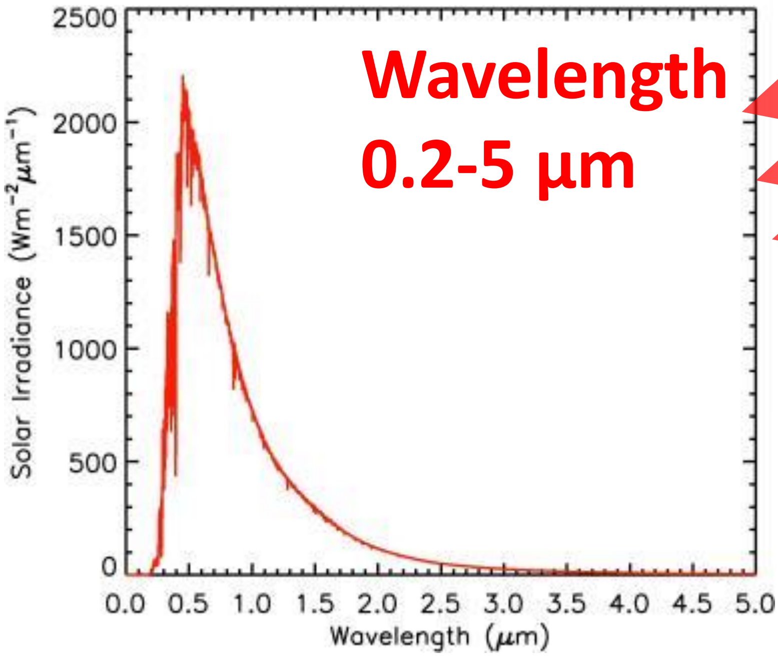
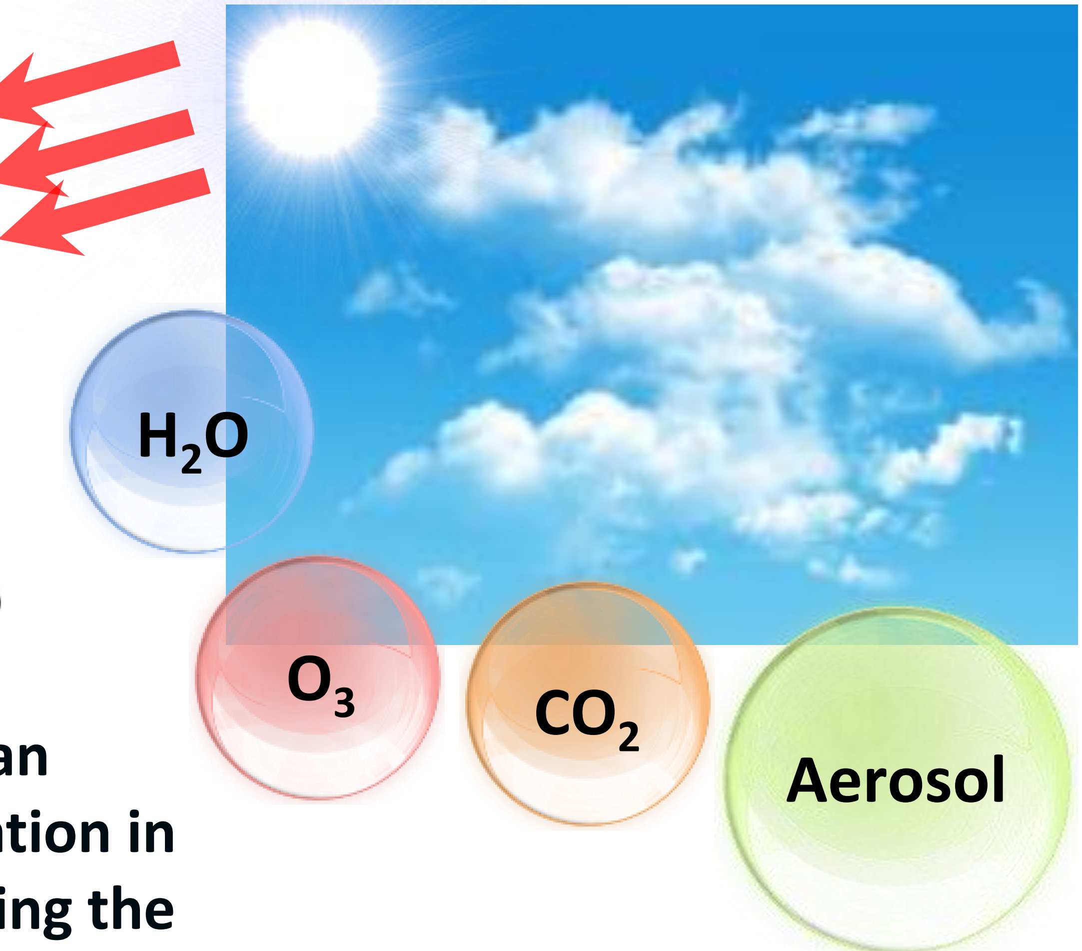
What is a Radiative Transfer Model?

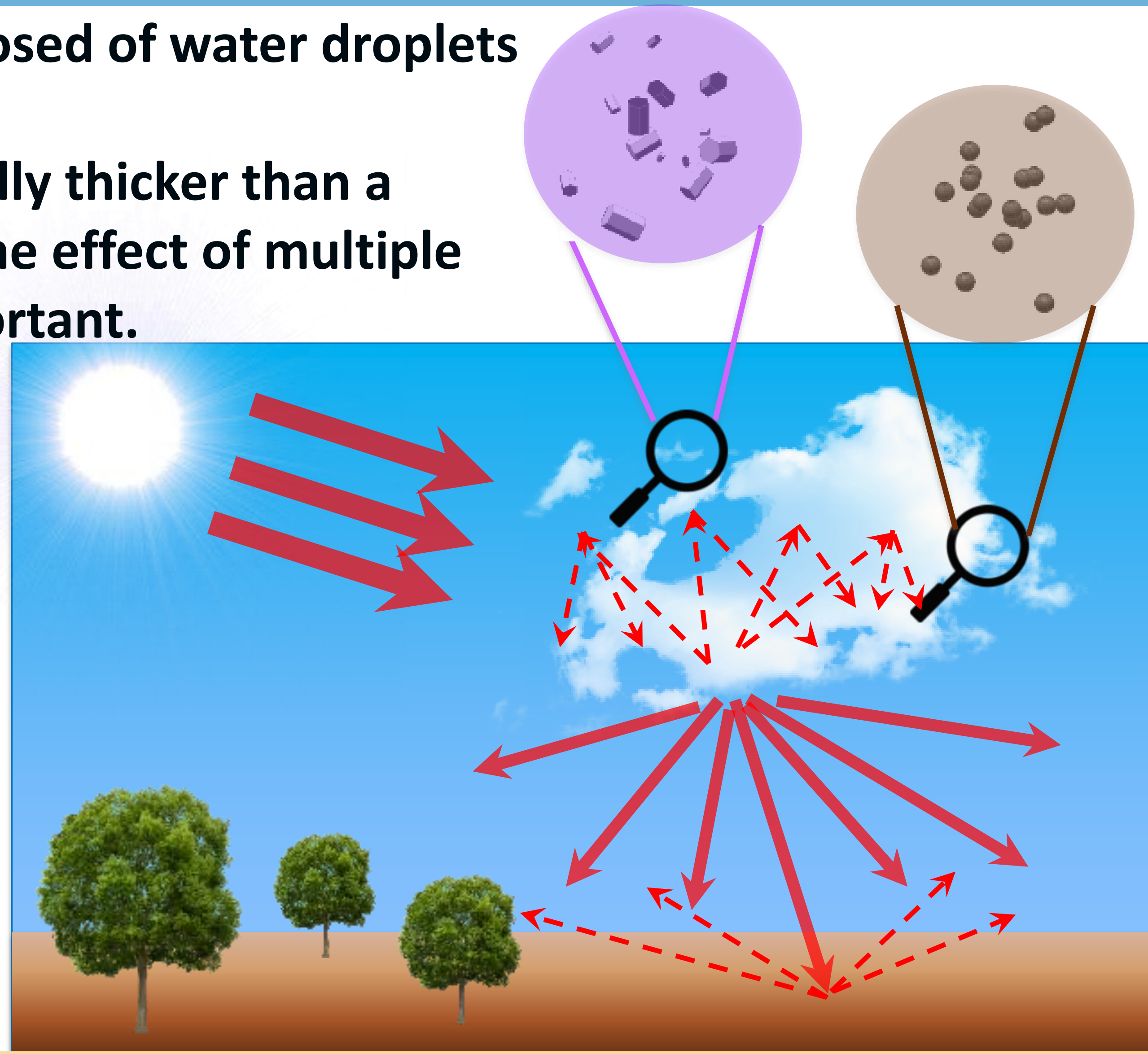




A radiative transfer model can numerically solve solar radiation in the atmosphere by considering the influence from trace gases, aerosols, land surfaces, and clouds.

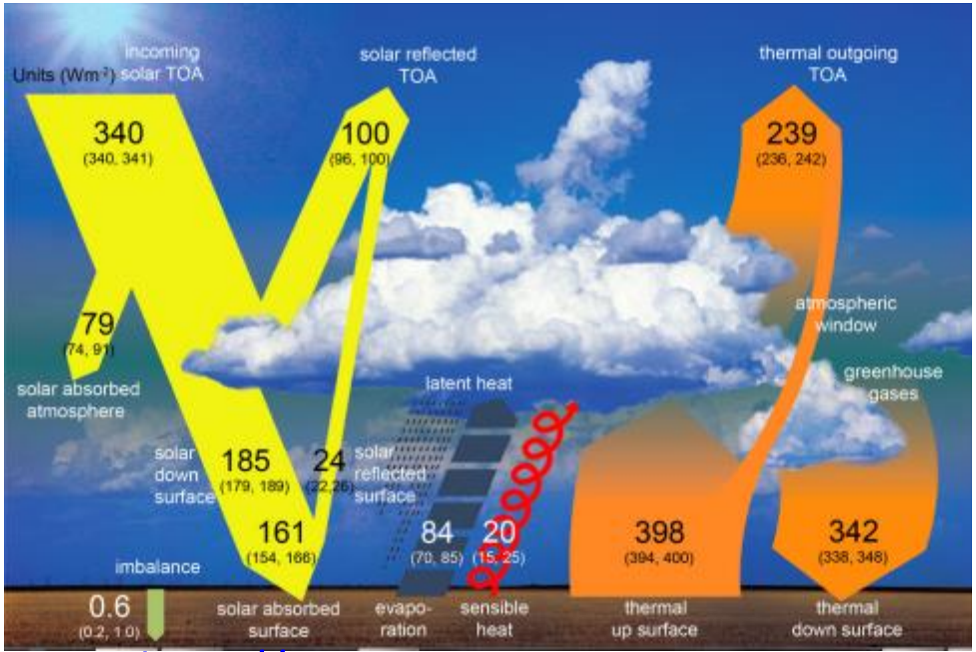
Cloudy-sky Radiative Transfer Model

- Clouds are composed of water droplets or ice crystals.
- Clouds are optically thicker than a clear-sky layer. The effect of multiple scattering is important.
- Energy distribution is different with a clear sky.
- Solving RT equation is time consuming.



Radiative transfer in clouds is complex and time consuming using regular RT models

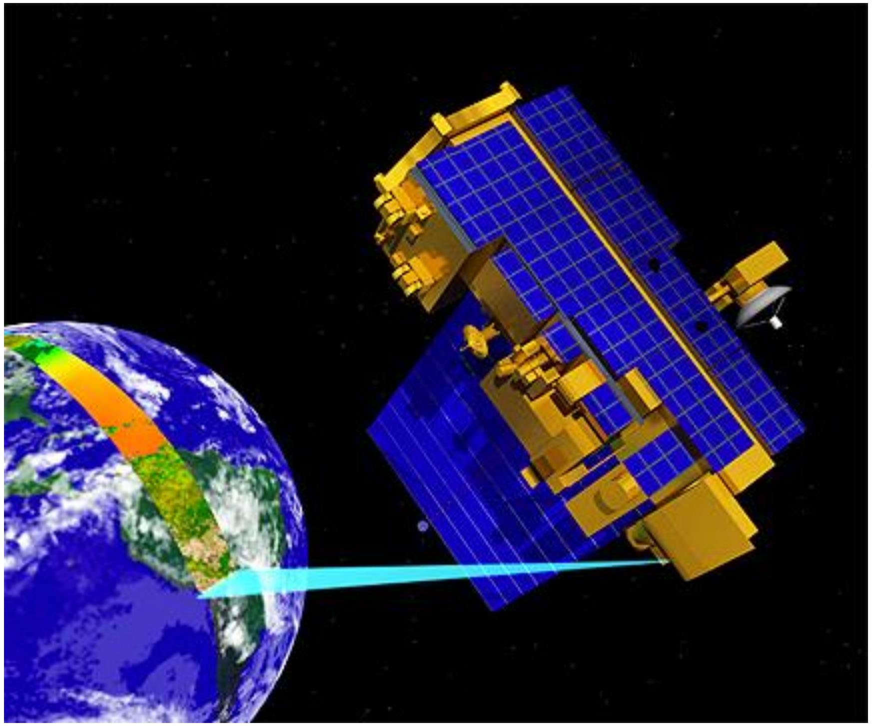
Models for Meteorology



http://environmentcouts.org

The net effect of solar radiation and thermal emission strongly impacts temperature, wind and precipitation.

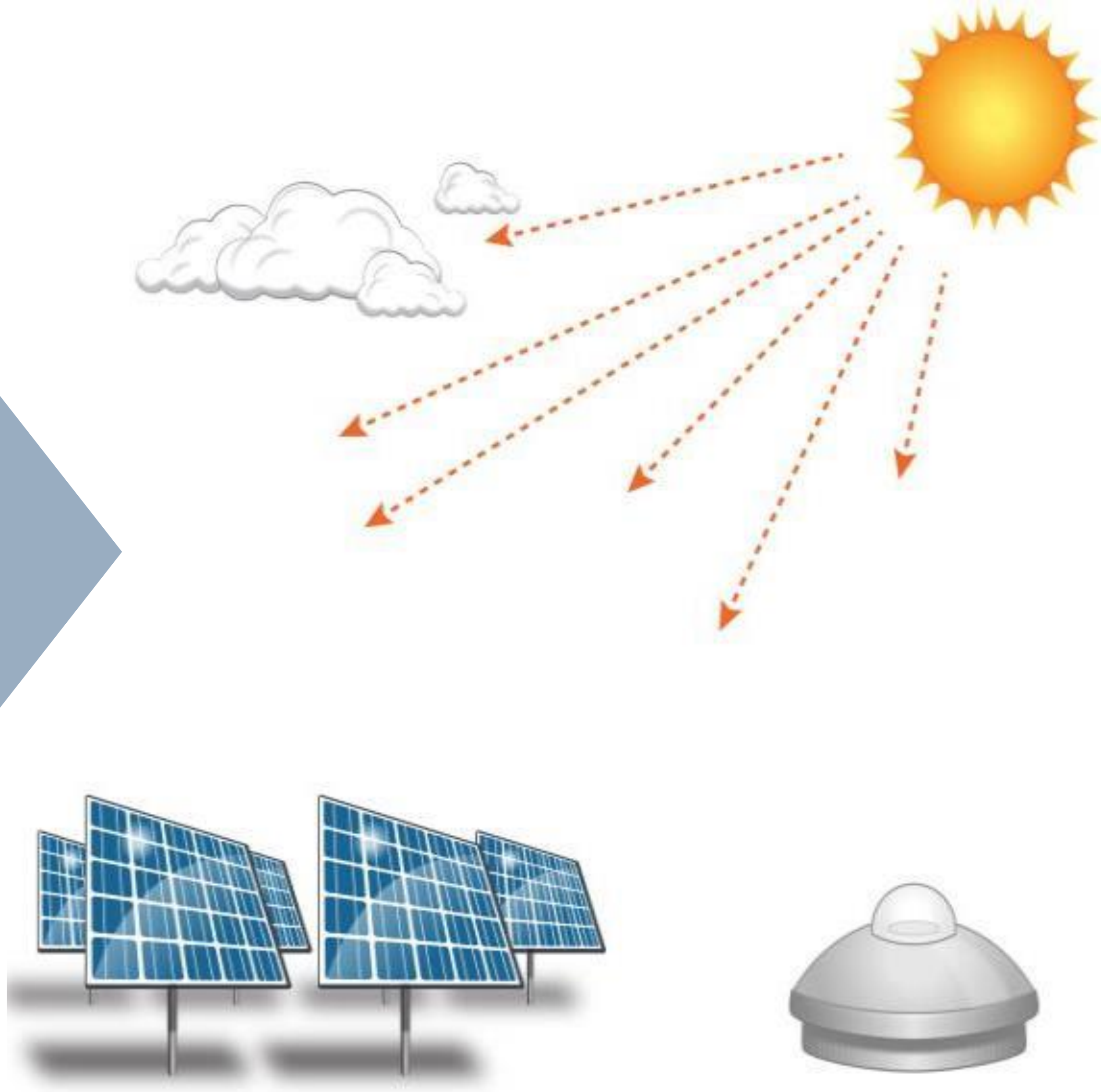
Satellite remote sensing uses radiative transfer models for narrow wavelength bands to retrieve atmospheric and land surface information.



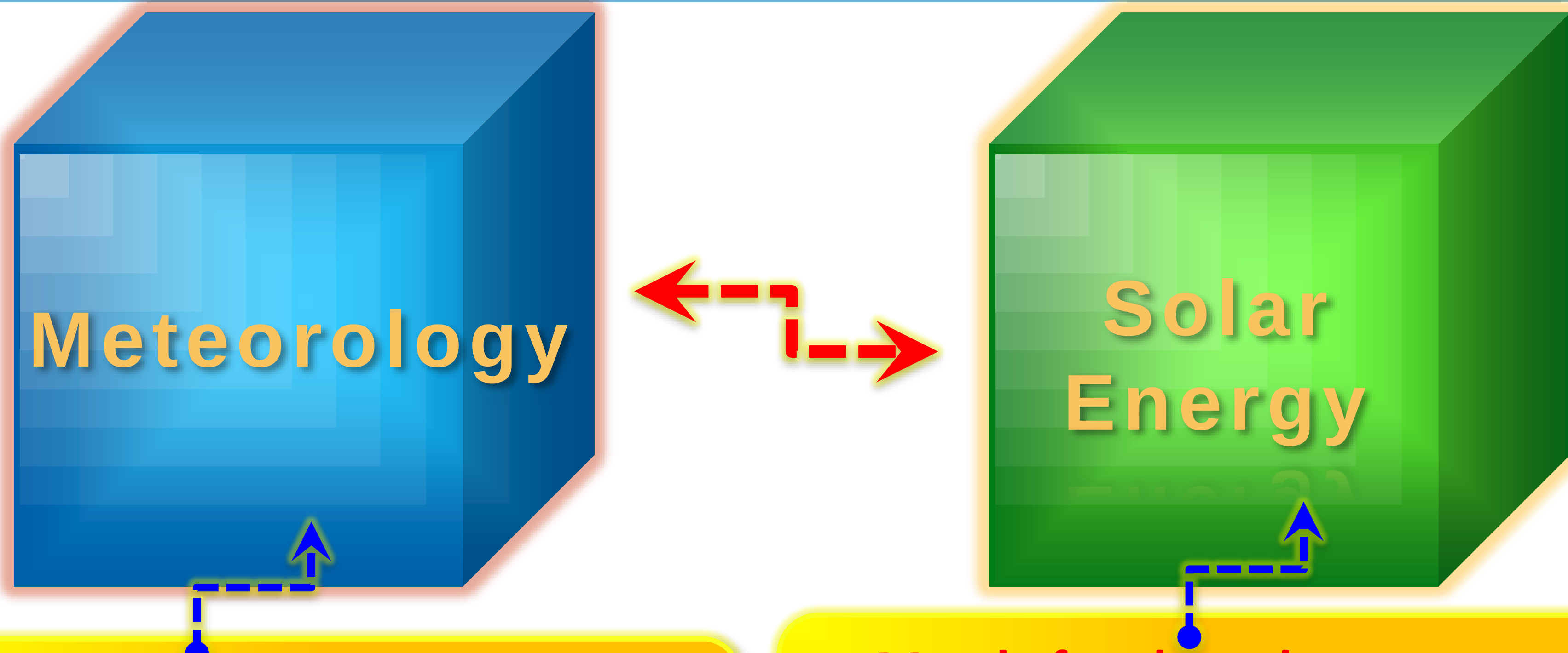
https://www.nasa.gov

Solar Energy has Unique Modeling Requirements

- Inclined Surfaces
- Fast Computation
- Bifacial PV
- Inhomogeneous surfaces
- Spectral radiation



Models in Meteorology and Solar Energy

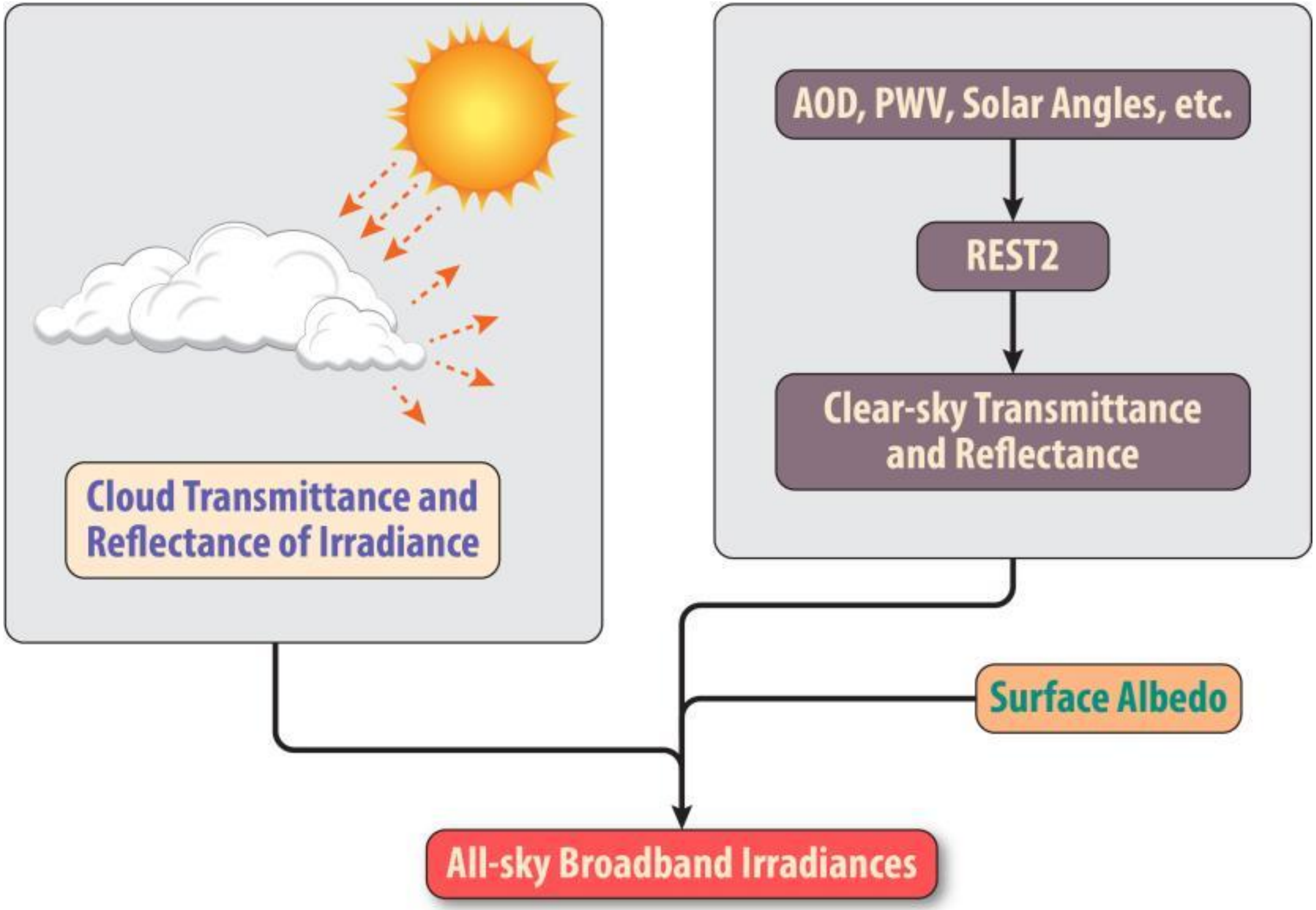


- Clear and cloudy
- Broadband/Monochromatic
- Irradiance/radiance
- Solution of RT equation
- Time consuming

- Mostly for clear sky
- Mostly for broadband
- Irradiances in direct and POA
- Parameterization from measurements
- Time efficient

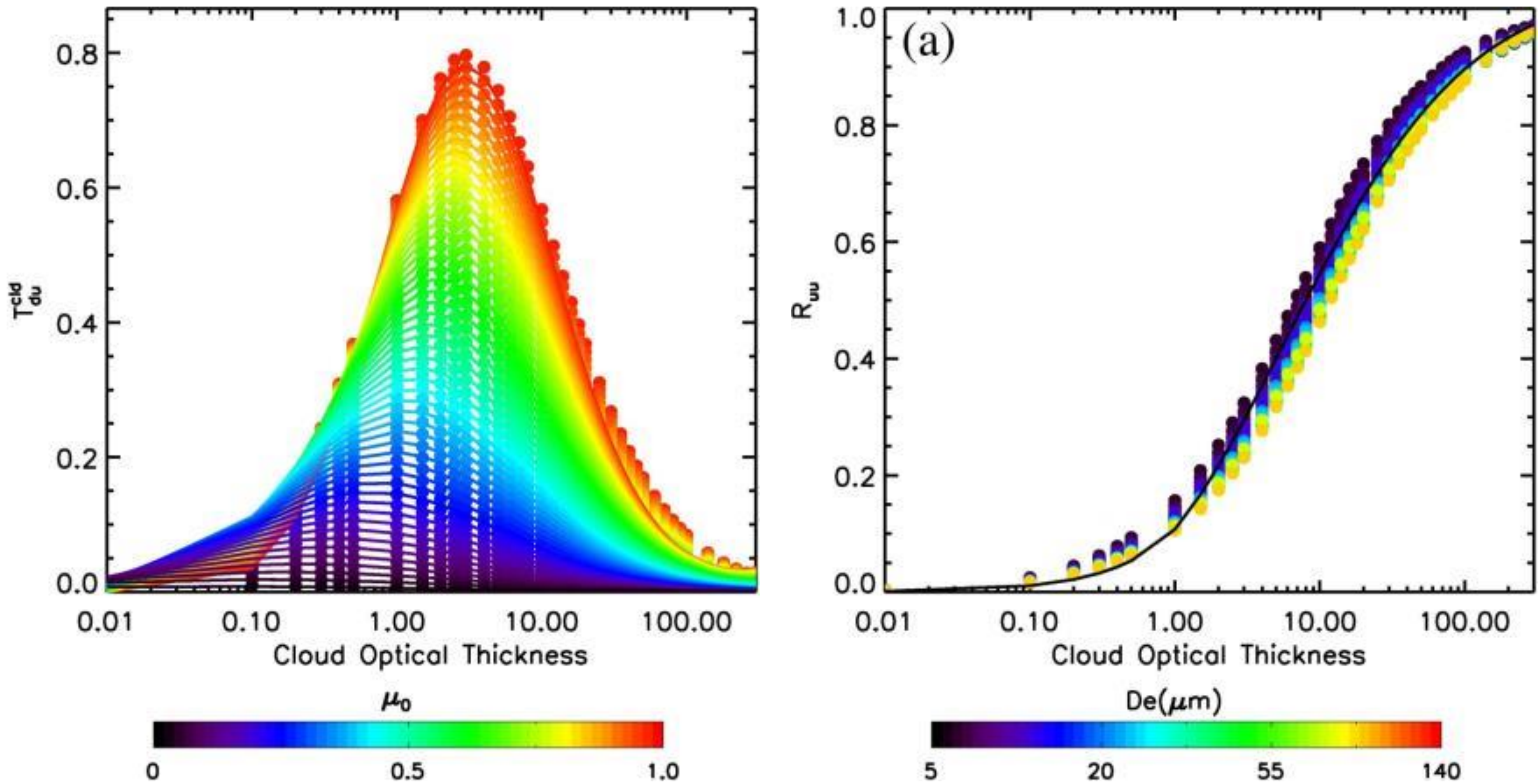
The advantages of the two types of models can complement each other.

Fast All-sky Radiation Model for Solar applications (FARMS)



Xie et al., *Solar Energy (2016)*

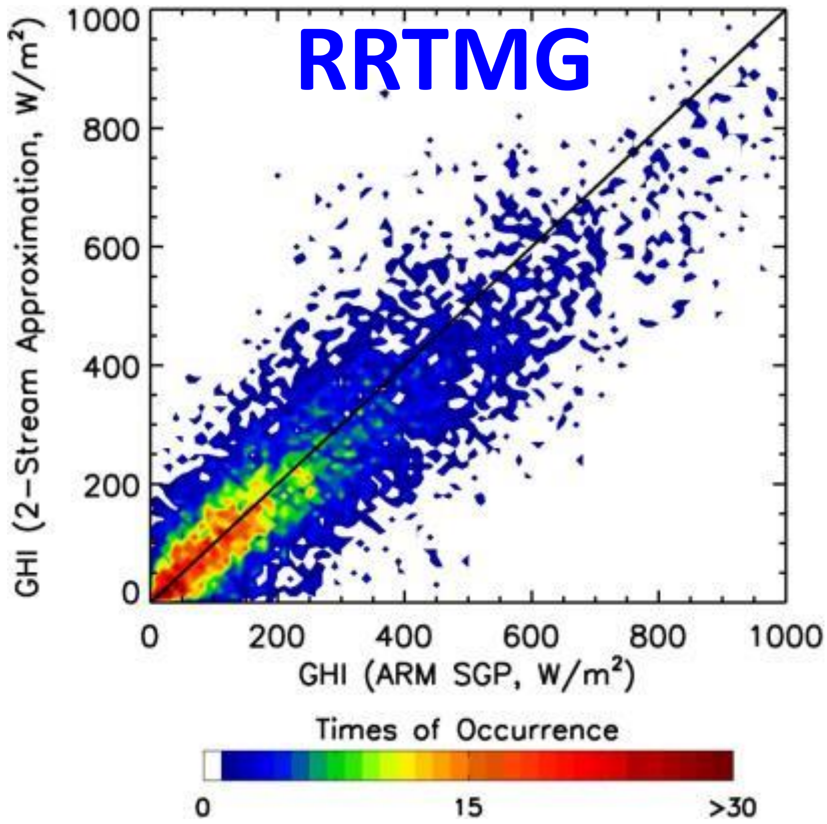
Parameterization of clouds in FARMS

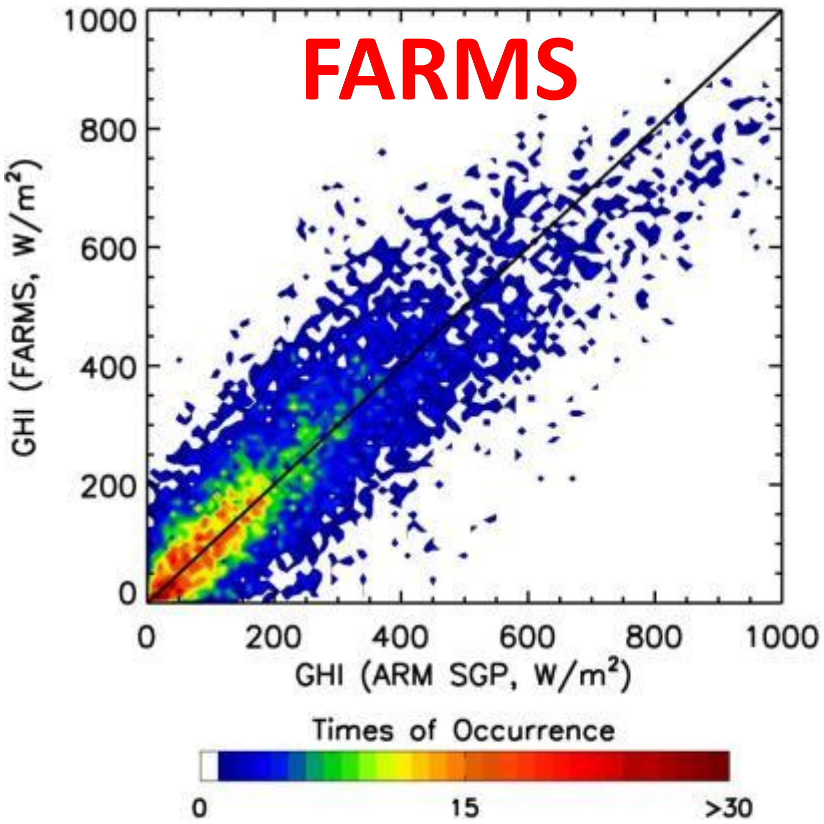


- **Cloud transmittance for diffuse radiation can be parameterized as exponential functions of cloud optical thickness and solar zenith angles.**
- **Cloud reflectance for diffuse radiation can be parameterized using simple equations of cloud optical thickness with good accuracy.**

Transmittance and Reflectance of diffuse radiation can be parameterized accurately.

Validation of FARMS

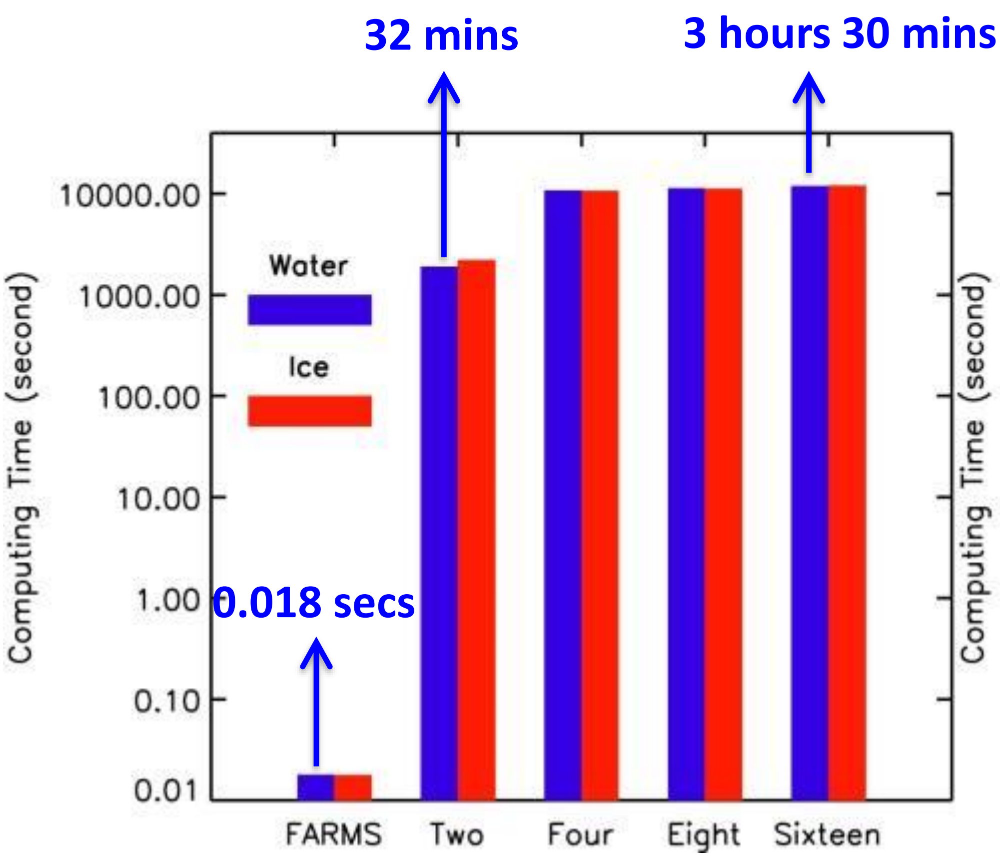




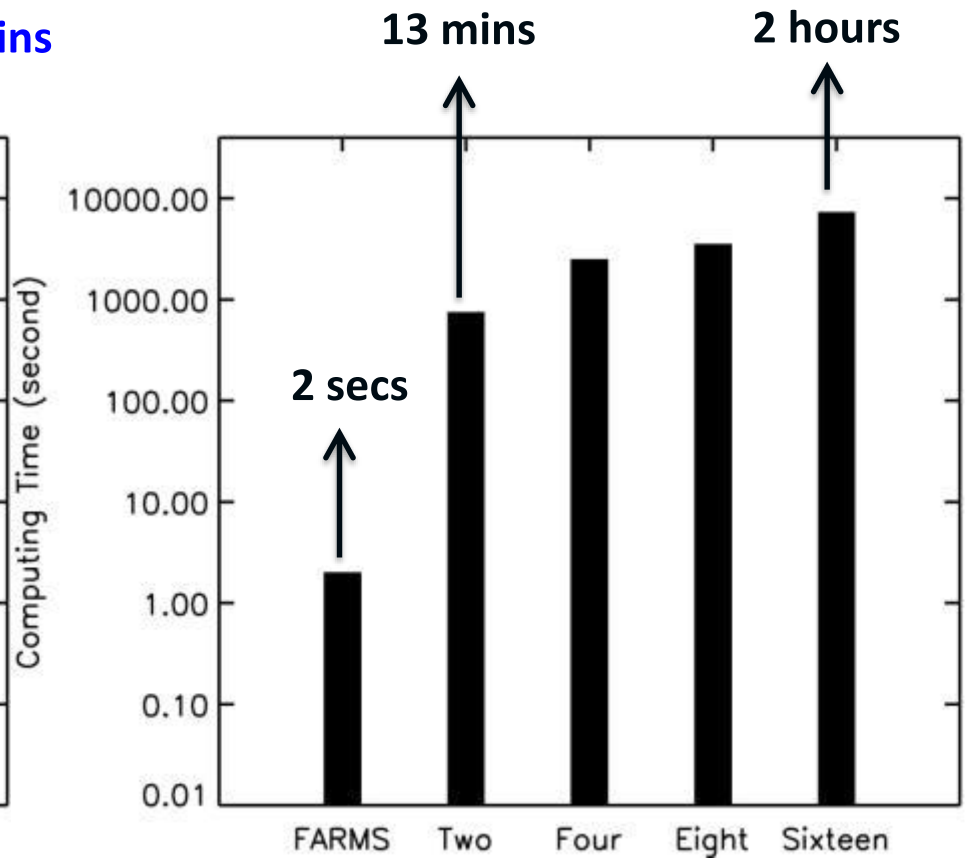
GOES satellite data is collocated to ARM SGP site. The satellite-based retrievals of cloud properties are used as inputs to the two-stream RRTMG(used in meteorological applications) and FARMS. A total number of 9669 scenarios associated with cloudy-sky are selected during 2009-2012.

The accuracy of FARMS is comparable to RRTMG

Computational Efficiency of FARMS



Computation of cloud T for 39 cloud optical thicknesses, 28 particle sizes, and 50 solar zenith angles.



Computation of solar radiation for 9669 scenarios of cloudy sky conditions over ARM SGP.

FARMS increases the computational efficiency by a factor of 400

Spectral Plane of Array (POA) Irradiance

FARMS computes broadband irradiances in the direct and global horizontal.

Solar energy applications require irradiances in POA and irradiances in narrow-wavelength bands.

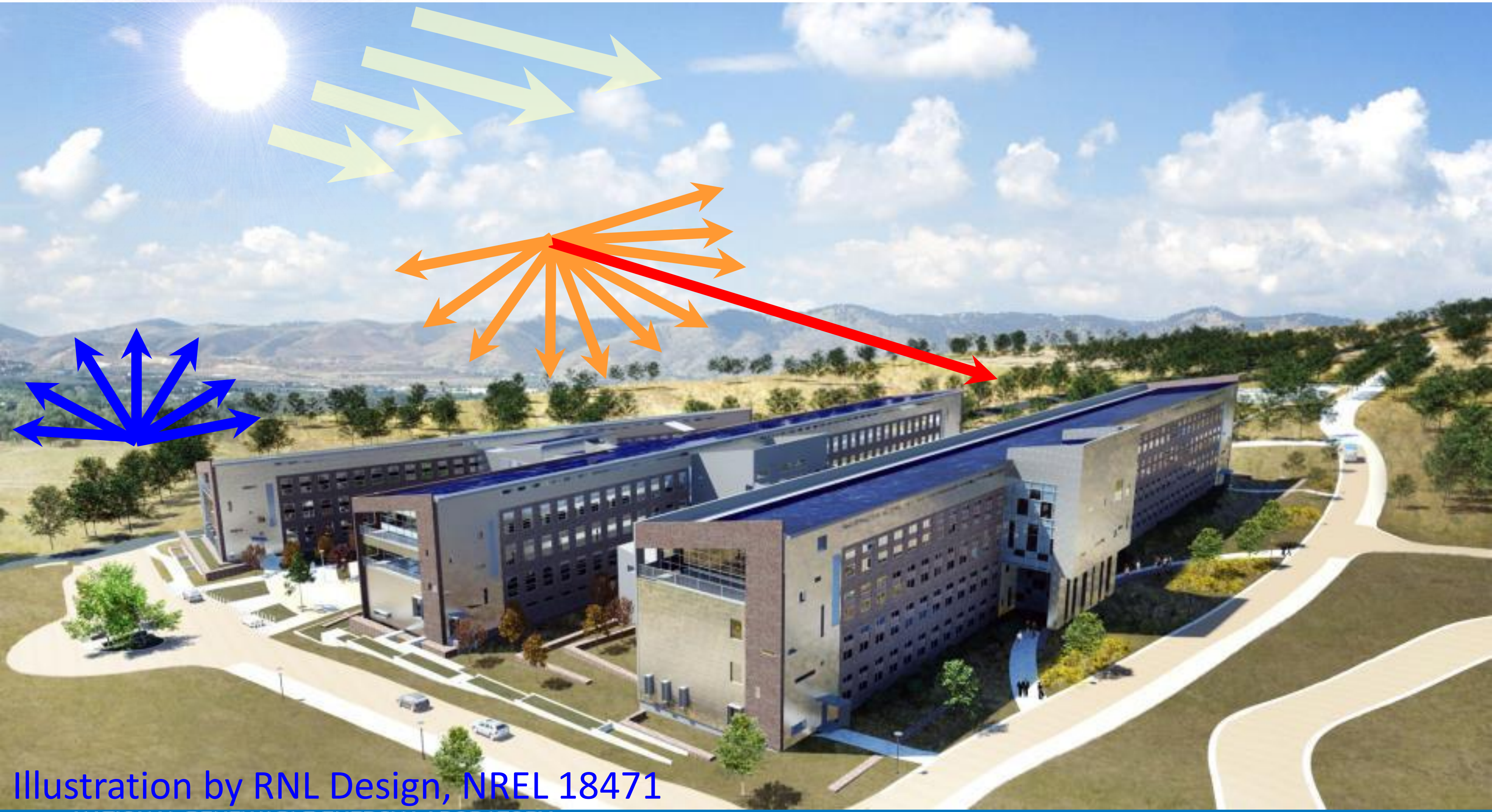
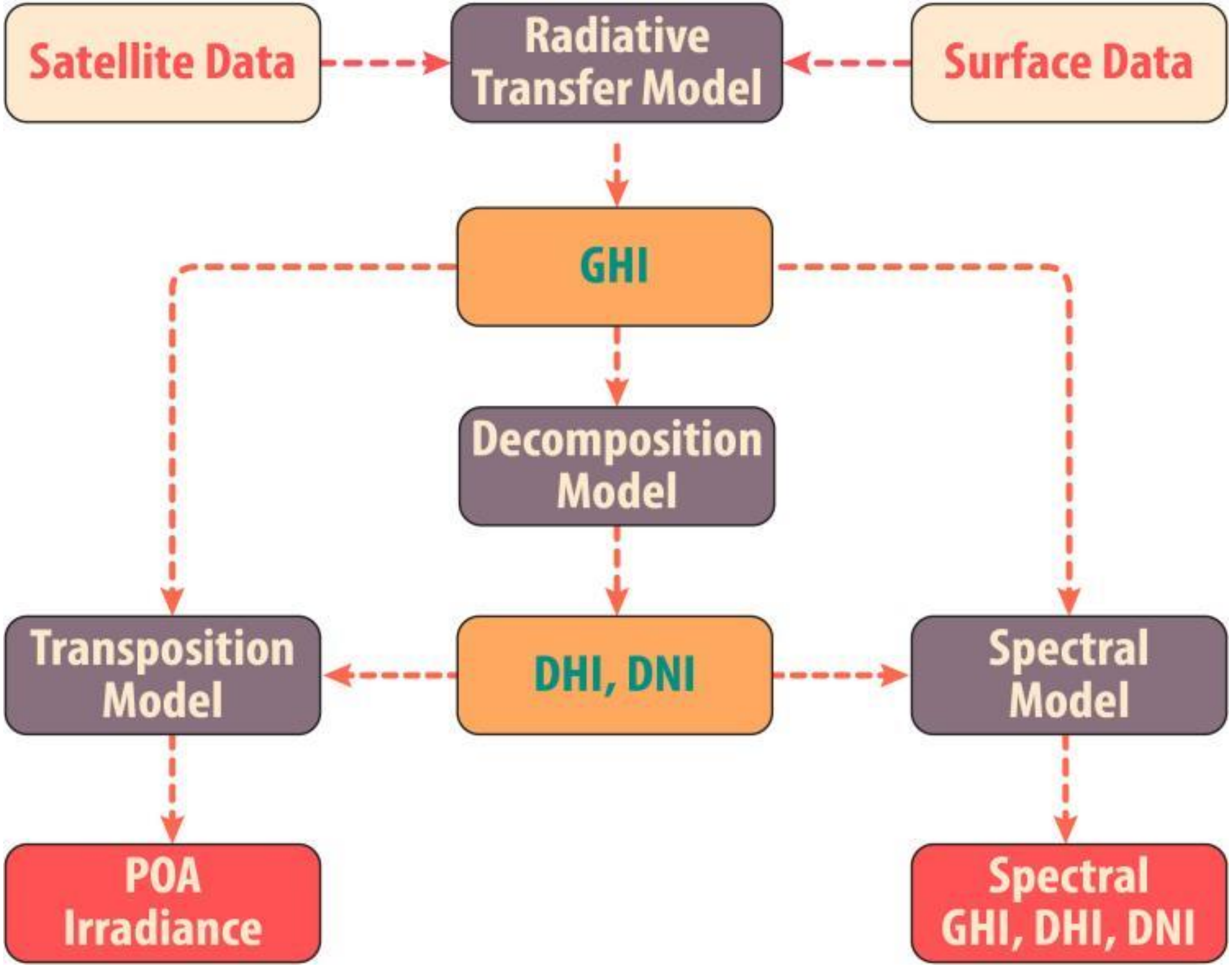
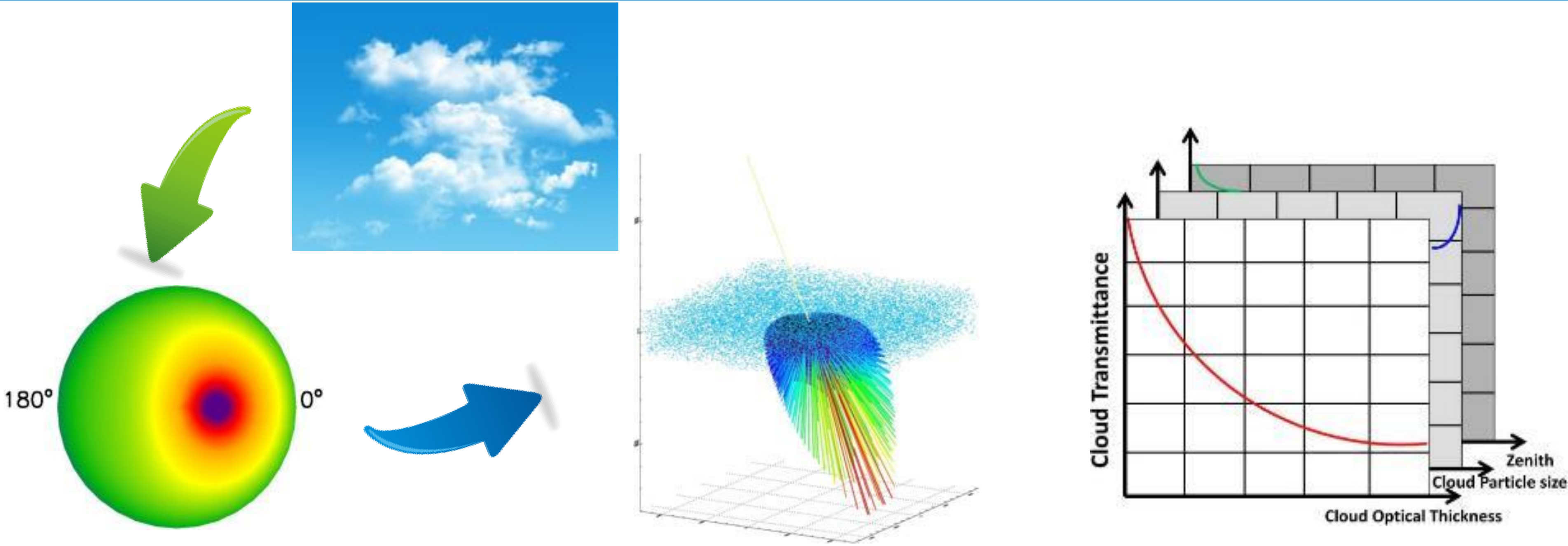


Illustration by RNL Design, NREL 18471

Current Spectral and POA Modeling has Significant Uncertainties



Narrowband Irradiances on Tilted Surfaces (FARMS-NIT)

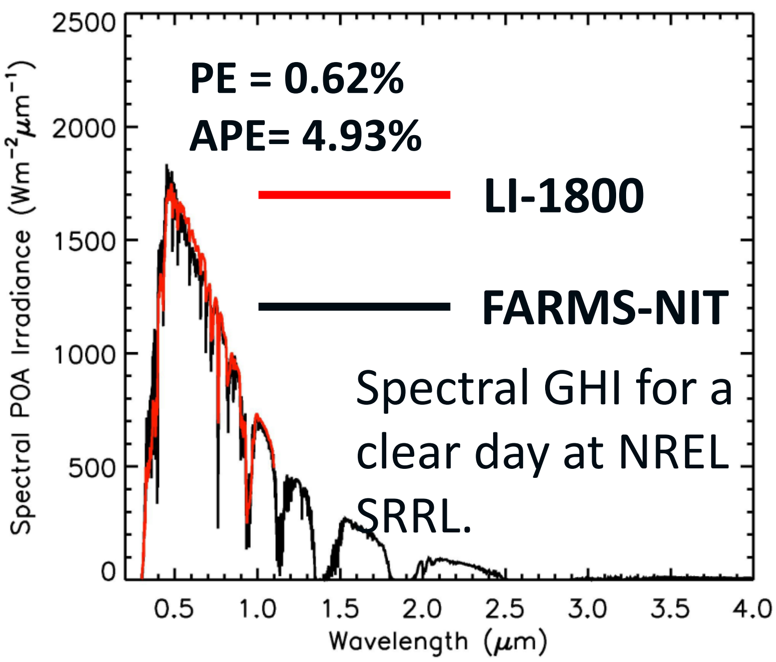


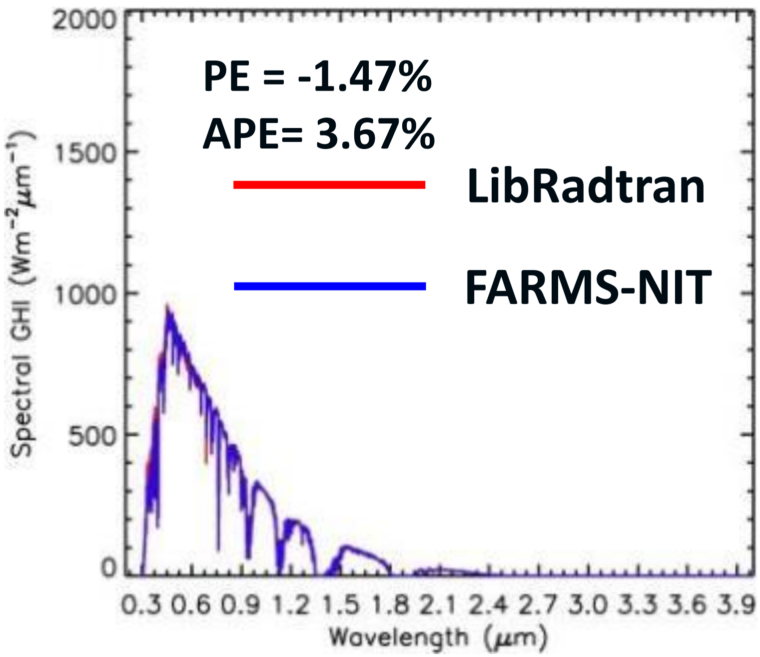
A lookup table of cloud transmittance using the LibRadtran model is computed for 2002 wavelengths, 39 cloud optical thicknesses, 28 cloud effective particle sizes, 50 solar zenith angles, 25 viewing zenith angles and 18 relative azimuth angles.

Bias of FARMS-NIT is within 5%

$$PE = \frac{\sum_{i=1}^{n}(x_{FARMS-NIT} - x_{Libratran})}{\sum_{i=1}^{n} x_{Libratran}}$$

$$APE = \frac{\sum_{i=1}^{n}\left|x_{FARMS-NIT} - x_{Libratran}\right|}{\sum_{i=1}^{n} x_{Libratran}}$$

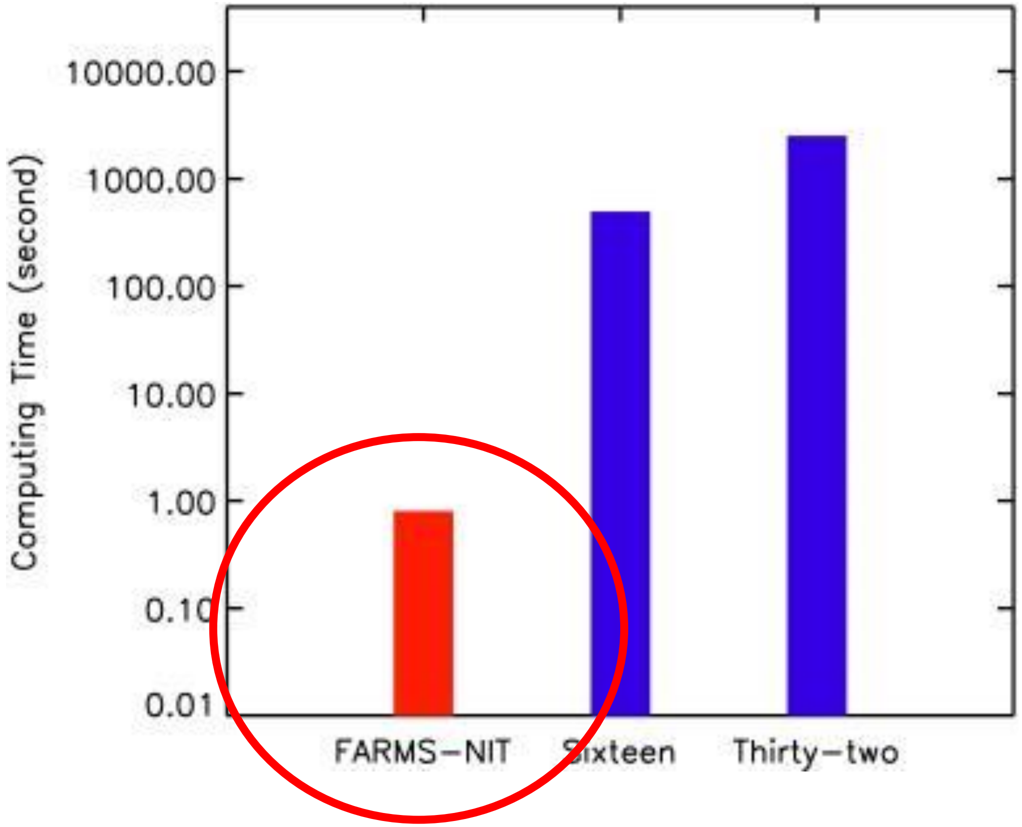




Spectral GHI at NREL for clear day (red: measurement; black: FARMS-NIT)

Spectral GHI for US standard atmosphere 1976 when θ_0=30°, τ=10, De=20μm, and surface albedo=0.0. (red: simulation by LibRadtran; blue: FARMS-NIT)

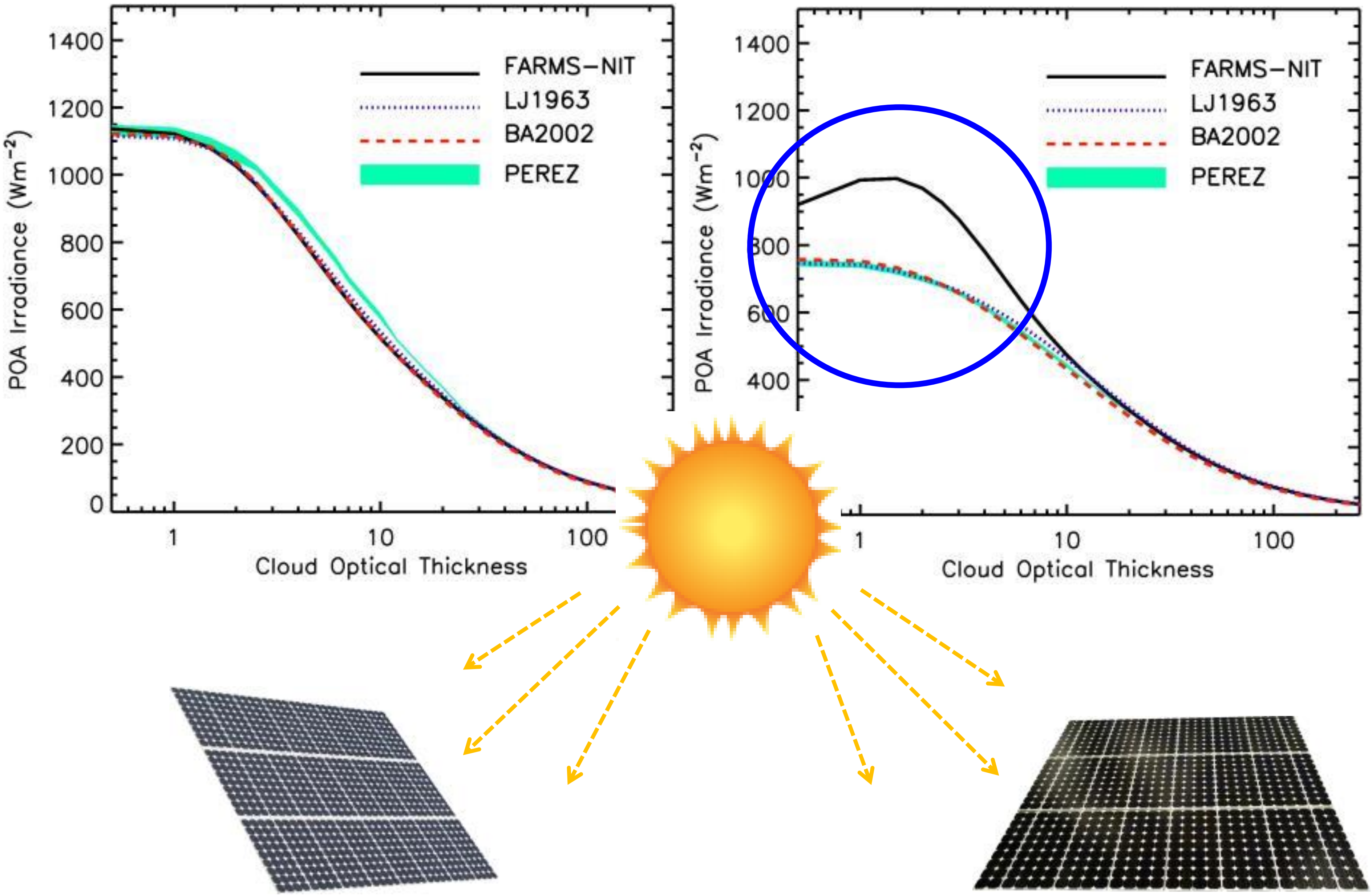
FARMS-NIT is computationally fast



FARMS-NIT: 0.8 second.
Libradtran (16 stream): 492 seconds.
Libradtran (32 stream): 2493 seconds.

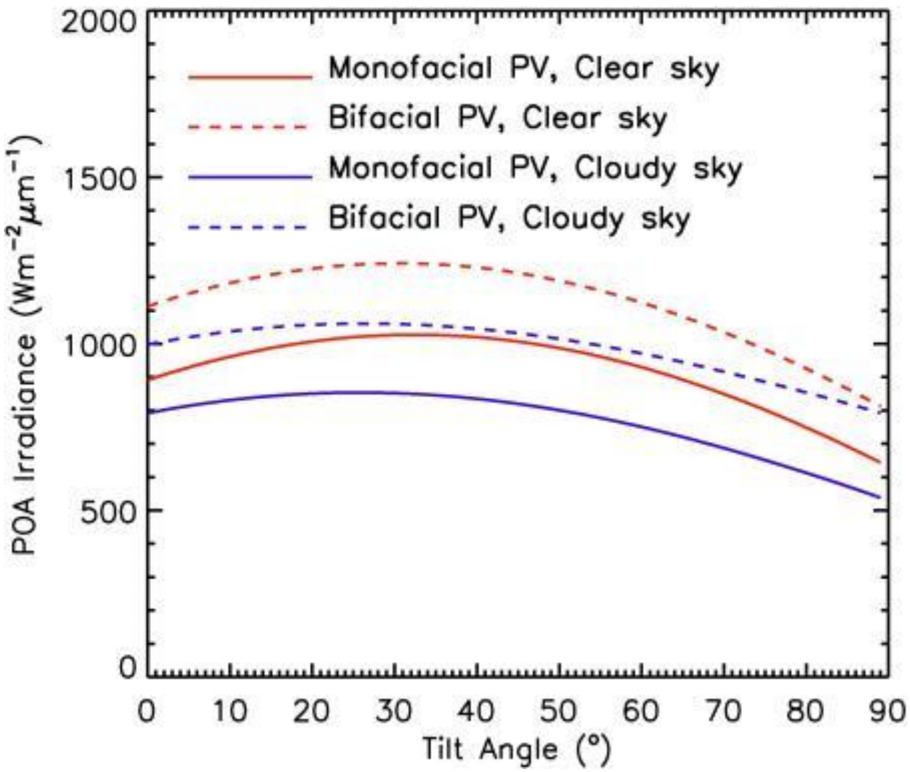
FARMS-NIT significantly reduces the computation time (factor of 500)

FARMS-NIT is more accurate than transposition models



FARMS-NIT can model Bifacial PV panels

FARMS-NIT has been extended to compute irradiances on bifacial PV panels.



http://solarprofessional.com

POA irradiances over monofacial and bifacial PV panels for a solar zenith angle of 30° and a land-surface albedo of 0.25. For the clear-sky condition, AOD is 0.5. For the cloudy-sky condition, a water cloud with cloud optical thickness of 3 and effective particle diameter of 10 µm is assumed.

Bifacial modules will produce 20% more energy than regular PV modules.

Conclusions

- **Integrated the advantages of radiative transfer models used in meteorology and solar energy research.**

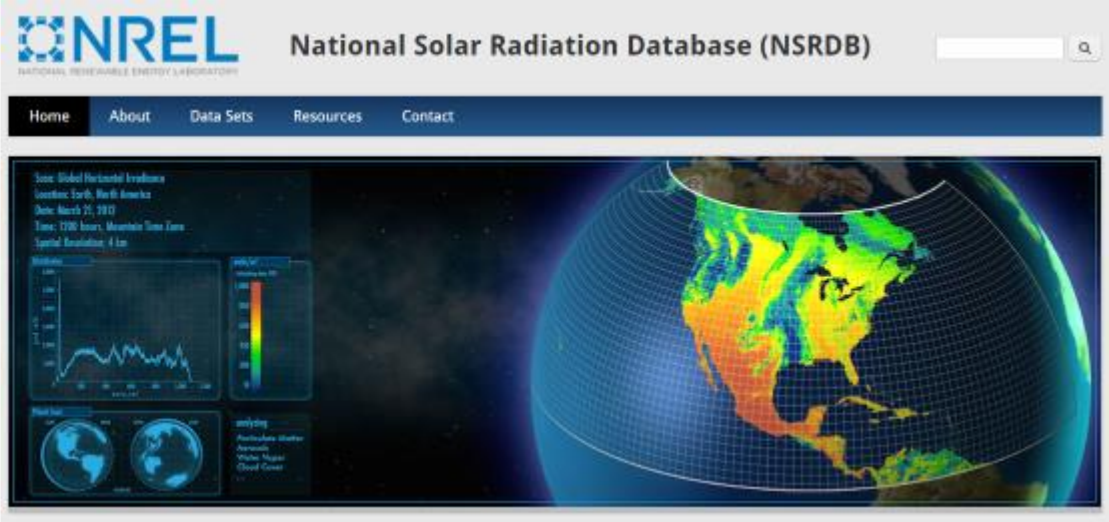
- **FARMS is developed to accurately compute broadband GHI and DNI for all-sky conditions. FARMS is ~400 times more efficient than radiative transfer models for meteorology.**
- **FARMS-NIT is developed to efficiently compute narrowband irradiances over inclined PV panels in one step.**
- **FARMS-NIT can compute irradiances on bifacial PV panels.**

Applications and Future Work

https://ral.ucar.edu/projects/wrf-solar

- **FARMS provides WRF-Solar an option to rapidly forecast GHI and DNI.**
- **FARMS is used in short-term solar forecasting from satellite and surface measurements.**

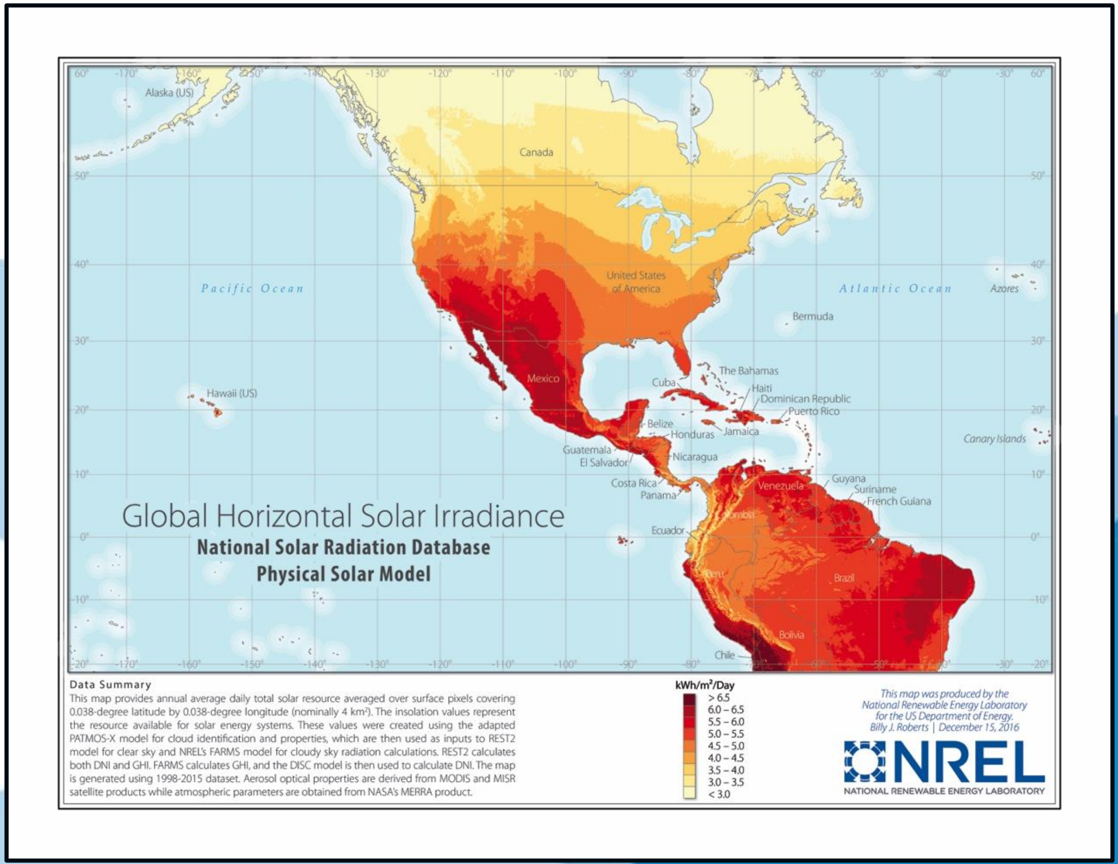
- **FARMS is the major radiative transfer model used in the NSRDB.**
- **FARMS-NIT will upgrade NSRDB with spectral irradiances in the POA.**

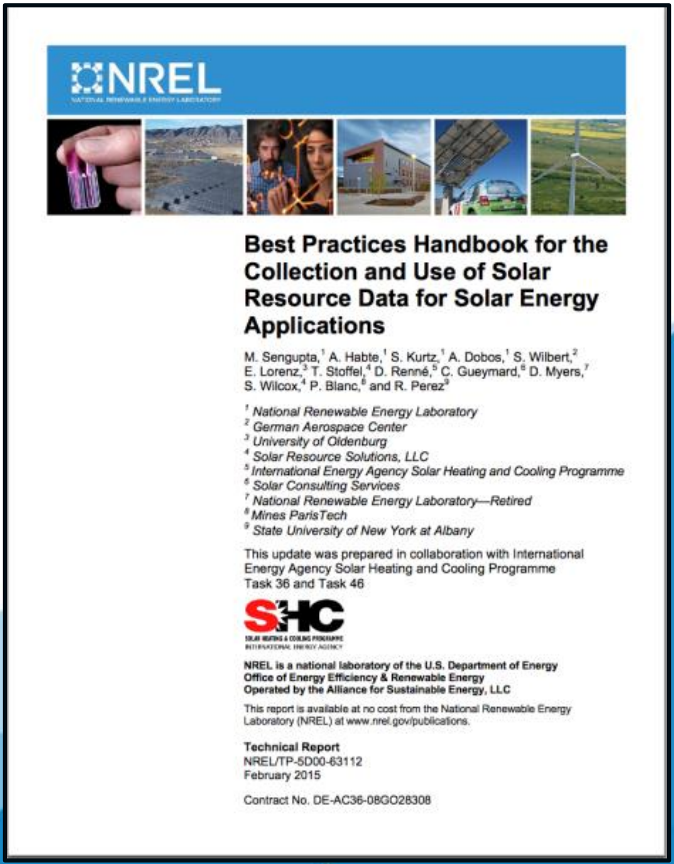


https://nsrdb.nrel.gov

Thank You! Contact: manajit@nrel.gov

NSRDB: http://nsrdb.nrel.gov





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Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications

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