Spectral and Broadband Data Sets from The National Solar Radiation Database (NSRDB)

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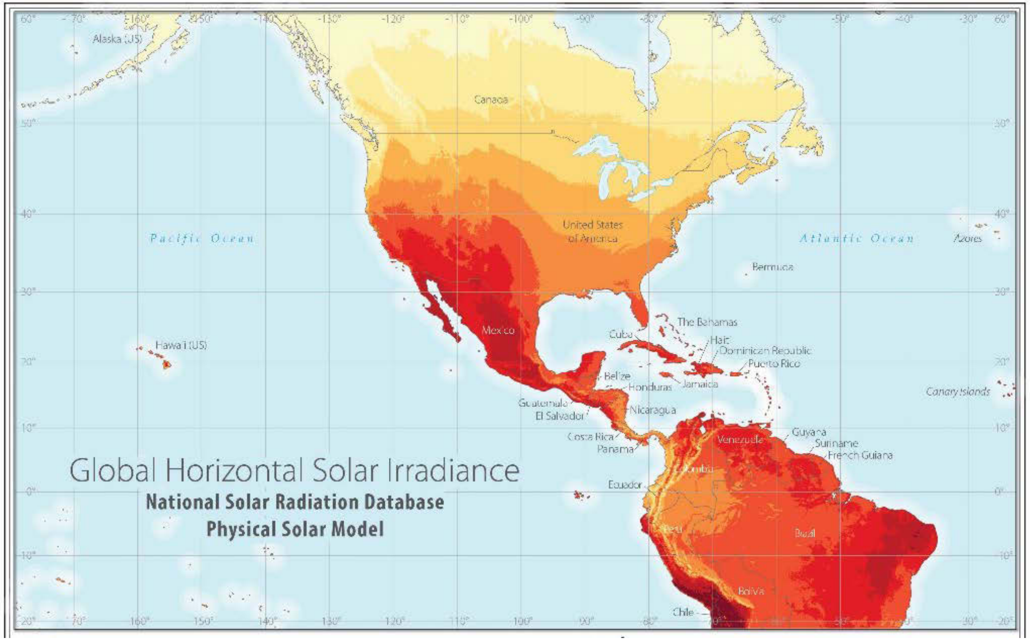
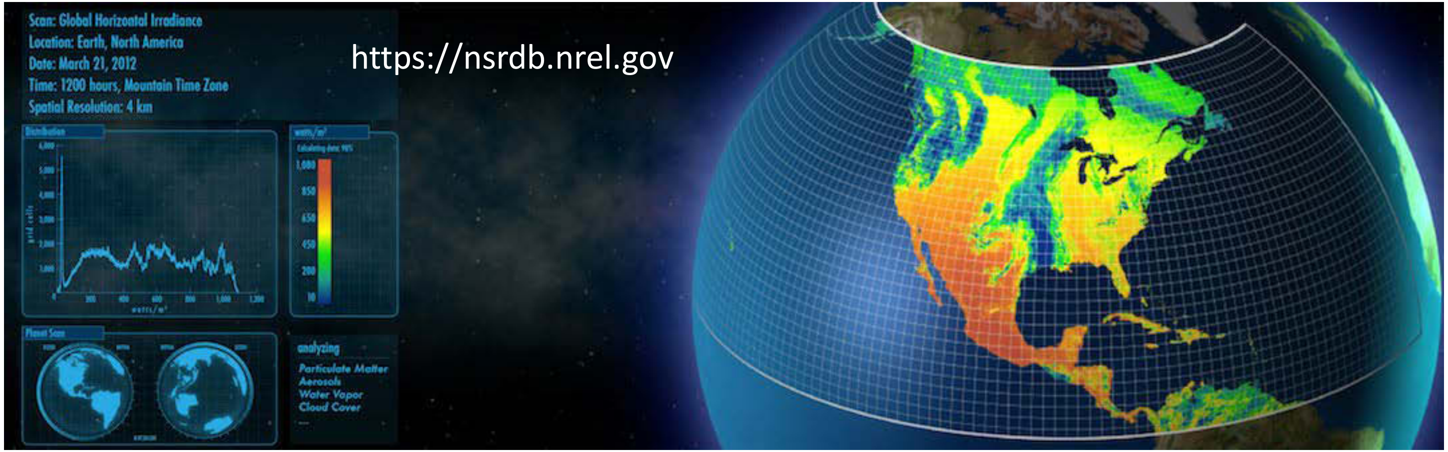
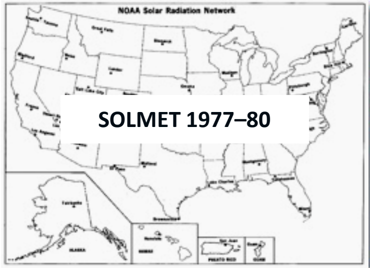


National Solar Radiation Database

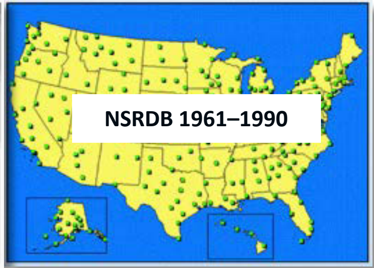
- The National Solar Radiation Database (NSRDB) seeks to advance our knowledge of solar radiation and its applications for renewable energy and beyond.
- The NSRDB provides a serially complete database of solar irradiance and meteorological information across the United States and in an increasing number of international locations.
- The NSRDB provides **20 years** (+ typical meteorological year [TMY]) of half-hourly data at a 4-km by 4-km spatial resolution.
- The NSRDB uses a physics-based model **(PSM)** consisting of two steps**.**



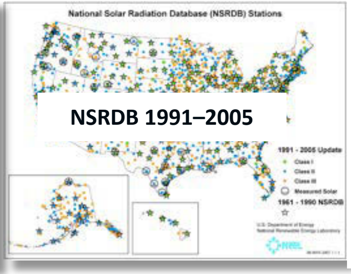
Evolution of the National Solar Radiation Database



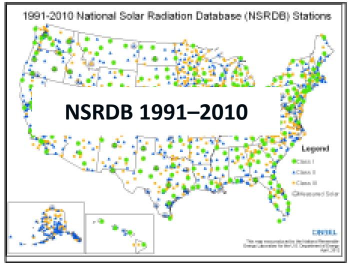
248 weather stations with 26 ***solar measurement*** stations (ERDA, NOAA, 1979)



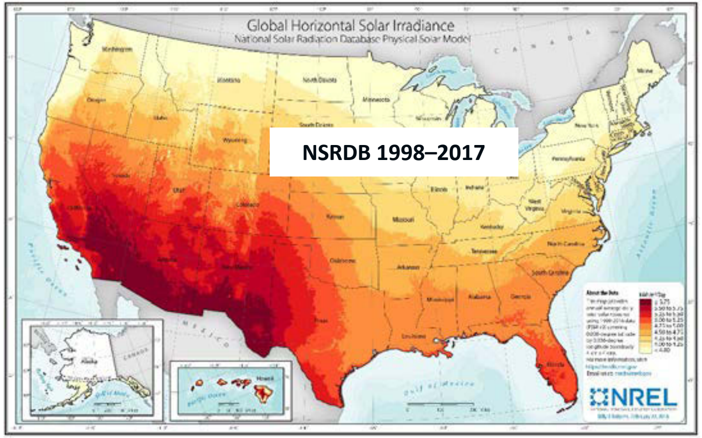
239 ***modeled*** stations with 56 partial measurement stations (DOE, NOAA, 1994)

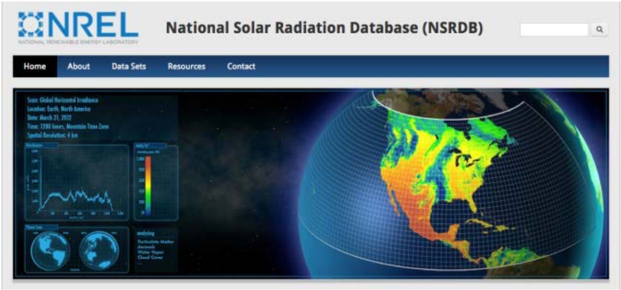


1,454 ***modeled*** locations (DOE, SUNY-A, NOAA, 2007)



1,454 ***modeled*** locations (DOE, CPR, 2012)





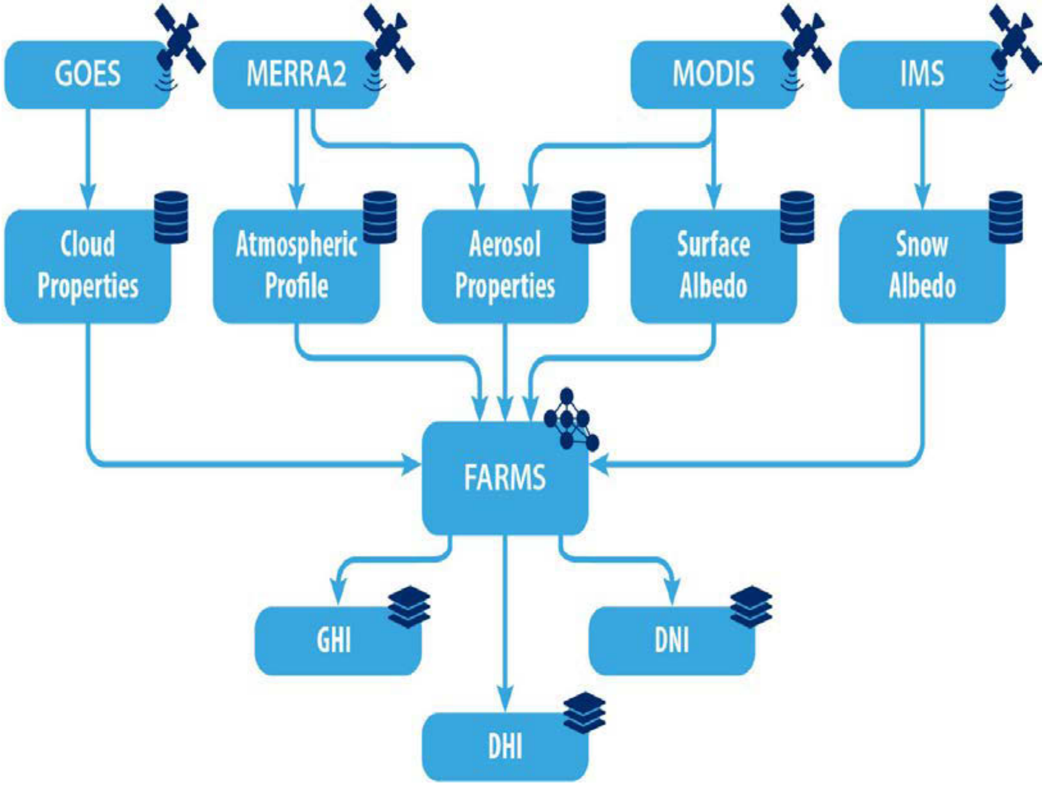
http://nsrdb.nrel.gov

Satellite-based, gridded, 4 km x 4 km, half-hourly (DOE, NOAA, UW, SCS 2017)

Broadband Solar Data from the NSRDB

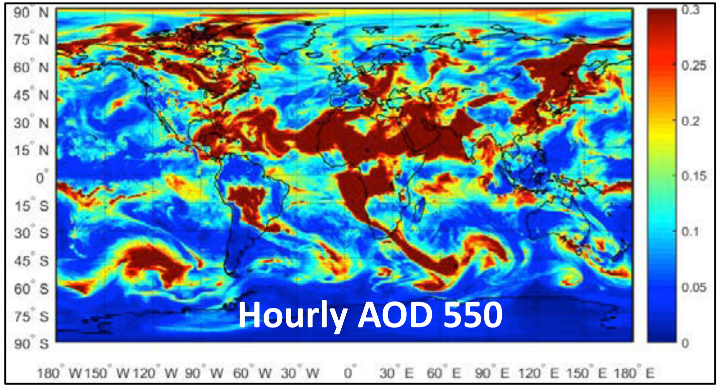
Physical Solar Model (PSM) V3

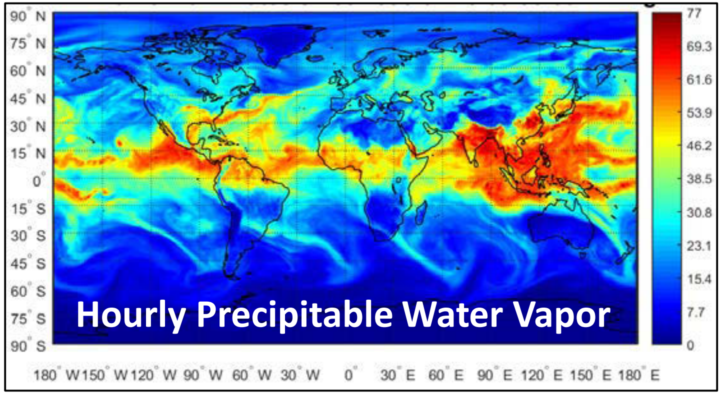
NSRDB: Physical Solar Model (PSM) Workflow



- Cloud properties calculated from Geostationary Operational Environmental Satellite (GOES) imagery
- Aerosol and ancillary data sets obtained from Modern Era Retrospective Analysis for Research and Applications (MERRA-2)
- Surface albedo developed from Moderate Resolution Imaging Spectroradiometer (MODIS) and Integrated Multisensor Snow and Ice Mapping (IMS)
- Cloud properties, aerosol, surface albedo, and meteorological data mapped to the NSRDB grid
- Gridded properties used in radiative transfer models (REST-2 and Fast All-Sky Radiation Model for Solar Applications [FARMS]) to calculate solar radiation (global horizontal irradiance [GHI] and direct normal irradiance [DNI])
- Missing values filled and data from two satellites merged
- New product validated using surface measurements
- Geographic information system-based NSRDB portal updated.

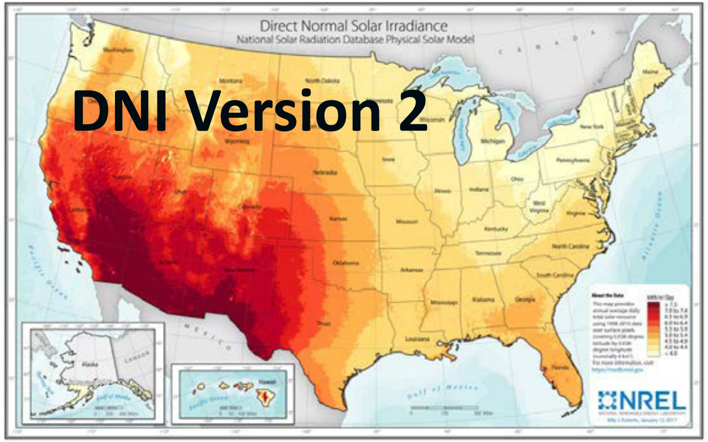
NSRDB (PSM Version3): What's New

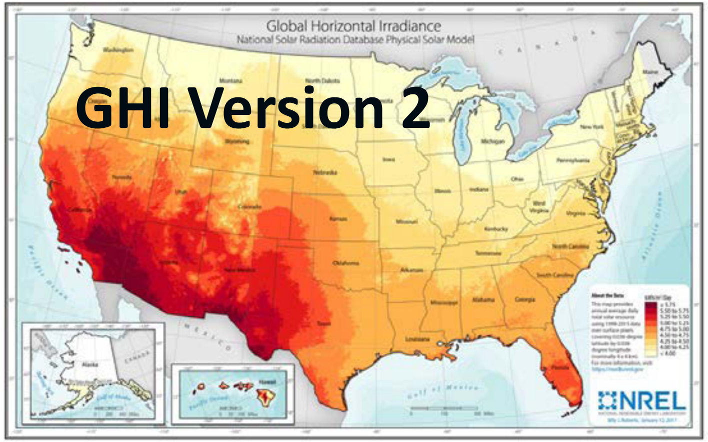


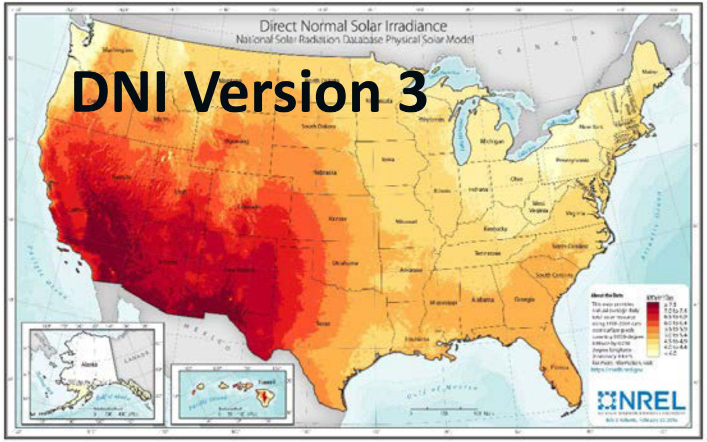


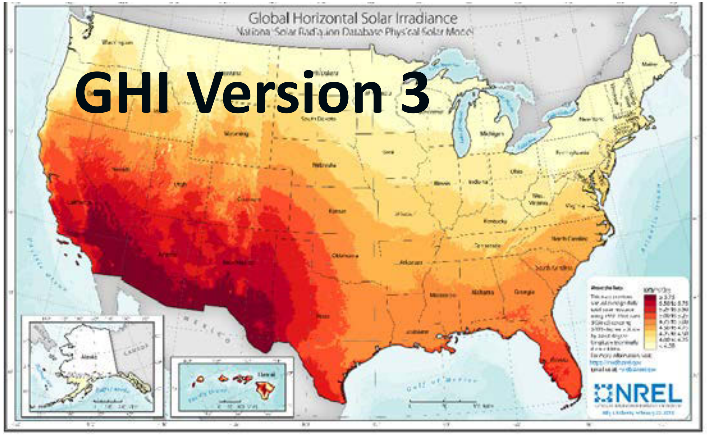
- Hourly aerosol optical depth (1998–2017) from MERRA-2
- Snow-free surface albedo from MODIS (2001–2015) (MCD43GF CMG gap-filled snow-free products from University of Massachusetts, Boston)
- Snow cover from IMS daily snow cover product (National Snow and Ice Data Center)
- GOES-East time-shift applied to cloud properties instead of solar radiation
- Ancillary data (pressure, humidity, wind speed, etc.) from MERRA-2.

NSRDB Version 2 and 3 Comparison





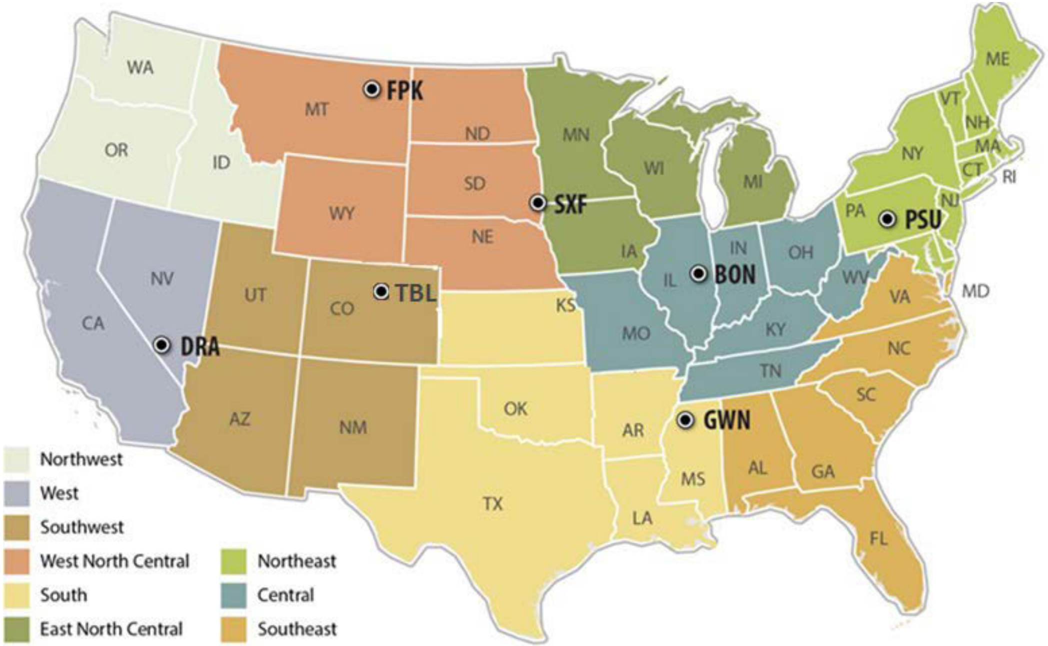




- **NSRDB Version 3 shows higher irradiance for south and southeastern United States.**
- **Higher Irradiance for Oregon, Idaho, and Wyoming.**

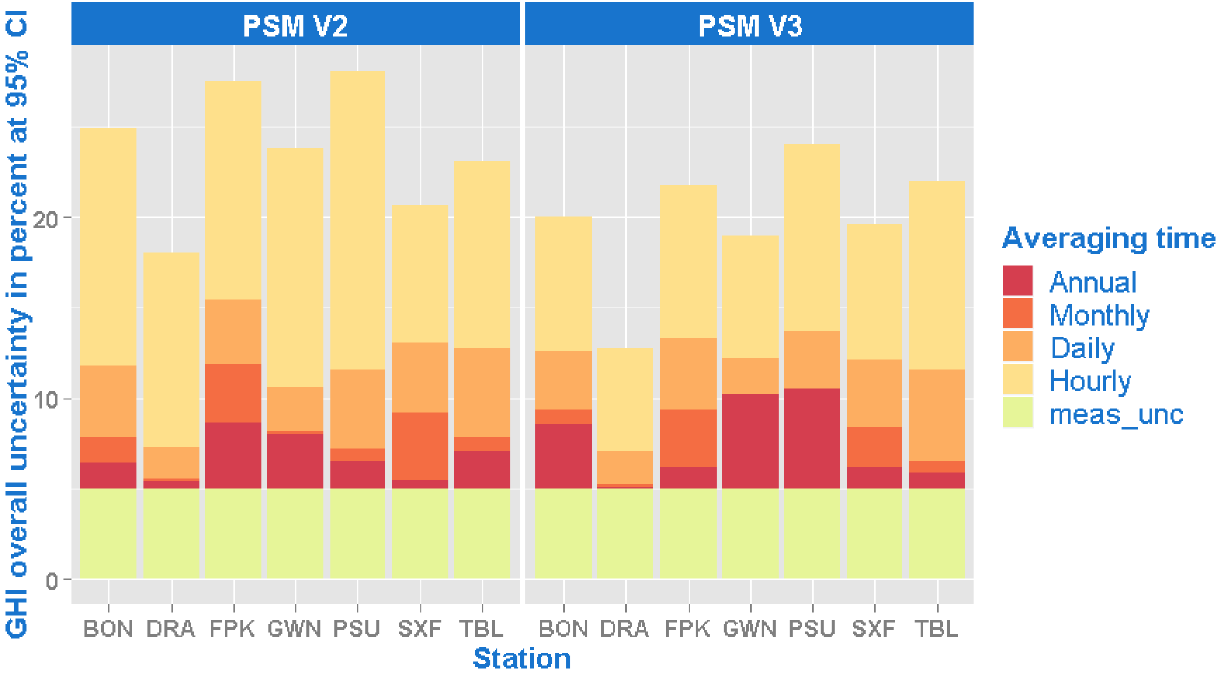
Validation of NSRDB Using Surface-Based Measurements

Surface Radiation (SURFRAD) Network



Validation of NSRDB Using Surface-Based Measurements

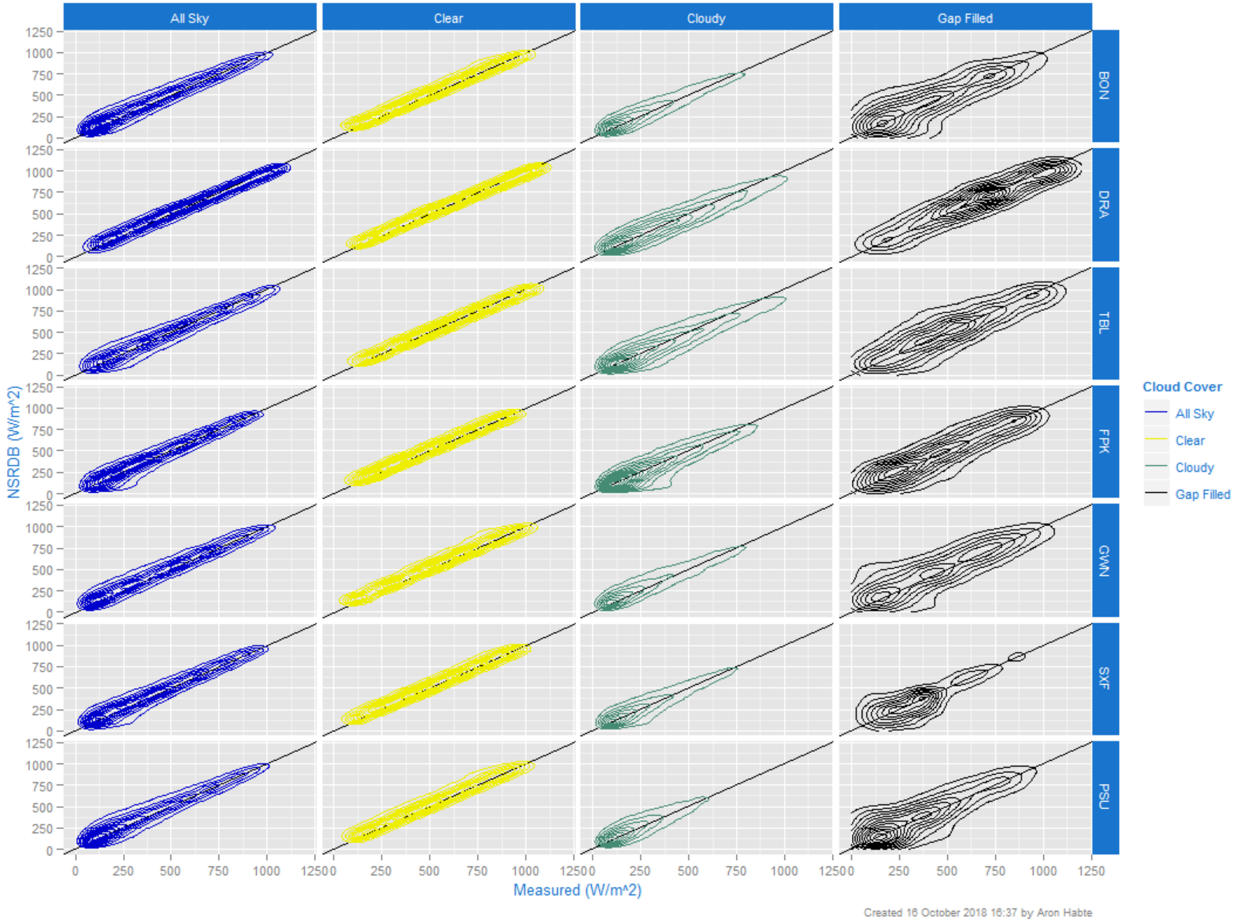
GHI: Overall uncertainty estimation of GHI for NSRDB PSM Version 2 (left) and PSM Version 3 (right) using seven ground-based solar measurement locations. Data used in this figure are from 1998–2015 for Version 2 and 1998–2017 for Version 3.



<u>Uncertainty estimation includes:</u>

- Mean bias error (MBE)
- Root mean square error (RMSE)
- Surface measurement uncertainty.

Validation of NSRDB Using Surface-Based Measurements

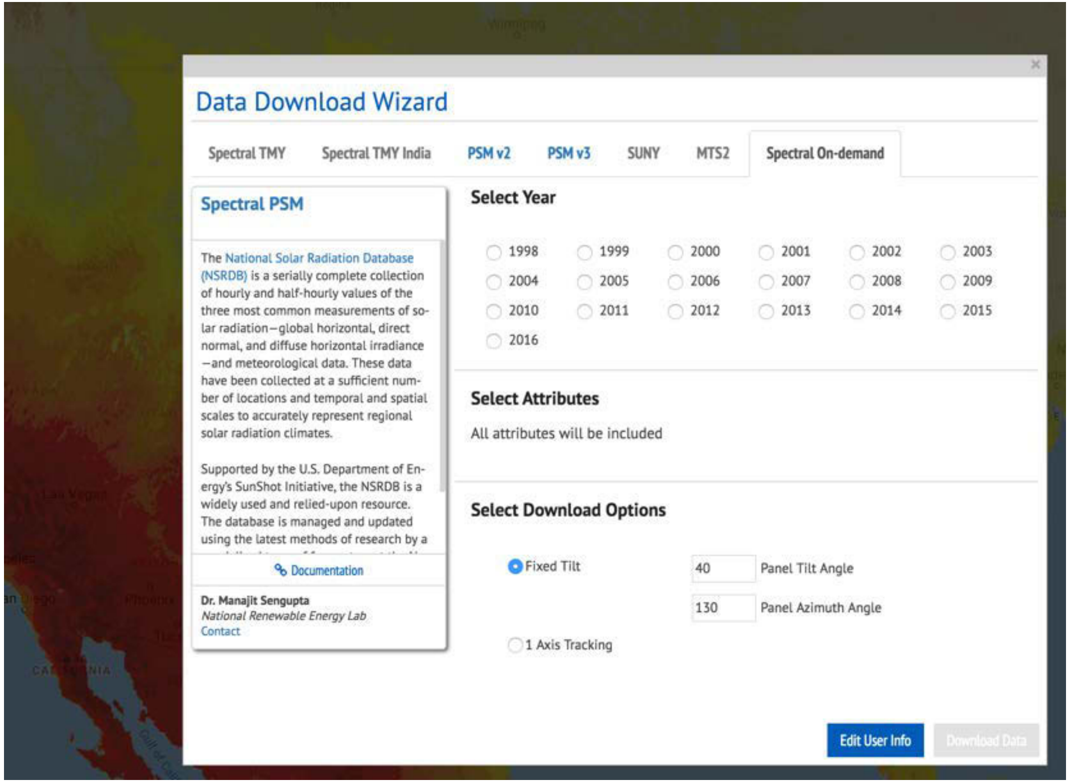


GHI distribution for the seven SURFRAD stations under varying sky conditions (PSM Version 3).

Spectral Data Sets from the NSRDB:

Fast All-Sky Model for Solar Applications – Narrowband Irradiance on Tilted Surfaces (FARMS-NIT)

Spectral Data in the Plane-of-Array

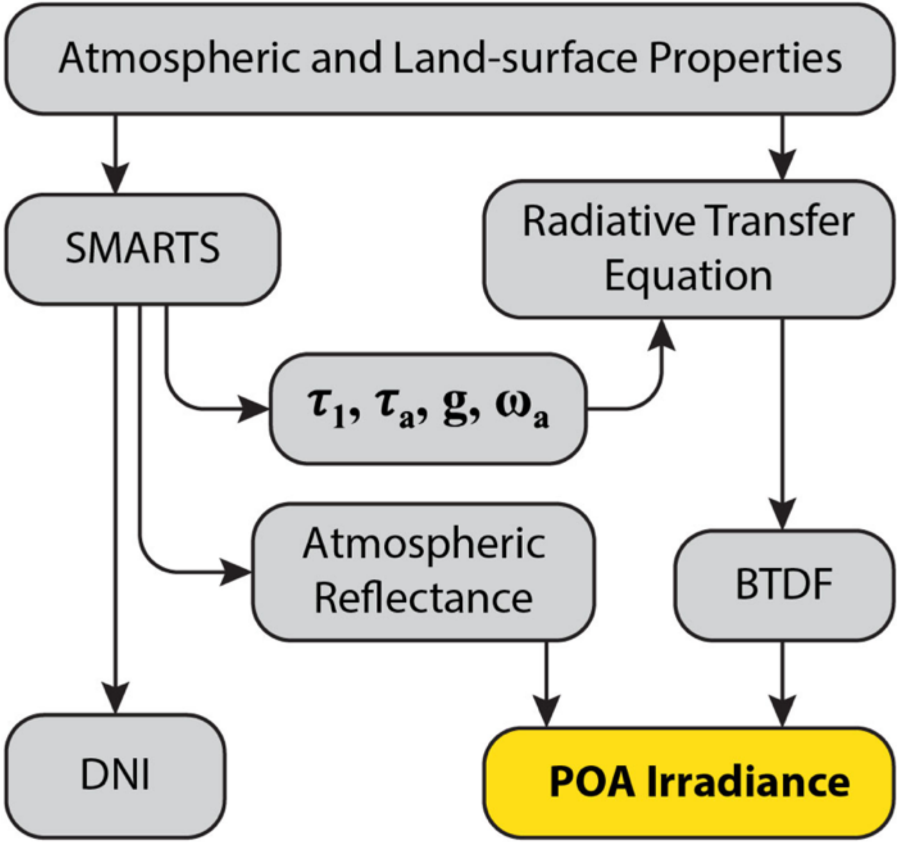


NSRDB Variables:

- Global horizontal irradiance (GHI)
- Direct normal irradiance (DNI)
- Diffuse horizontal irradiance (DHI)
- Clear-sky GHI, DNI, and DHI
- Cloud type
- Dew point**
- Air temperature*
- Atmospheric pressure*
- Relative humidity**
- Solar zenith angle
- Precipitable water*
- Wind direction**
- Wind speed**
- Surface albedo***
- **Spectral POA (2002 wavelengths)**

* From MERRA-2
** Recalculated from MERRA-2
*** MODIS and IMS

FARMS-NIT for Clear Sky



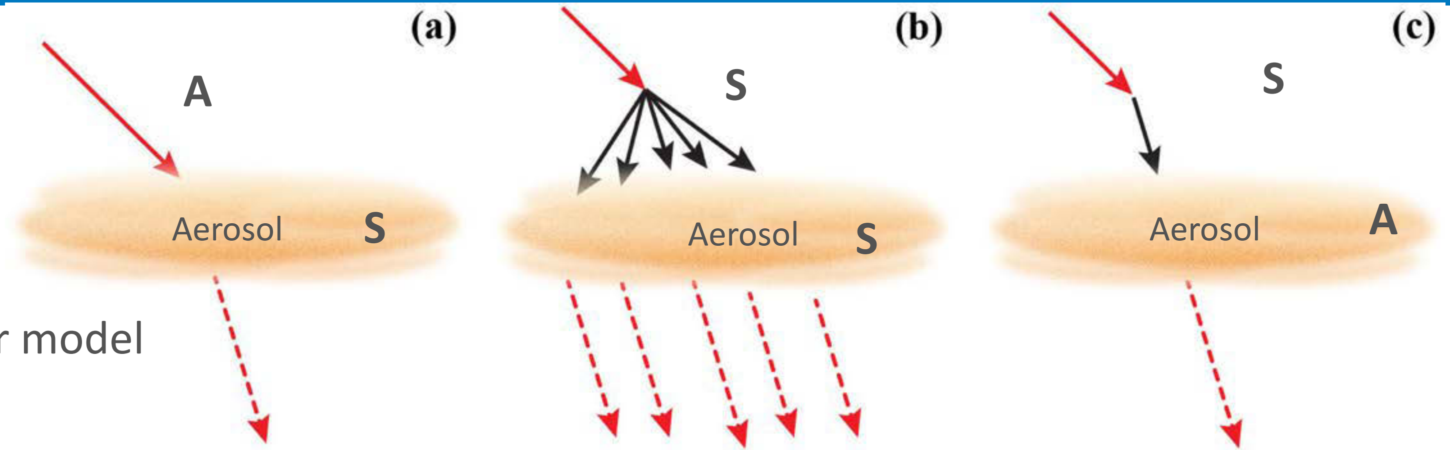
Simplified Model of Atmospheric Radiative Transfer of Sunshine (SMARTS) v2.9.5 used.

Provides atmospheric properties, including atmospheric optical depth, aerosol optical depth, asymmetry parameter, and single-scattering albedo

Two-layer model with aerosol in lower layer for irradiance computations

Radiances computed for 450 sky-view angles at 2002 wavelengths that can be integrated for any tilt-geometry.

FARMS-NIT for Clear Sky

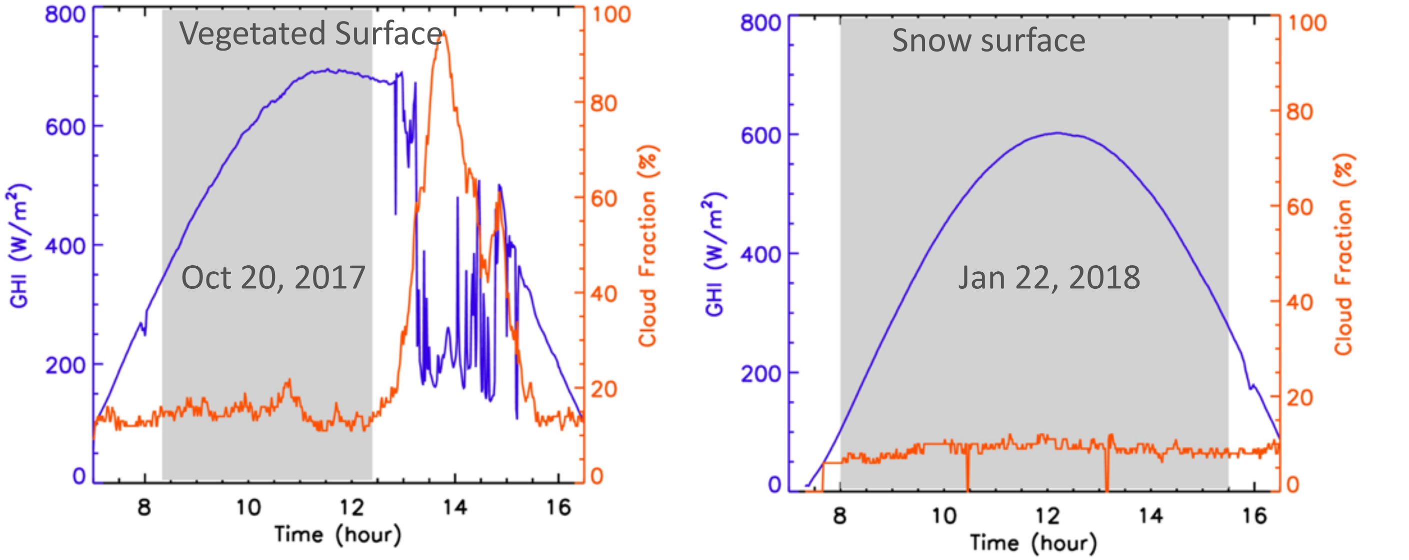


Two-layer model

- Spectral radiances are computed by solving the **radiative transfer equation** with the single-scattering approximation for three individual photon paths.
- The atmospheric radiances are given by radiances related to the three photon paths.
- POA irradiances are efficiently computed for 2002 wavelength bands (0.28–4.0 μm) from the radiances.

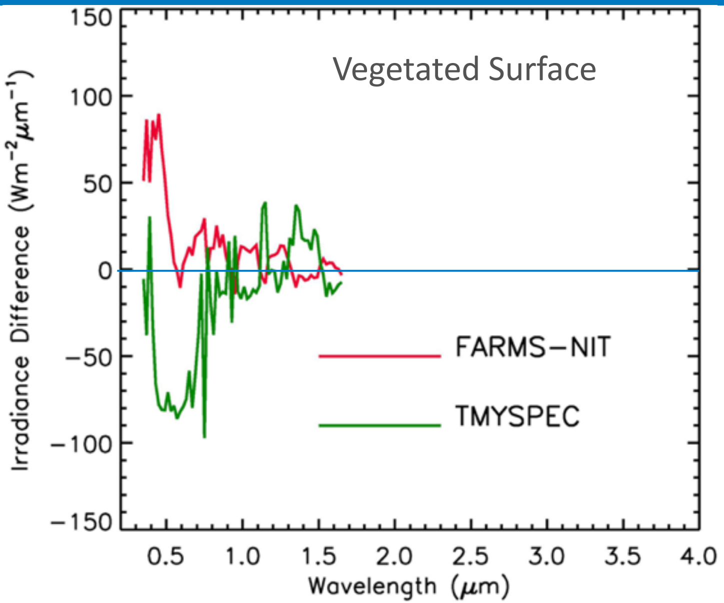
Xie, Y., Sengupta, M., 2018. "A Fast All-Sky Radiation Model for Solar applications with Narrowband Irradiances on Tilted Surfaces (FARMS-NIT): Part I. The Clear-Sky Model." ***Solar Energy*****, 174C, 691-702.**

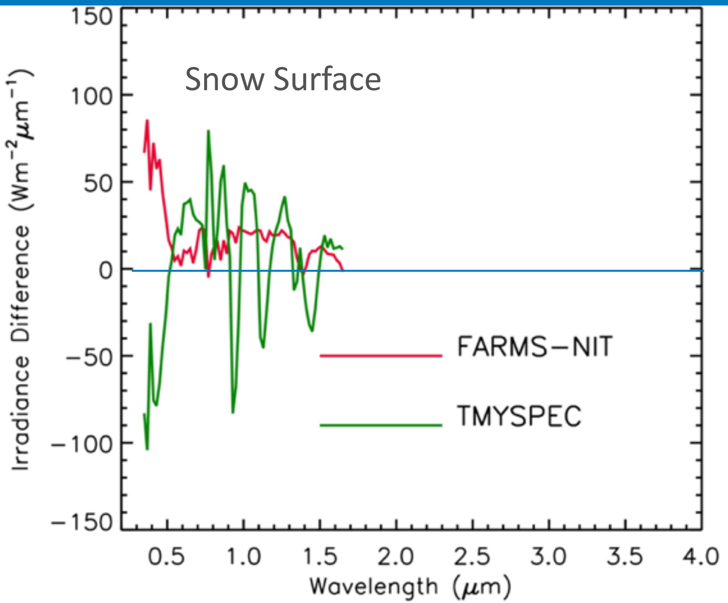
Evaluation of FARMS-NIT for Clear Sky



- To validate FARMS-NIT, we use measurements of GHI and cloud fraction at NREL's SRRL to identify clear-sky conditions (shadows).
- Measurements of precipitable water vapor, aerosol optical depth (AOD), and surface albedo are used by the models.
- Measurements from EKO-WISER spectroradiometer (MS-711 and MS-712) on a 1-axis tracker is compared with FARMS-NIT and TMYSpec (parameterized model, Myers, 2012).

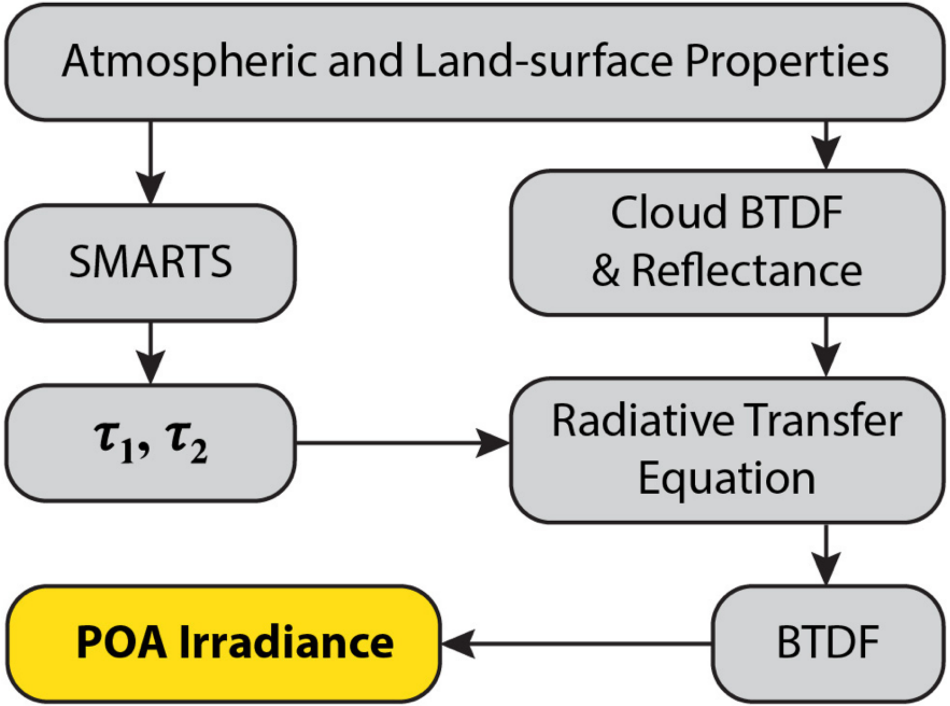
Evaluation of FARMS-NIT for Clear Sky





- FARMS-NIT has improved performance compared to TMYSPEC, especially on the snowy day when validated with spectral measurements from the EKO MS-711 spectroradiometer.
- FARMS-NIT slightly overestimates spectral radiation in the UV and visible regions while TMYSPEC underestimates it.
- FARMS-NIT MBE < 1% and absolute MBE <4%.

FARMS-NIT for Cloudy-Sky

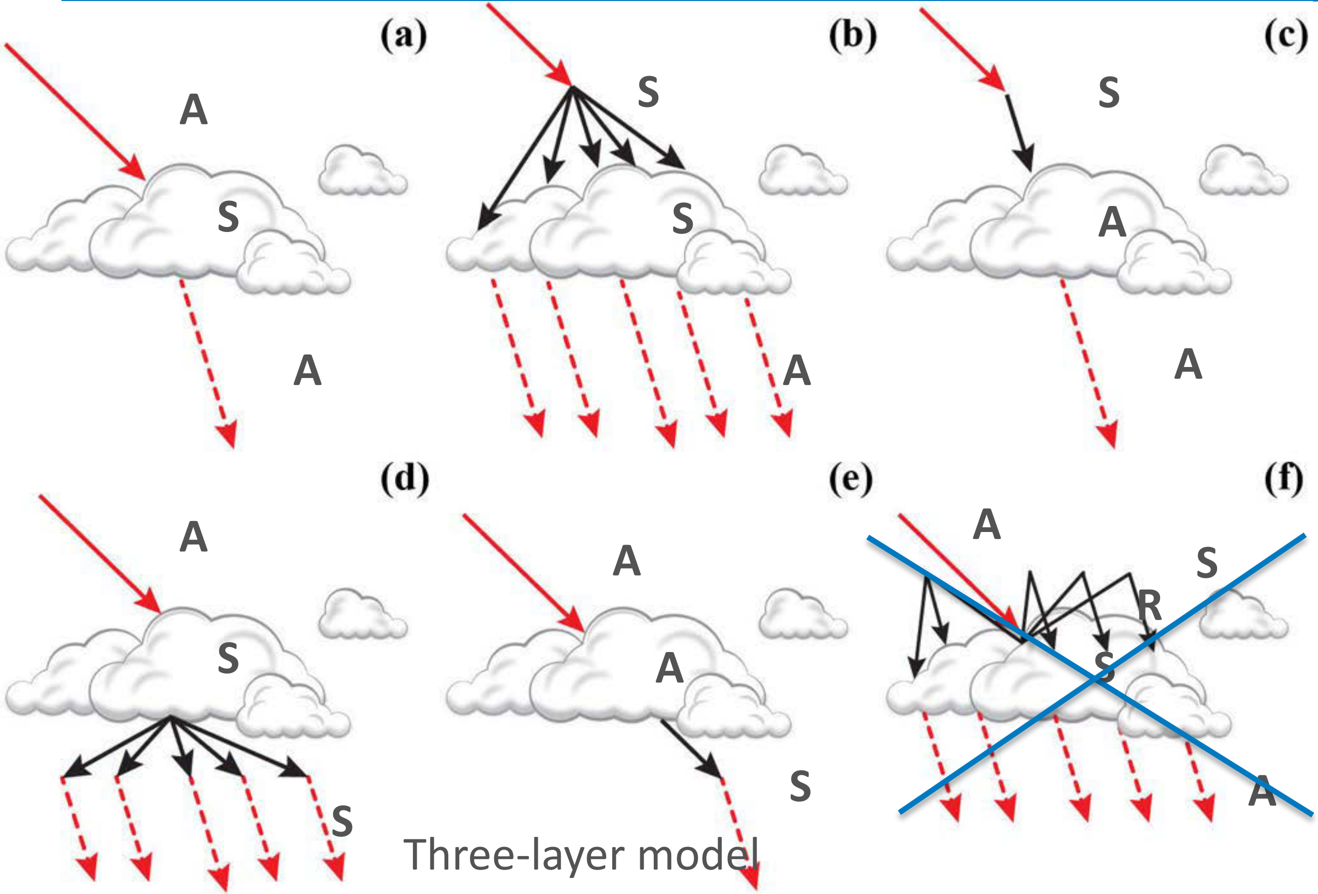


SMARTS provides atmospheric optical depth for layers below and above cloud (three-layer model).

Aerosols are not important in cloudy-sky situation.

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.

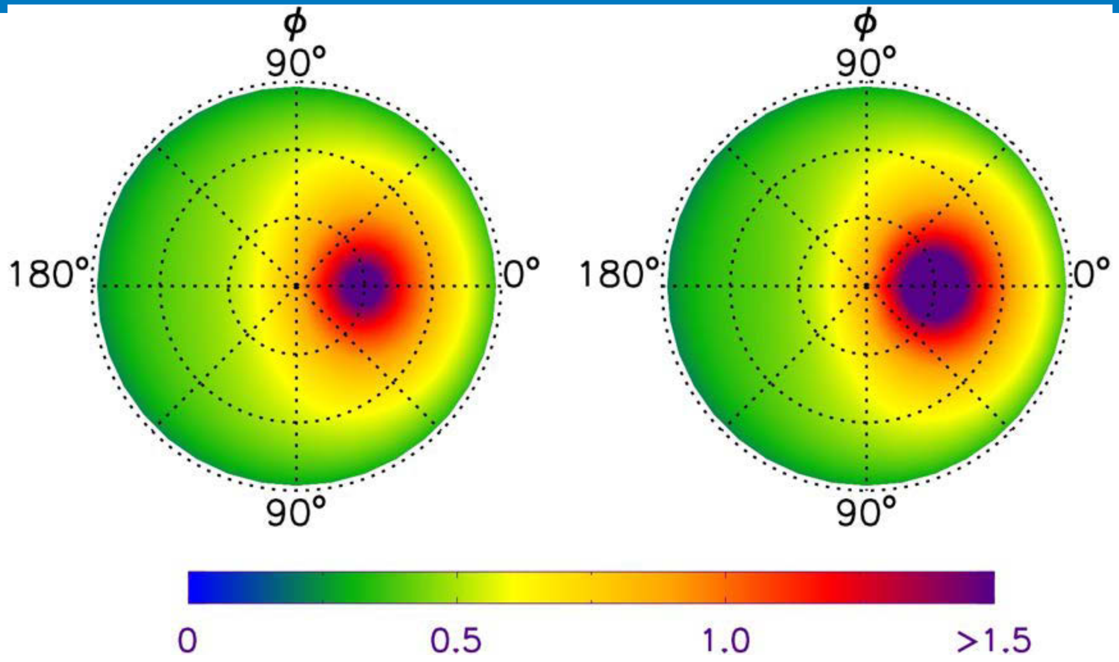
FARMS-NIT for Cloudy-Sky Conditions



Three-layer model

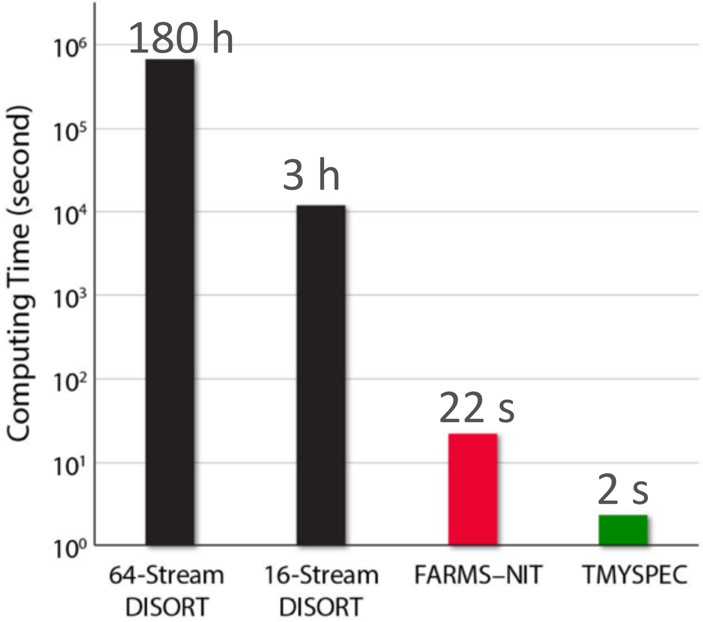
- Spectral radiances are computed by solving the **radiative transfer equation.**
- Two additional photon paths are considered for Rayleigh scattering under the clouds.

FARMS-NIT for Cloudy-Sky Conditions



Cloud BTDF for water (left) and ice (right) clouds for $\tau = 5$, $\mathrm{De} = 10\ \mu m$, $\theta_0 = 30°$ at 0.6 μm. The viewing zenith angle increases from 0 to 90 degree along the radial direction.

Computing Time for FARMS-NIT



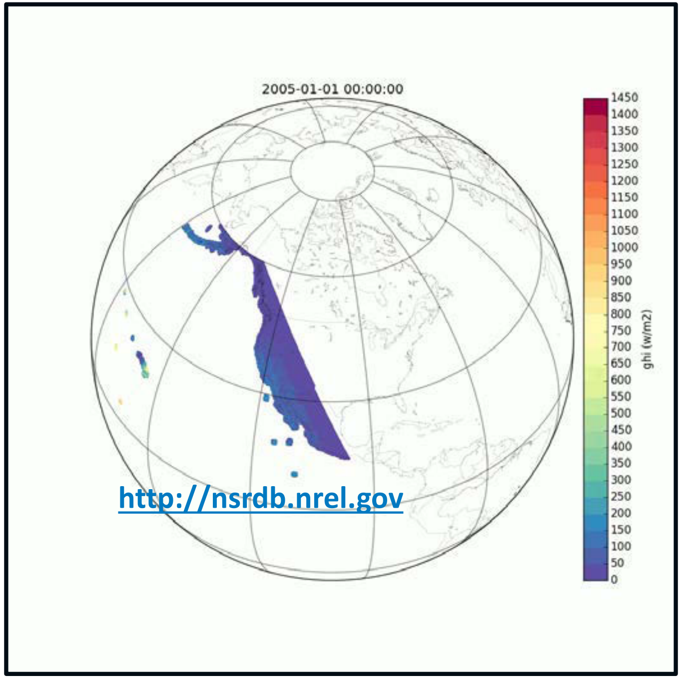
- For computing hourly spectral POA irradiances for a day, the 64-stream DISORT, 16-stream DISORT, FARMS-NIT, and TMYSPEC consume 180 hours 48 minutes, 3 hours 18 minutes, 21.9 seconds, and 2.31 seconds.
- **Our current server uses multiple-processors, and we can compute and deliver spectral data for 1 year in ~2 minutes.**

Conclusions

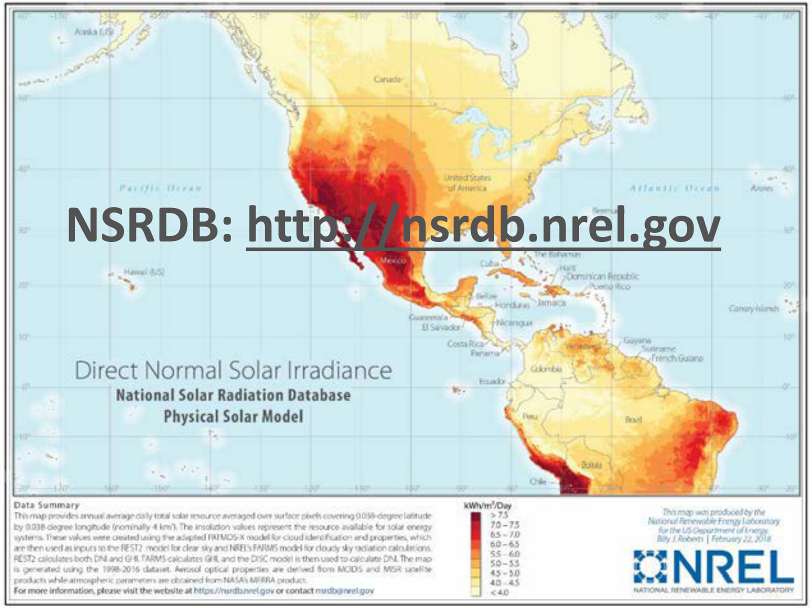
- The "improvements" in GHI and DNI are a result of a combination of factors, including:
    - Better downscaling methodologies, particularly in the interpolation and extrapolation used to align the multiple data sets to the same grid
    - The use of hourly values of AOD
    - Using a time shift of cloud properties instead of shifting the solar radiation
    - Time series of surface albedo might have contributed to the improvement of GHI estimates in cloudy periods.
- Fast Spectral Model FARMS-NIT has been deployed in the NSRDB and provides spectral time series.

Future Work

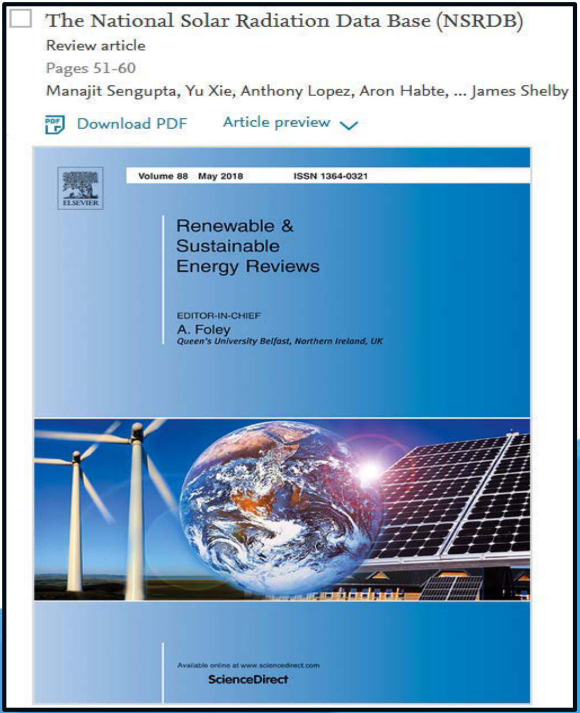
- Improved identification of high albedo surfaces (sand and snow)
- Improved cloud identification and retrievals from GOES-16/17
- Aerosol retrieval from GOES-16/17
- 5-min., 2-km data from GOES-16
- Exploring 0.5-km cloud properties.



Thank You! Contact: Manajit.Sengupta@nrel.gov



NSRDB: http://nsrdb.nrel.gov



Sengupta, M., Y. Xie, A. Lopez, A. Habte, G. Maclaurin, and J. Shelby (2018), "The National Solar Radiation Data Base (NSRDB)," *Renew. Sustain. Energy Rev.*, 89, 51–60. https://doi.org/10.1016/j.rser.2018.03.003

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