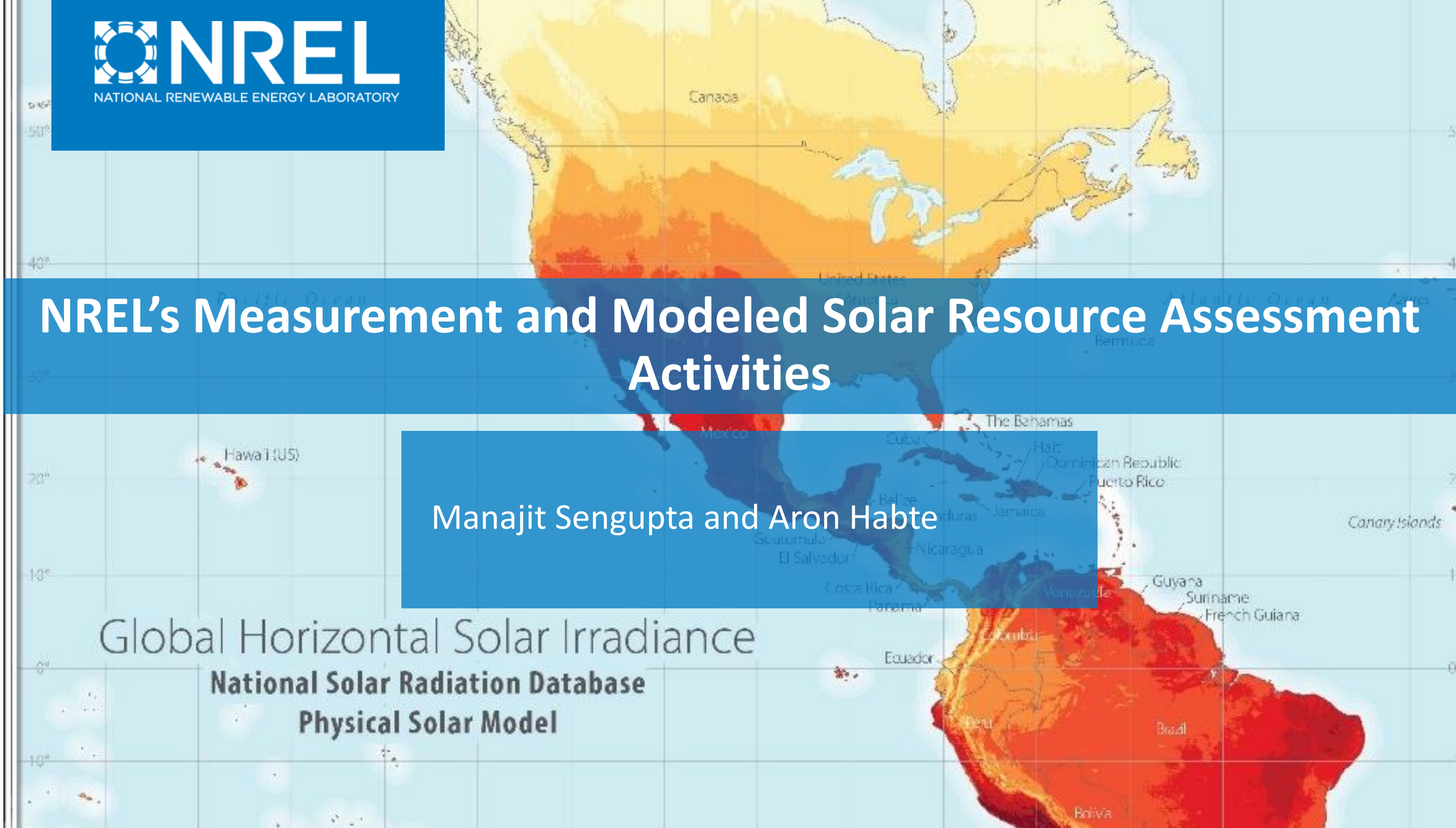
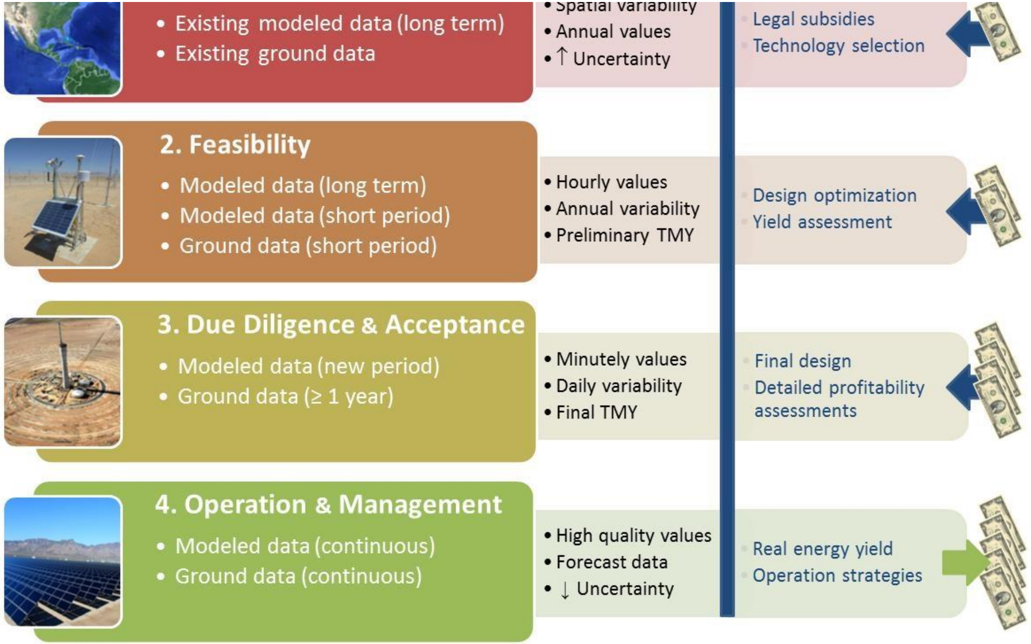
NREL's Measurement and Modeled Solar Resource Assessment Activities

Manajit Sengupta and Aron Habte



Solar Resource Assessment

Support the U.S. Department of Energy (DOE) Solar Energy Technology Office (SETO) of reducing solar deployment and financing costs through improving accuracy in solar resource measurement and modeling.

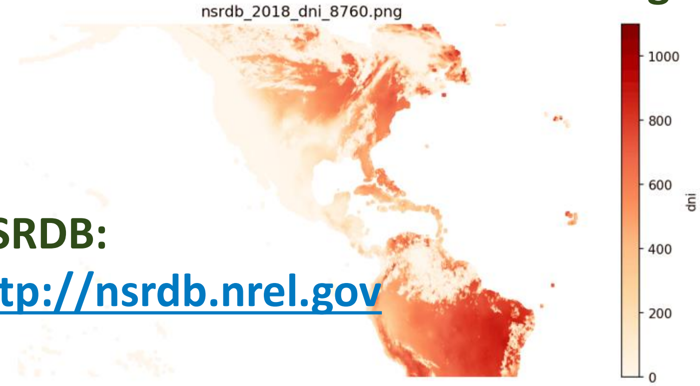


Source: https://www.nrel.gov/docs/fy18osti/68886.pdf

Solar Resource Assessment

- Develops state-of-the-art models and creates high quality long-term solar resource data for the U.S. and distributes it through the **National Solar Radiation Database (NSRDB)**.
- Conducts research on **accurate, robust and low-cost solar radiation instrumentation and methods**.
- Uses new knowledge and technology to develop **consensus national standards and best practices** for solar energy.
- Provides **solar measurement reference to all instruments in the US** through the annual NREL Pyrheliometer Comparison conducted by the Solar Radiation Research Laboratory (SRRL).

Satellite-based Irradiance modeling



NSRDB:
http://nsrdb.nrel.gov

Irradiance measurements in global horizontal and single axis tracking MIDC: https://midcdmz.nrel.gov/

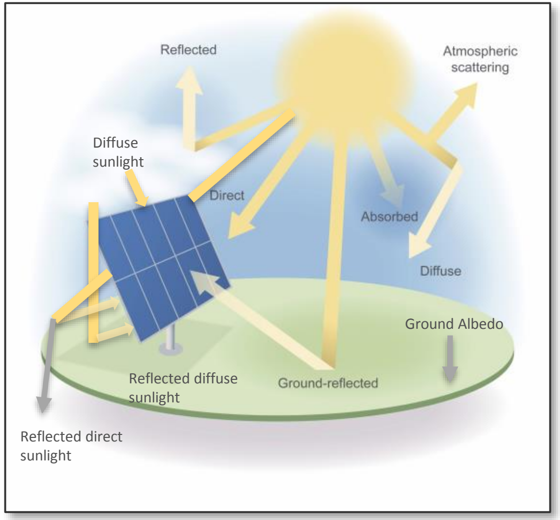
Solar Radiation Components

Radiation from the Sky Dome

- ***Directly*** from the sun
- Everywhere ***except*** the sun
- ***Entire*** sky
- Available to a PV **panel.**

We Call It

- Direct Normal Irradiance (DNI)
- Diffuse Horizontal Irradiance (DHI)
- Global Horizontal Irradiance (GHI)
- Plane-of-Array Irradiance (POA)



Broadband Solar Irradiance Specification

Table 1 — Pyranometer classification list

Specification parameter No. (see 4.3.2)	Parameter	Name of the classes, acceptance intervals and width of the guard bands (in brackets)		
	Name of the class	A	B	C
	Roughly corresponding class from ISO 9060:1990[1)]	*Secondary standard*	*First class*	*Second class*
a	Response time (see also 4.3.3 on fast response pyranometers): time for 95 % response	< 10 s (1 s)	< 20 s (1 s)	< 30 s (1 s)
b	Zero off-set: a) response to −200 W·m^{-2} net thermal radiation b) response to 5 K·h^{-1} change in ambient temperature c) total zero off-set including the effects a), b) and other sources	±7 W·m^{-2} (2 Wm^{-2}) ±2 W·m^{-2} (0,5 Wm^{-2}) ±10 W·m^{-2} (2 W·m^{-2})	±15 W·m^{-2} (2 Wm^{-2}) ±4 W·m^{-2} (0,5 Wm^{-2}) ±21 W·m^{-2} (2 W·m^{-2})	±30 W·m^{-2} (3 Wm^{-2}) ±8 W·m^{-2} (1 Wm^{-2}) ±41 W·m^{-2} (3 W·m^{-2})
c1	Non-stability: percentage change in responsivity per year	±0,8 % (0,25 %)	±1,5 % (0,25 %)	±3 % (0,5 %)
c2	Nonlinearity: percentage deviation from the responsivity at 500 W·m^{-2} due to the change in irradiance within 100 W·m^{-2} to 1 000 W·m^{-2}	±0,5 % (0,2 %)	±1 % (0,2 %)	±3 % (0,5 %)
c3	Directional response (for beam radiation): the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction (with an incidence angle of up to 90° or even from below the sensor) a beam radiation whose normal incidence irradiance is 1 000 W·m^{-2}	±10 W·m^{-2} (4 W·m^{-2})	±20 W·m^{-2} (5 W·m^{-2})	±30 W·m^{-2} (7 W·m^{-2})
NOTE The acceptance intervals should not be used for uncertainty estimations for conditions different from the ones stated for each criterion. In particular the spectral error can be different under different conditions. The spectral error for diffuse horizontal irradiance measurements is also different from that for global horizontal irradiance.				

ISO-9060: 2018
Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation

IEC 61724
Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis

Broadband Radiometer Calibration

Absolutely Critical for Maintaining Minimum Measurement Uncertainties

Traceable to the World Radiometric Reference (WRR)

Standard Procedures

International Organization for Standardization

ASTM G167-15
ASTM E816-15
ASTM E824-10
ASTM G207-11

ISO 9847:1992
ISO 9846:1993

Accredited Facilities

ISO 17025

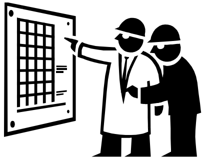
World Radiation Center, Davos

Standard Radiometers

Field Instruments

Maintaining Data Quality

- Quality Assessment Requires Judgment and Analysis. *This happens after the measurements*.



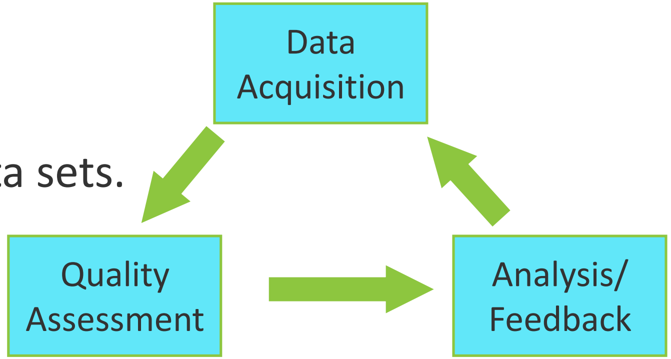
- Quality Control Is a Supervisory Process. *This happens before and during the measurements*.

Data Quality and Uncertainty: What Do You Get?

Data Quality Analysis Procedure

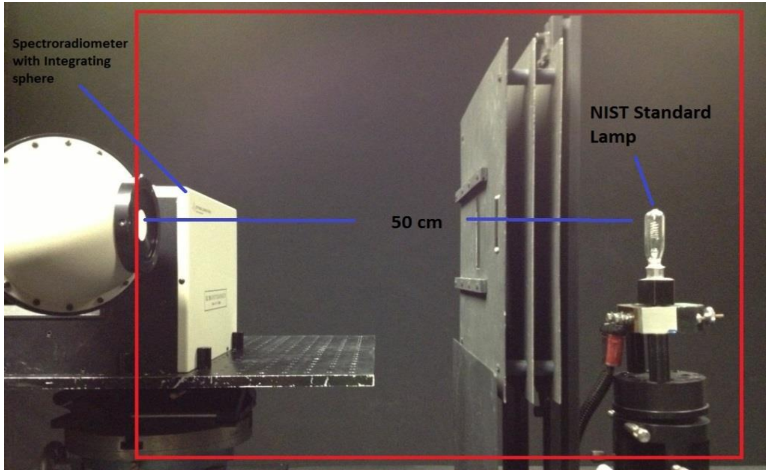
- **View all data as frequently as possible (daily is best)**
  - The longer the delay, the longer error conditions will persist
  - The more frequent your data checks, the more in tune you are with your stations.

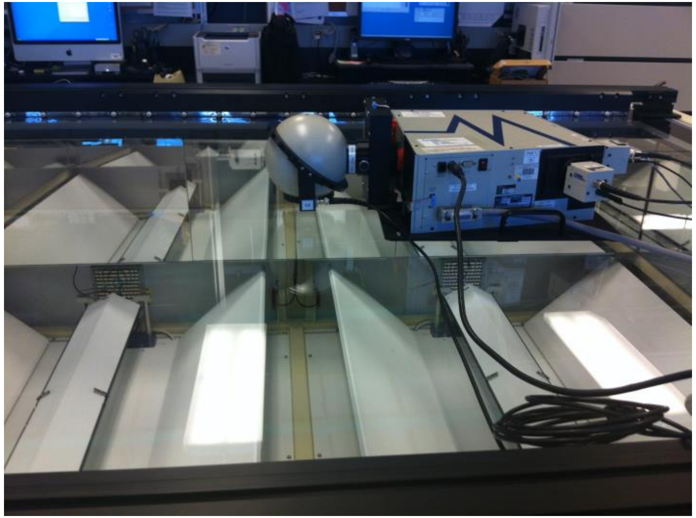
- View in context of other measurements
  - Measurements by themselves can be deceiving.
- Automate the data plots as much as possible
  - Spend your time *analyzing* data, not assembling data sets.
- Set up a feedback infrastructure
  - Communicate findings back to the station
  - Good results should be communicated also.



Spectral radiometer traceability and ISO-17025 accreditation

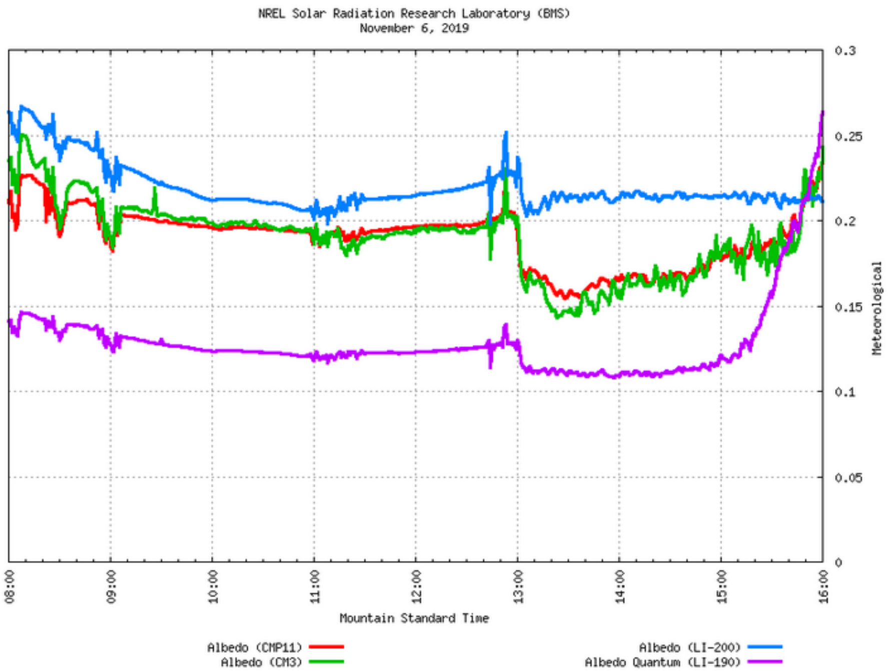
Spectral radiometric calibrations are ISO accredited and traceable to NIST enabling accurate baseline datasets for model and standards development, PV cell and module characterization and reliability studies.

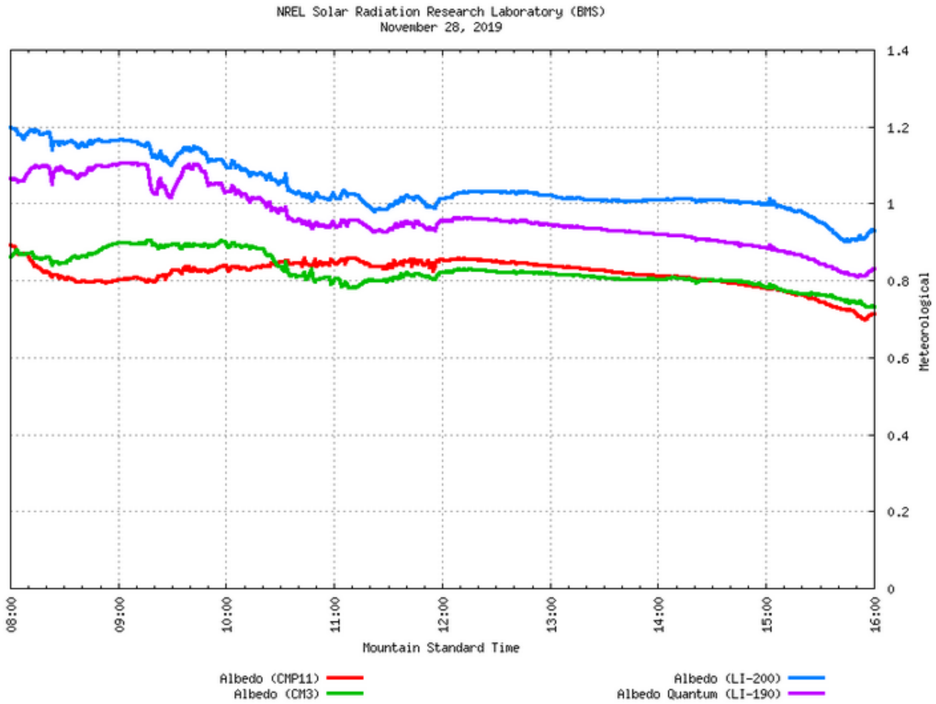




NREL-SRRL Albedo Data

NREL-SRRL Albedo Data





Why spectral albedo matters….. put more text here

Ultraviolet (UV) measurement and modeling

Component	Manufacturer	Model	#	Band	Spectral range (nm)	Notes
Direct (5° FOV)	Kipp & Zonen	CUVA2	1	UVA	315-400	
	Kipp & Zonen	UVB	1	UVB	280-315	
	Eppley	TUVR	1	TUV	295-385	Response time is order(milliseconds)
Global (180° FOV)	Kipp & Zonen	CUVA1	1	UVA	315-400	
	Yankee Environmental Systems, INC.	UVA-1	1	UVA	320-400	
	Kipp & Zonen	UVS-A-T	1	UVA	315-400	Response time < 2 seconds
	Kipp & Zonen	UVS-B-T	1	UVB	280-315	Response time < 2 seconds
	Kipp & Zonen	CUVB1	1	UVB	280-315	
	Yankee Environmental Systems, INC.	UVB-1	1	UVB	280-320	
	EKO	MS-210W	1	UVB	280-320	Response time ~ 1 second
	Solar Light	501A	1	UVB	280-315	
	Kipp & Zonen	CUV4	1	TUV	280-400	Response time < 1 second
	Eppley	TUVR	1	TUV	295-385	Response time is order(milliseconds)

Ultraviolet (UV) measurement and modeling

- Developed UV conversion model using SMARTS model and global horizontal irradiance.
  - Based on the model, a new ASTM standard is under development.

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IEEE *Xplore*® Digital Library

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National Renewable Energy Laboratory
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All
Enter keywords or phrases (Note: Searches metadata only by default. A search for 'smart grid' = 'smart AND grid')

Journals & Magazines > IEEE Journal of Photovoltaics > Volume: 9 Issue: 1

Estimating Ultraviolet Radiation From Global Horizontal Irradiance

6 Author(s) Aron Habte ; Manajit Sengupta ; Christian A. Gueymard ; Ranganath Narasappa ; Olivier Rosseler ;... View All Authors

13 Full Text Views

Abstract

Document Sections

I. Introduction

II. Method

III. Results and Discussion

IV. Conclusion

Authors

Abstract:
Terrestrial ultraviolet radiation (UV) radiation is a primary factor contributing to the degradation of photovoltaic (PV) modules' efficiency and reliability over time. Therefore, accurate knowledge of terrestrial UV incident on the surface of the PV materials is essential to understand the degradation of PV modules and provide reliable assessment of their service life. As PV is deployed in various climate zones, it is crucial that terrestrial UV information is available at various locations. However, the availability of terrestrial UV data—measured or modeled—is extremely limited. On the other hand, total solar irradiance (TS) datasets are relatively abundant. In this study, the National Renewable Energy Laboratory, its industry partners, and ASTM's International Subcommittee on Radiometry and Service Life Prediction are developing a simple method to estimate the clear-sky terrestrial UV irradiance (280–400 nm, 295–400 nm, 285–385 nm, or 295–385 nm) from total irradiance data (280–4000 nm). The goal is to provide reliable estimates of the UV received by samples as a function of location, orientation, tilt, and airmass, thus encompassing a variety of conditions. The Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) model is used to estimate the UV:TS ratio under various scenarios, and examines the

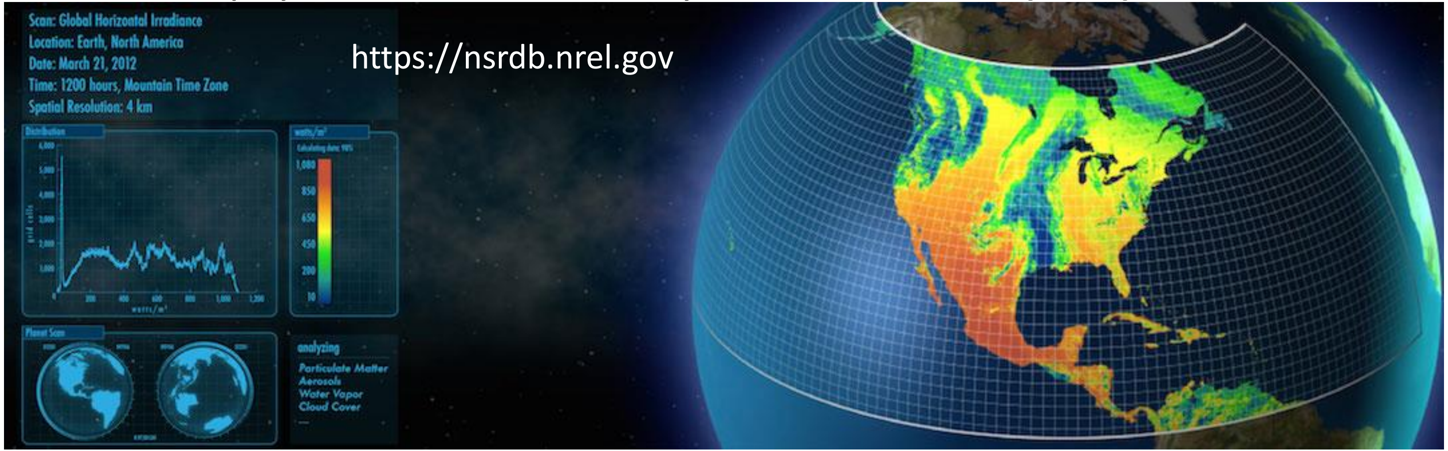
https://ieeexplore.ieee.org/abstract/document/8529229

Broadband and Spectral Solar Resource Data from the National Solar Radiation Data Base (NSRDB)

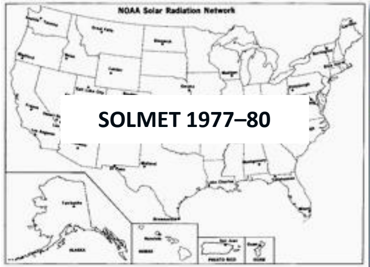
Physical Solar Model (PSM) V3

The National Solar Radiation Database

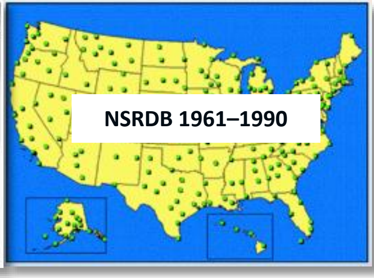
- The National Solar Radiation Database (NSRDB) seeks to advance our knowledge of solar radiation and its applications for renewable energy and beyond.
- The NSRDB provides a serially complete database of solar irradiance and meteorological information across the United States and in an increasing number of international locations.
- The NSRDB provides **21 years** (+ typical meteorological year [TMY]) of half-hourly data at a 4-km by 4-km spatial resolution. 5 min 2km data is also available from 2018.
- The NSRDB uses a physics-based model, Physical Solar Model **(PSM).**



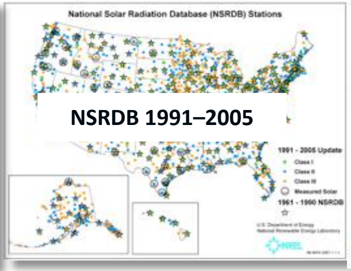
Evolution of the National Solar Radiation Database



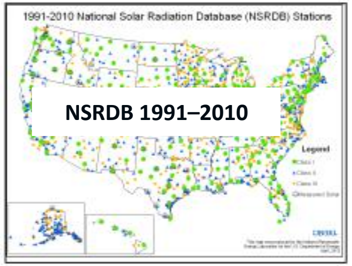
248 weather stations with 26 ***solar measurement*** stations (ERDA, NOAA, 1979)



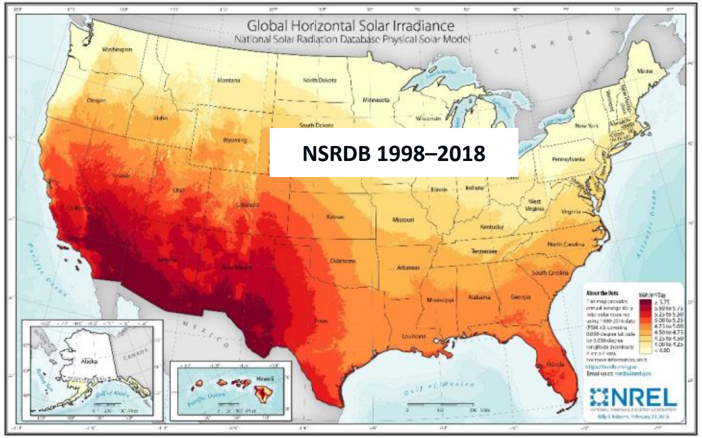
239 ***modeled*** stations with 56 partial measurement stations (DOE, NOAA, 1994)

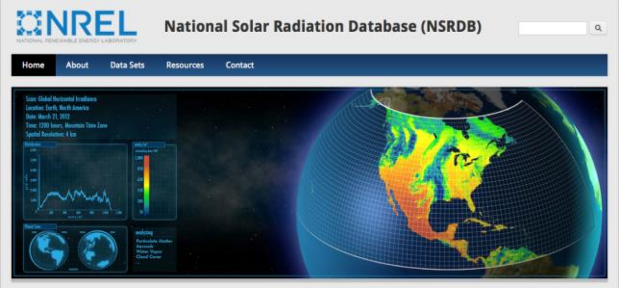


1,454 ***modeled*** locations (DOE, SUNY-A, NOAA, 2007)



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

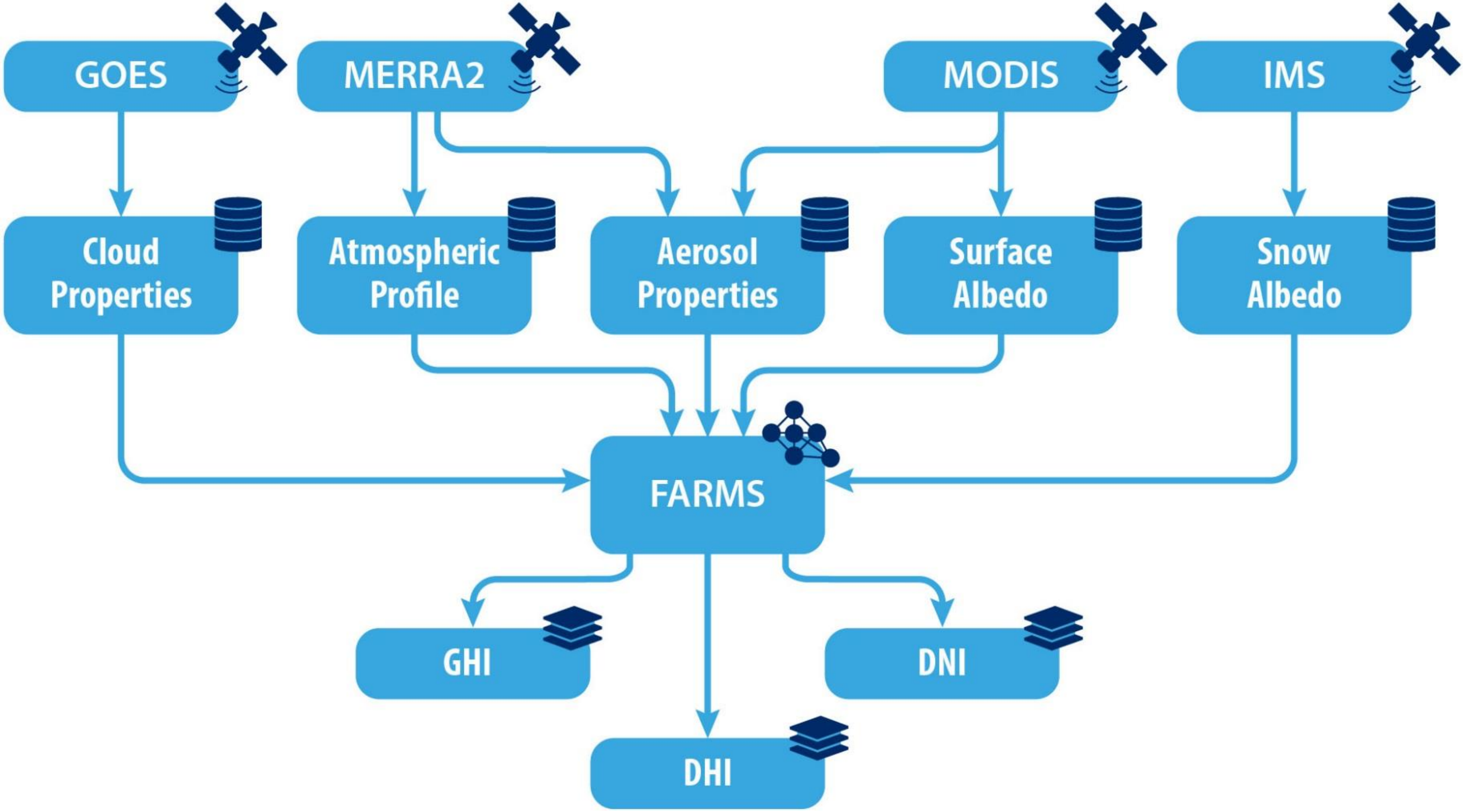




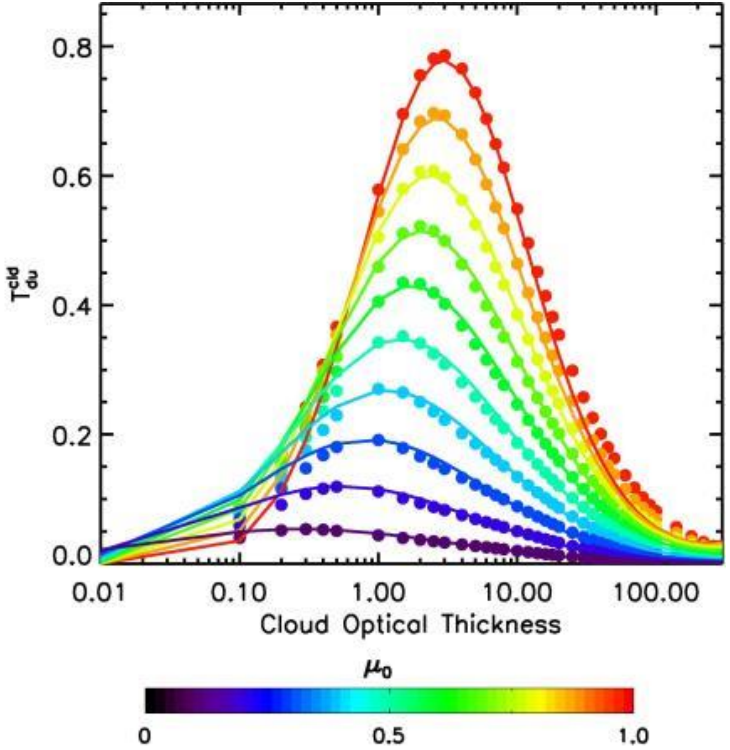
http://nsrdb.nrel.gov

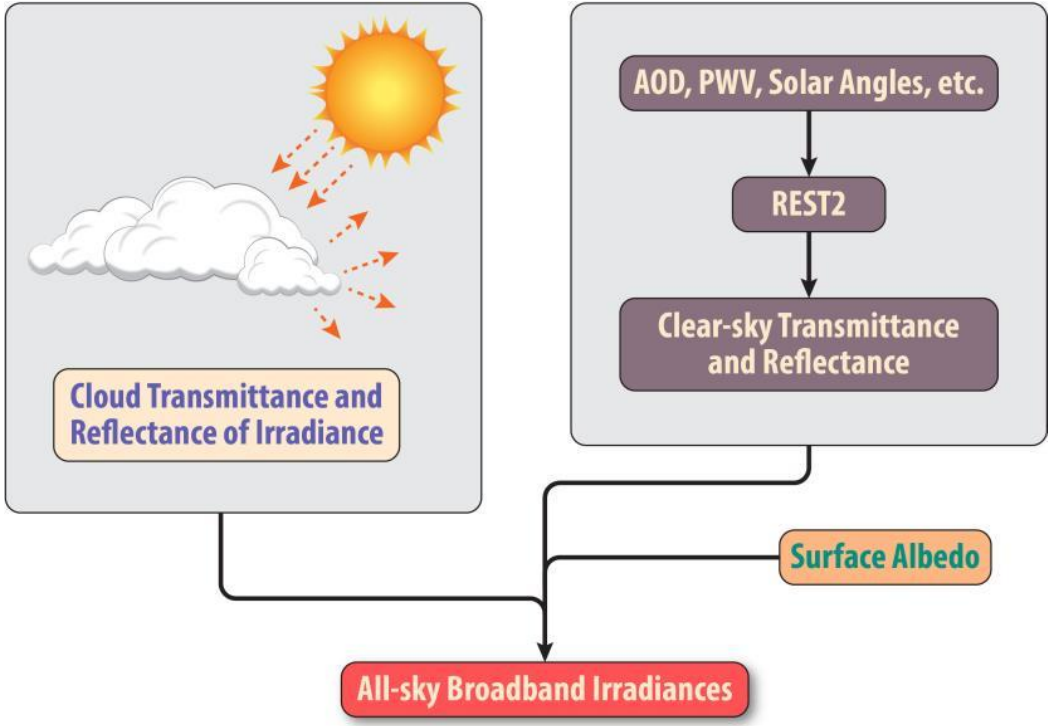
Satellite-based, gridded, 4 km x 4 km, half-hourly (DOE, NOAA, UW, SCS 2018)

NSRDB: Physical Solar Model (PSM) Workflow



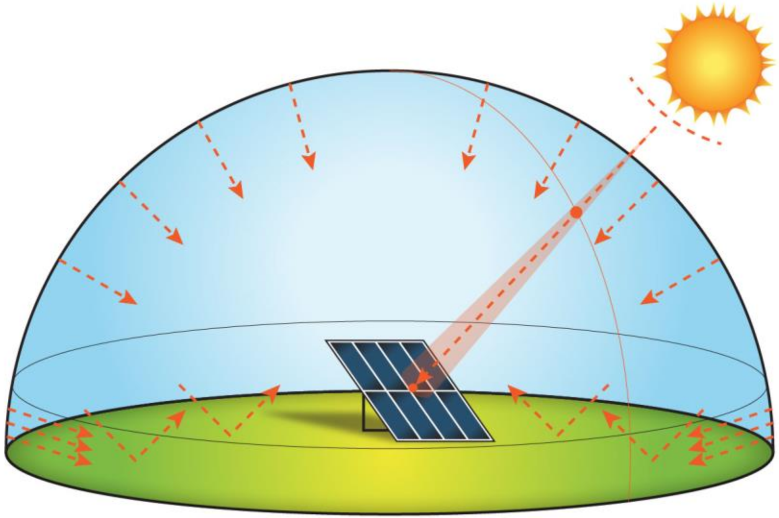
Fast All-sky Radiation Model for Solar applications (FARMS)

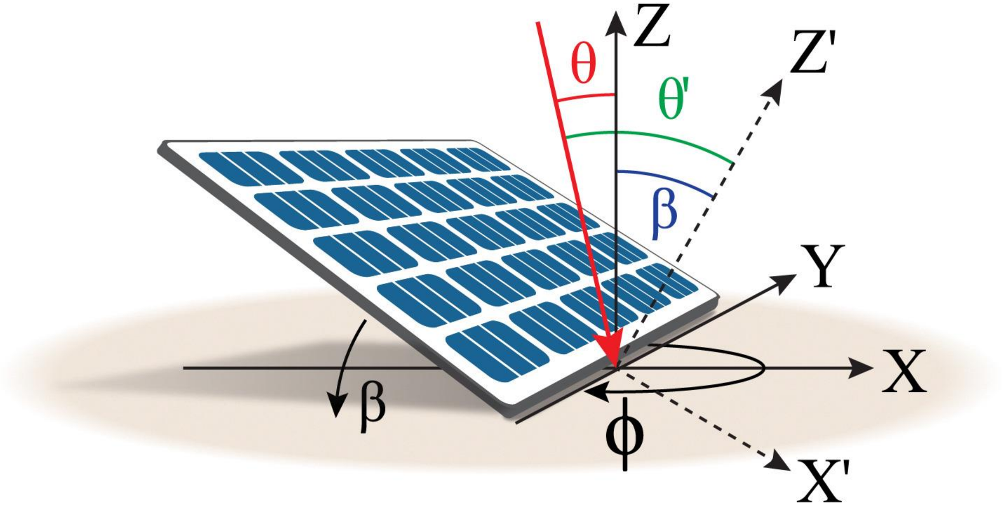




Cloud transmittances can be parameterized as exponential functions of cloud optical thickness and solar zenith angles.

FARMS for Narrowband Irradiances on Tilted surfaces (FARMS-NIT)

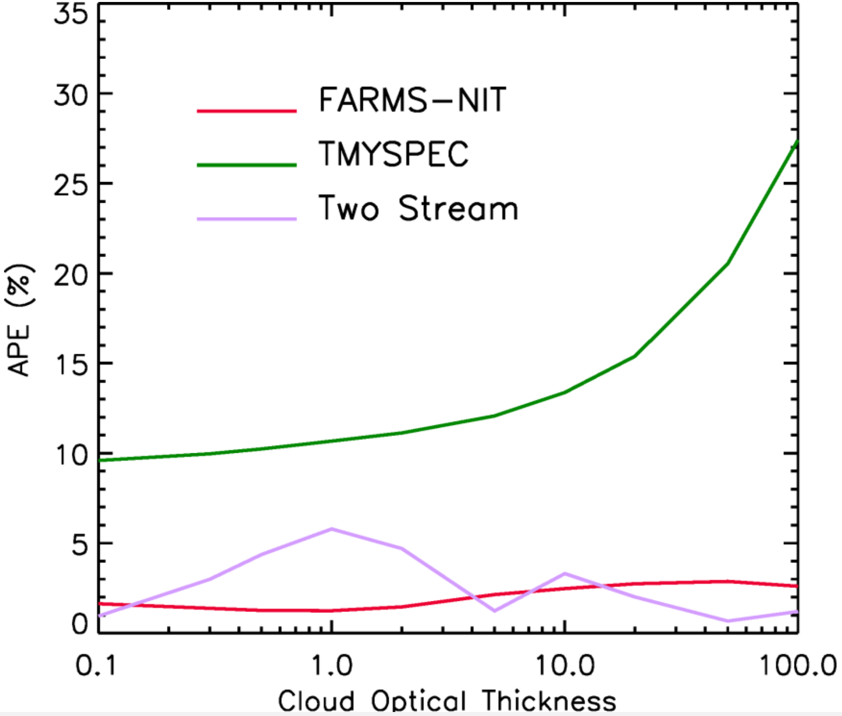


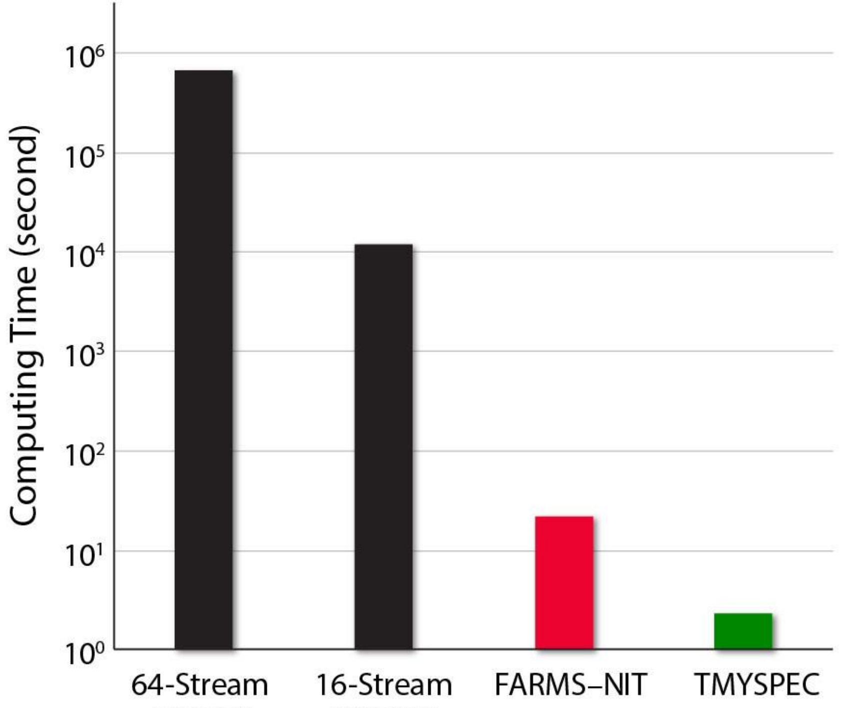


Models for meteorology can solve solar radiances in all possible directions.

Models for solar energy use regression functions to empirically link with long-term observations of GHI.

FARMS-NIT is accurate and time efficient



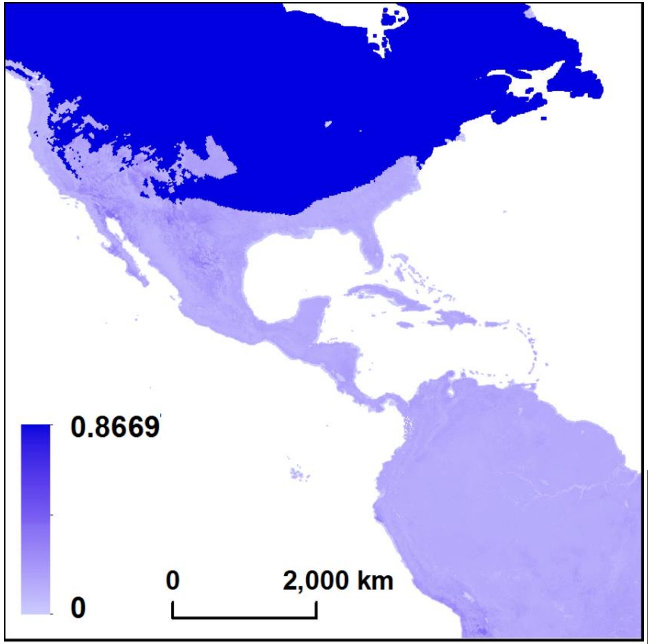


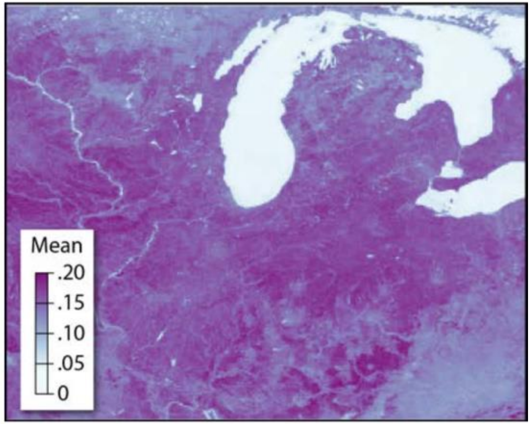
The overall difference between DISORT and FARMS-NIT is **less than 5%** for both clear-sky and cloudy-sky conditions.

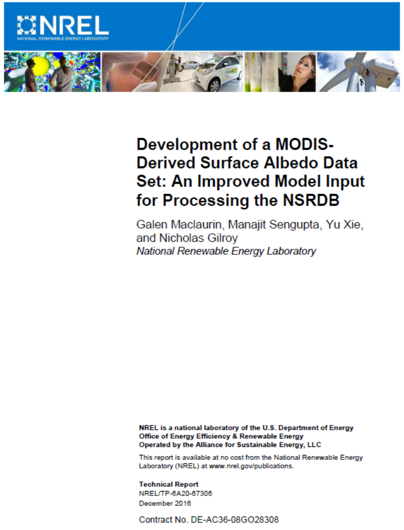
FARMS-NIT has a better accuracy than TMYSPEC.

NSRDB Surface Albedo

NSRDB Improvement: MODIS-Derived Surface Albedo Data Set







Development of a MODIS-Derived Surface Albedo Data Set: An Improved Model Input for Processing the NSRDB

Galen Maclaurin, Manajit Sengupta, Yu Xie, and Nicholas Gilroy
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Technical Report
NREL/TP-6A20-67306
December 2016

Contract No. DE-AC36-08GO28308

Technical Report: NREL developed an improved white-sky (bi-hemispherical reflectance) broadband (0.3–5.0 µm) surface albedo data set for processing the NSRDB from two existing data sets: a gap-filled albedo product and a daily snow cover product.
http://www.nrel.gov/docs/fy17osti/67306.pdf

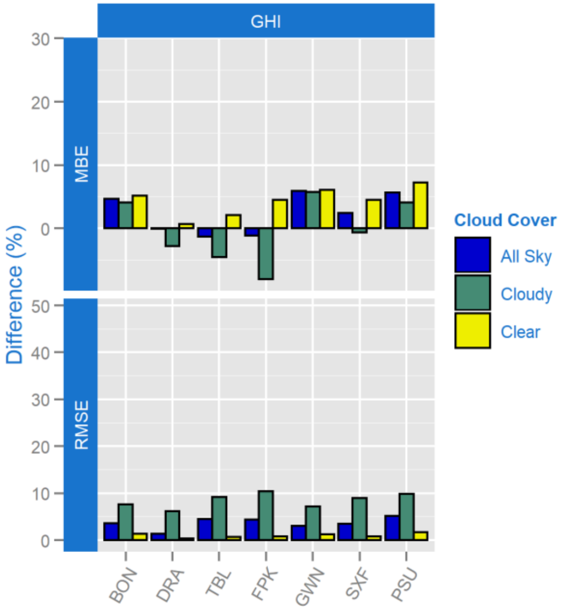
What is available from NSRDB

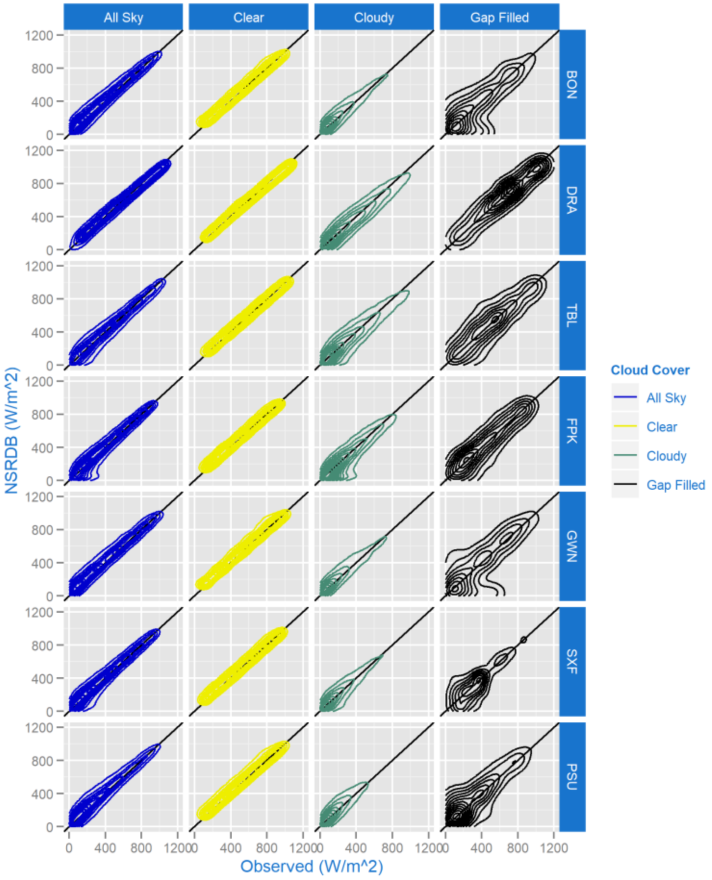
- Global horizontal irradiance (GHI)
- Direct normal irradiance (DNI)
- Diffuse horizontal irradiance (DHI)
- Clear-sky GHI, DNI, and DHI
- Cloud type
- Dew point*
- Air temperature*
- Atmospheric pressure*
- Relative humidity*
- Solar zenith angle
- Precipitable water*
- Wind direction*
- Surface Albedo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

* Source: MERRA-2

Validation of NSRDB

1998-2018





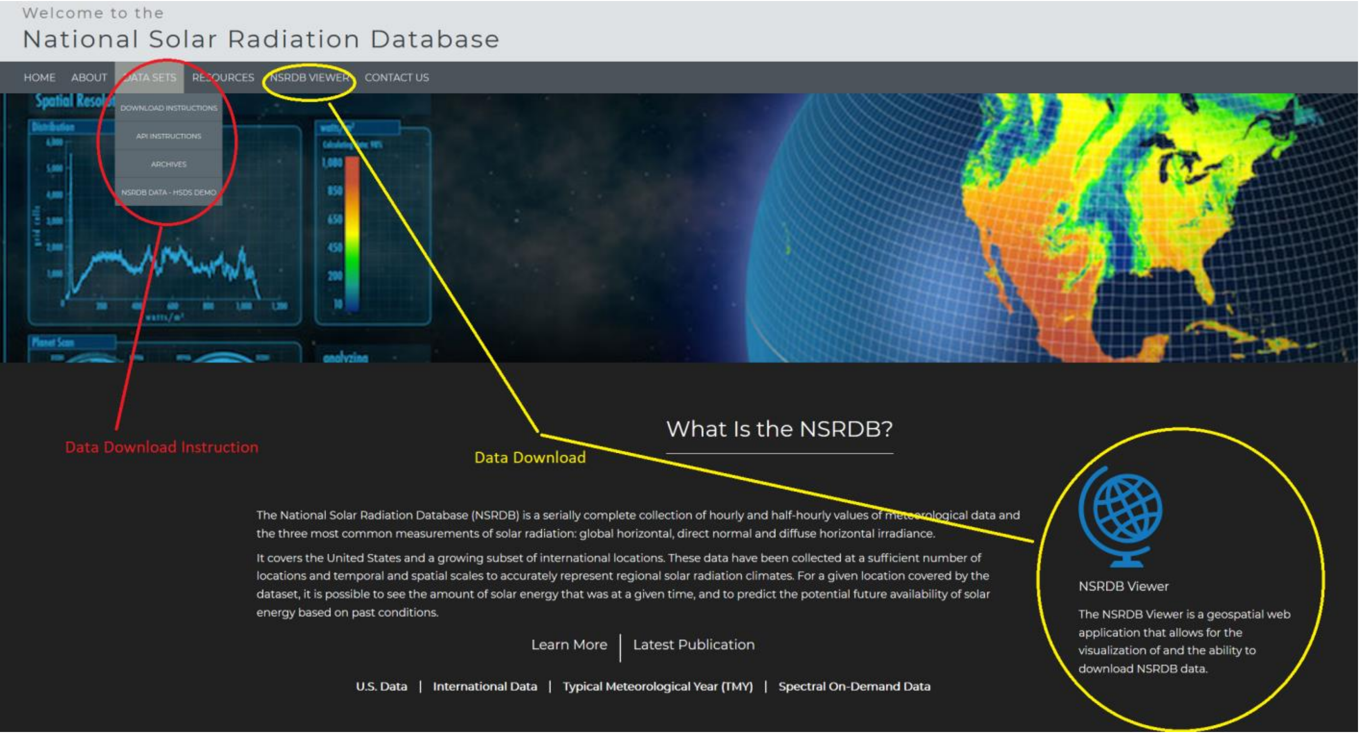
Impact: *Improvement in the NSRDB accuracy has directly impacted the accuracy of grid integration, energy modeling, resource planning, production cost modeling and project and product development.*

Typical Meteorological Year (TMY)

- TMY data was first created by Sandia National Laboratories to assess building performance.
- TMY data sets were developed from long-term data such as in the National Solar Radiation Data Base (NSRDB)

Source	Years	Description	Spatial Information	Temporal Information	Comment
NSRDB MTS1	1961–1990	TMY 2: METSTAT (METeorological STATistical) Model—93% and Measured— 7%	Point data set	1-Hour	239 stations. TMY3 was generated using Version 1 and 2 of the NSRDB
NSRDB MTS1 and MTS 2	1961–2005	TMY 3: METSTAT SUNY Empirical model Measured (<1%)	Point data set	1-Hour	The update includes fields that allow users the flexibility to choose modeled or, if available, measured data for an application. Includes 1,020 stations.
NSRDB Version v3 –PSM TMY	1998–2018	Gridded TMY	Gridded	1-Hour	4 sq. km spatial resolution for all U.S. and part of South America

NSRDB Data Access

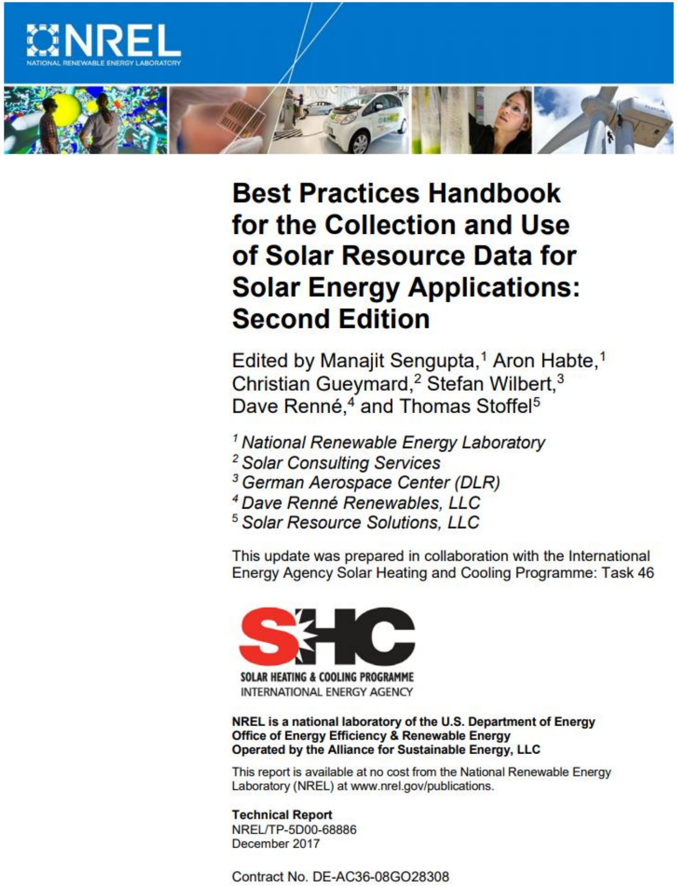


Data download Options:

- NSRDB Viewer
- API
- AWS

https://nsrdb.nrel.gov/

Other Sources of Solar Resource Data


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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

Edited by Manajit Sengupta,[1] Aron Habte,[1] Christian Gueymard,[2] Stefan Wilbert,[3] Dave Renné,[4] and Thomas Stoffel[5]

[1] *National Renewable Energy Laboratory*
[2] *Solar Consulting Services*
[3] *German Aerospace Center (DLR)*
[4] *Dave Renné Renewables, LLC*
[5] *Solar Resource Solutions, LLC*

This update was prepared in collaboration with the International Energy Agency Solar Heating and Cooling Programme: Task 46

SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

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Office of Energy Efficiency & Renewable Energy
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Technical Report
NREL/TP-5D00-68886
December 2017

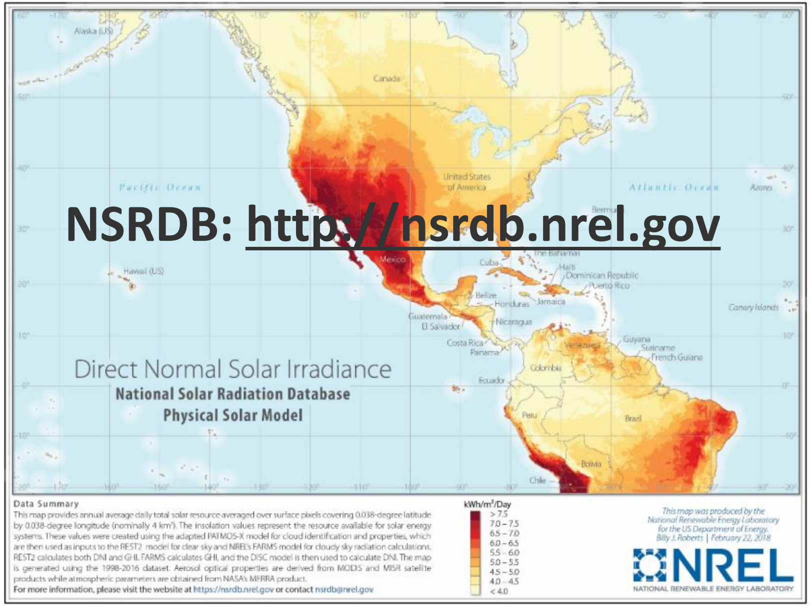
Contract No. DE-AC36-08GO28308

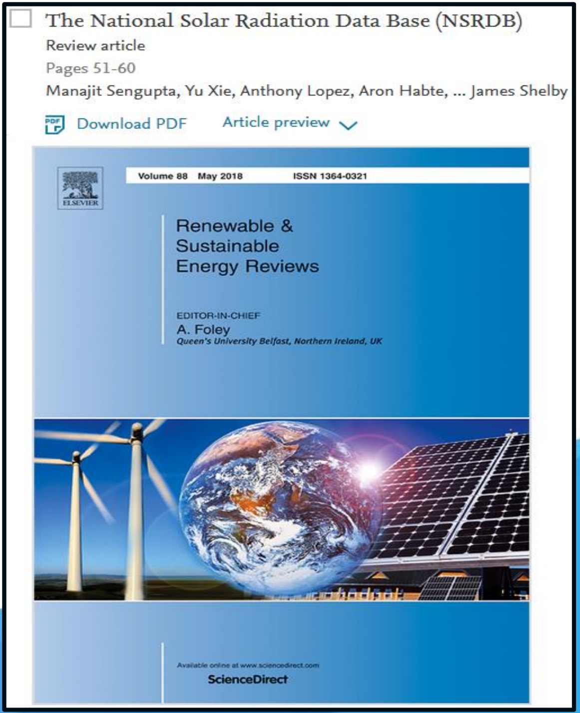
https://www.nrel.gov/docs/fy18osti/68886.pdf

Table 5-1 in the handbook contains list of data sources around the world

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

This work was authored by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Solar Energy Technology Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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