Advanced Energy Partnership for Asia

Development and Validation of Southeast Asia Solar Resource Data

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Illustration by Billy Roberts, NREL

Democratizing Time Series Solar Data

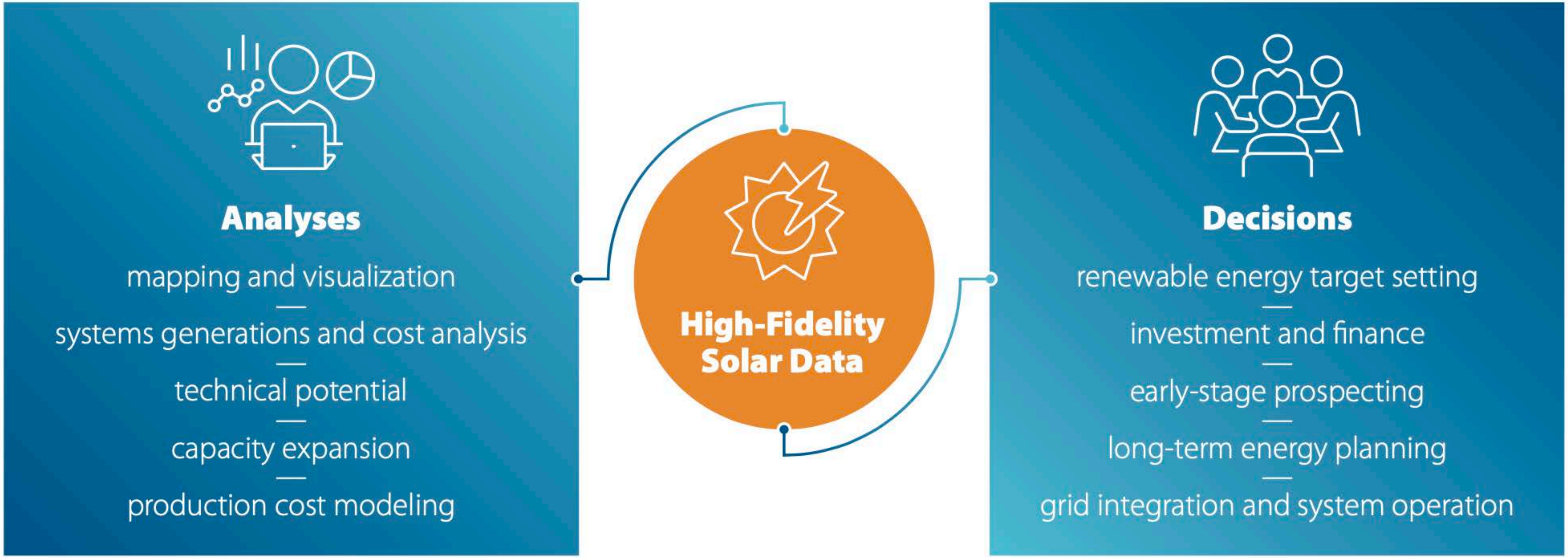
Challenge: Lack of access to high-quality, publicly available, time series solar data to inform decisions that will transform energy sectors in Southeast Asia.

Floating PV array on a water retention pond. Photo by Dennis Schroeder, NREL

Solution: Level the playing field by offering free, high-quality, robust solar data to inform private sector investment and policymaking:

- Leverage deep NREL expertise in atmospheric science, solar resource assessment, high-performance computing, and cloud-based data dissemination
- Produce and validate high spatial and temporal resolution solar resource data
- Make data available on the USAID-funded global Renewable Energy Data Explorer platform
- Provide capacity building for data and applications
- Inform future demand-driven tool development

High-Quality Data for Decisions



High-quality, reliable data are at the core of critical decisions to enable energy transitions. Illustration by Christopher Schwing, NREL

Data Development Algorithm

NREL's Physical Solar Model (PSM)

- Models the transfer of solar radiation through Earth's atmosphere
- Considers interactions with atmospheric constituents (e.g., CO_2, O_3, H_2O) and land surface
- Characterizes absorption and scattering of solar radiation from clouds and aerosols
- Visit https://nsrdb.nrel.gov/ for more information.

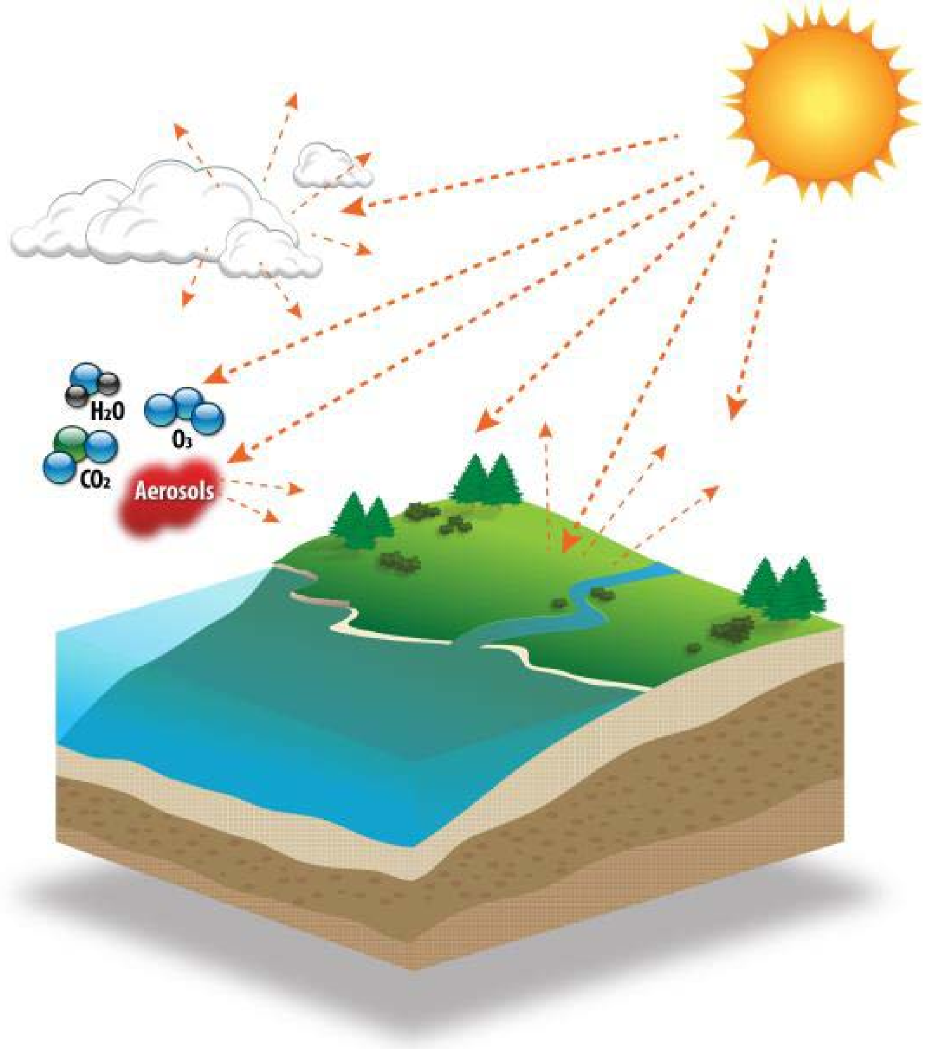
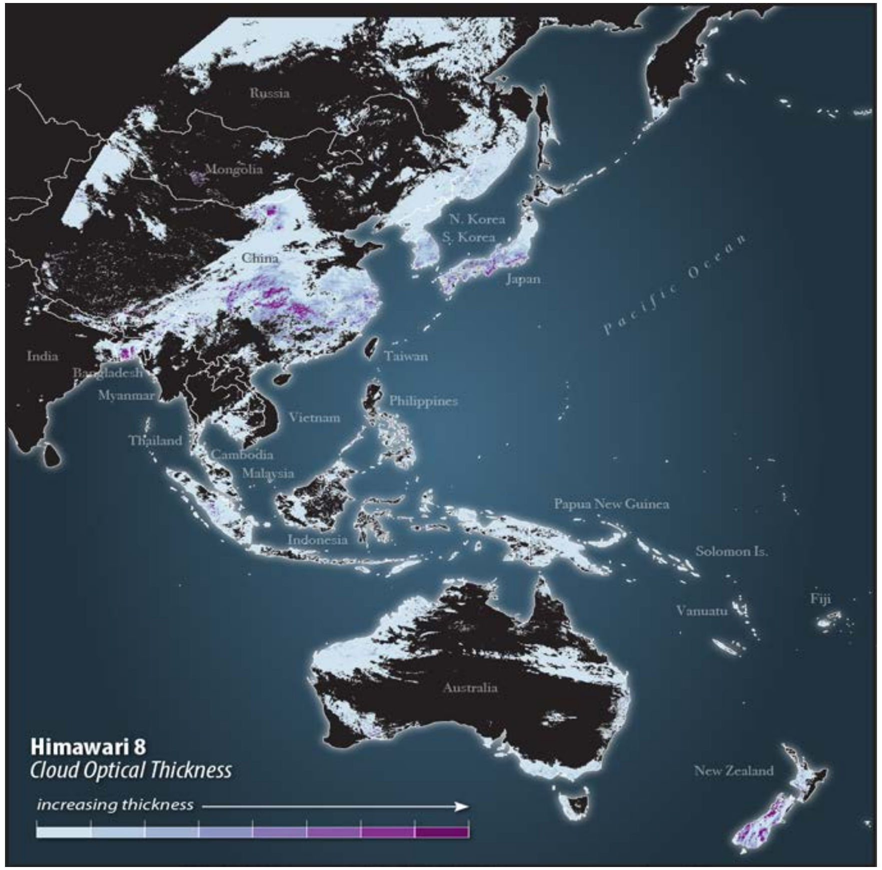


Illustration by Billy Roberts, NREL

Himawari Satellite Imagery

- Cloud characteristics are a key input for the PSM to estimate absorption and scattering of the incoming solar radiation
- Imagery from the Japanese Meteorological Agency's (JMA's) Himawari 7 and 8 satellites covers much of Asia and Oceania at high spatial and temporal resolutions
- NREL partnered with the University of Wisconsin to model cloud type, thickness, and properties.



Cloud optical thickness shown for April 1, 2019. *Illustration by Billy Roberts, NREL*

Physical Solar Model (PSM)

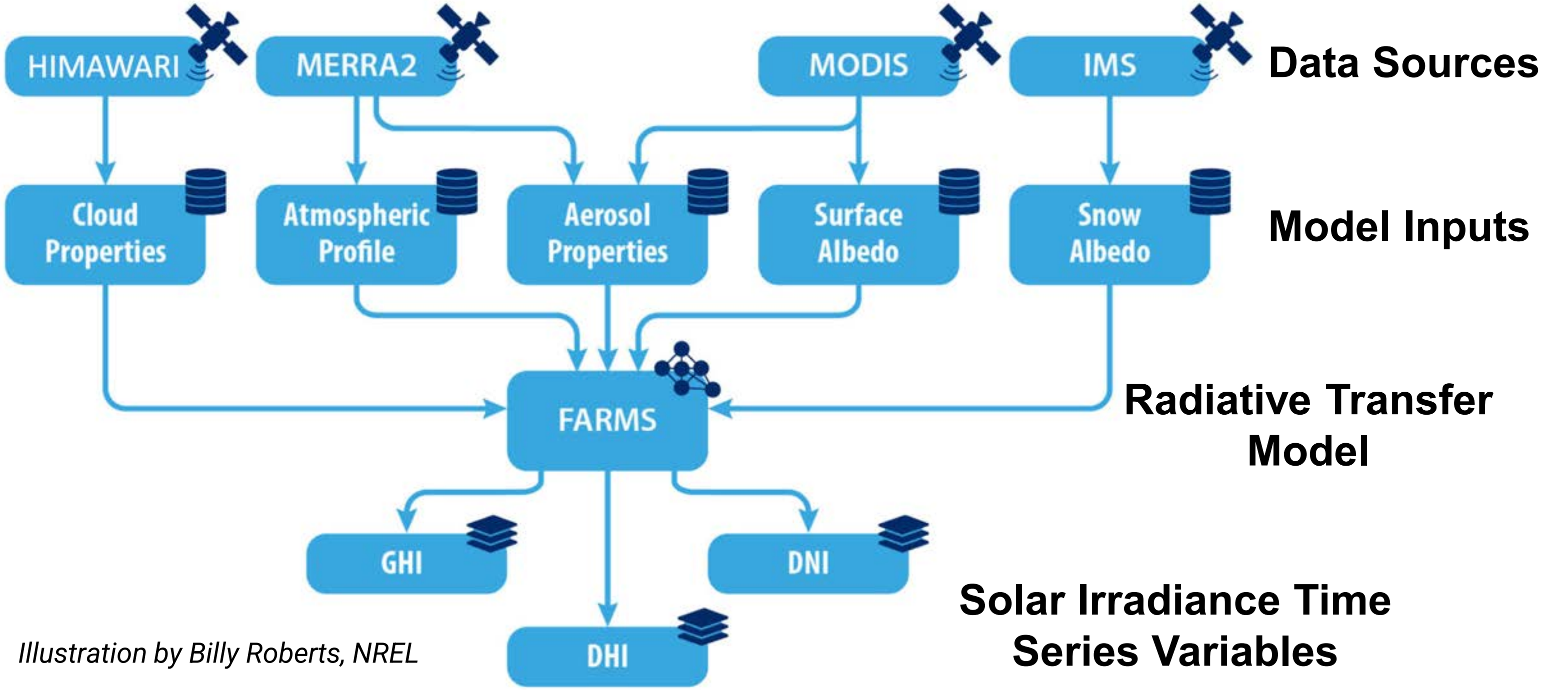


Illustration by Billy Roberts, NREL

Himawari – Geostationary weather satellites from the Japanese Meteorological Agency. Publicly available data was used from Himawari 7 and 8 satellites.

MERRA2 – Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) provides ancillary meteorological variables, including aerosol optical depth (AOD) and the atmospheric profile.

MODIS – Moderate Resolution Imaging Spectroradiometer (MODIS) provides satellite-derived AOD and albedo.

IMS – Interactive Multisensor Snow and Ice Mapping System (IMS) provides daily snow coverage to represent snow albedo.

FARMS – Fast All-sky Radiation Model for Solar (FARMS) applications developed by NREL. This is a suite of radiative transfer models that represent how solar radiation interacts with the atmosphere and the Earth's land cover as it reaches the surface.

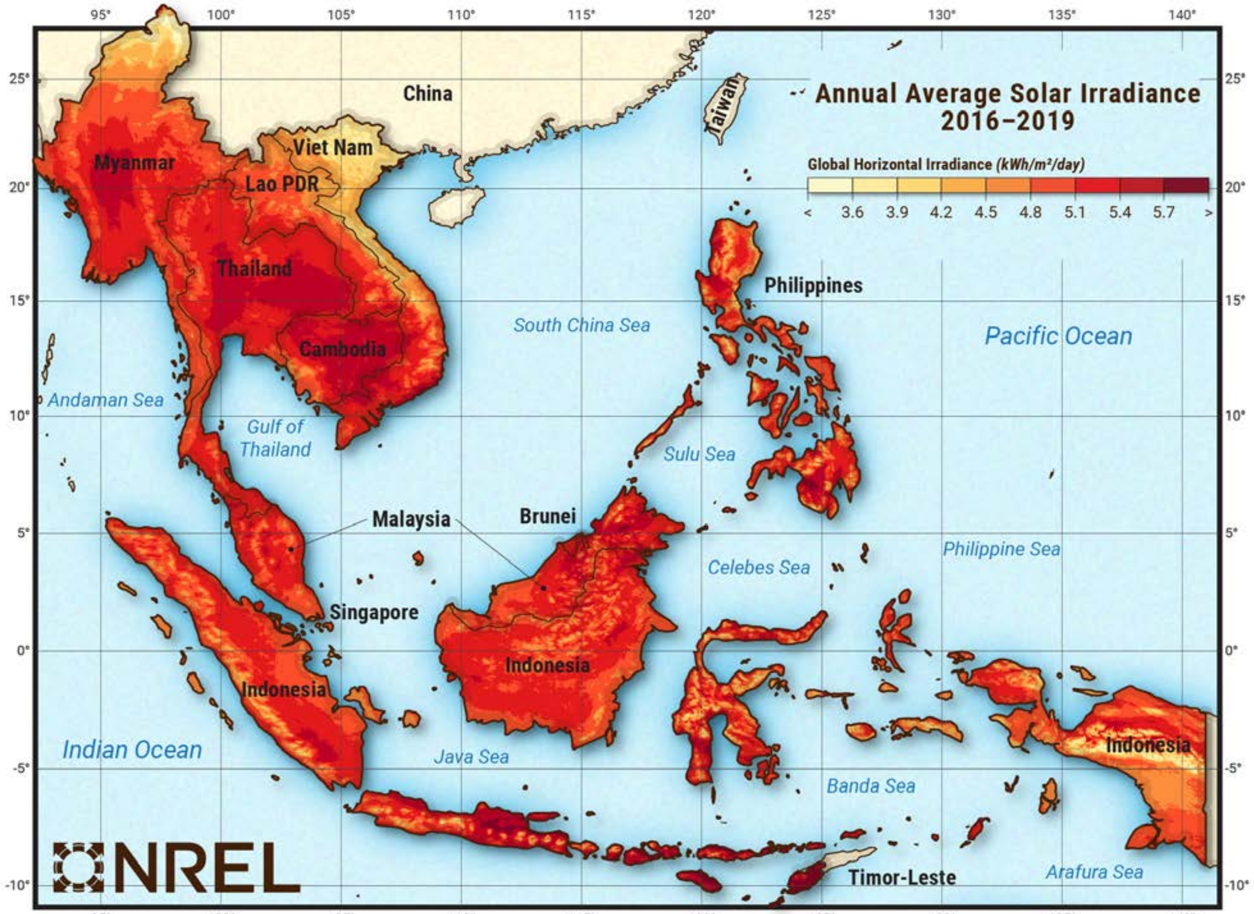
DNI – Direct Normal Irradiance is the amount of incoming solar radiation directly from the sun (i.e., from the direct solar beam) that reaches a plane perpendicular to the solar zenith angle.

DHI – Diffuse Horizontal Irradiance is the amount of solar radiation incident on a horizontal plane that has been diffused or scattered by the atmosphere or surface (i.e., the indirect incoming solar radiation).

GHI – Global Horizontal Irradiance is the total amount of solar radiation incident on a horizontal plane. GHI is calculated as DHI + DNI • cosine (Solar Zenith Angle).

* DNI, DHI, and GHI are typically measured in Watts/meter^2.

High-Fidelity Solar Data for SE Asia

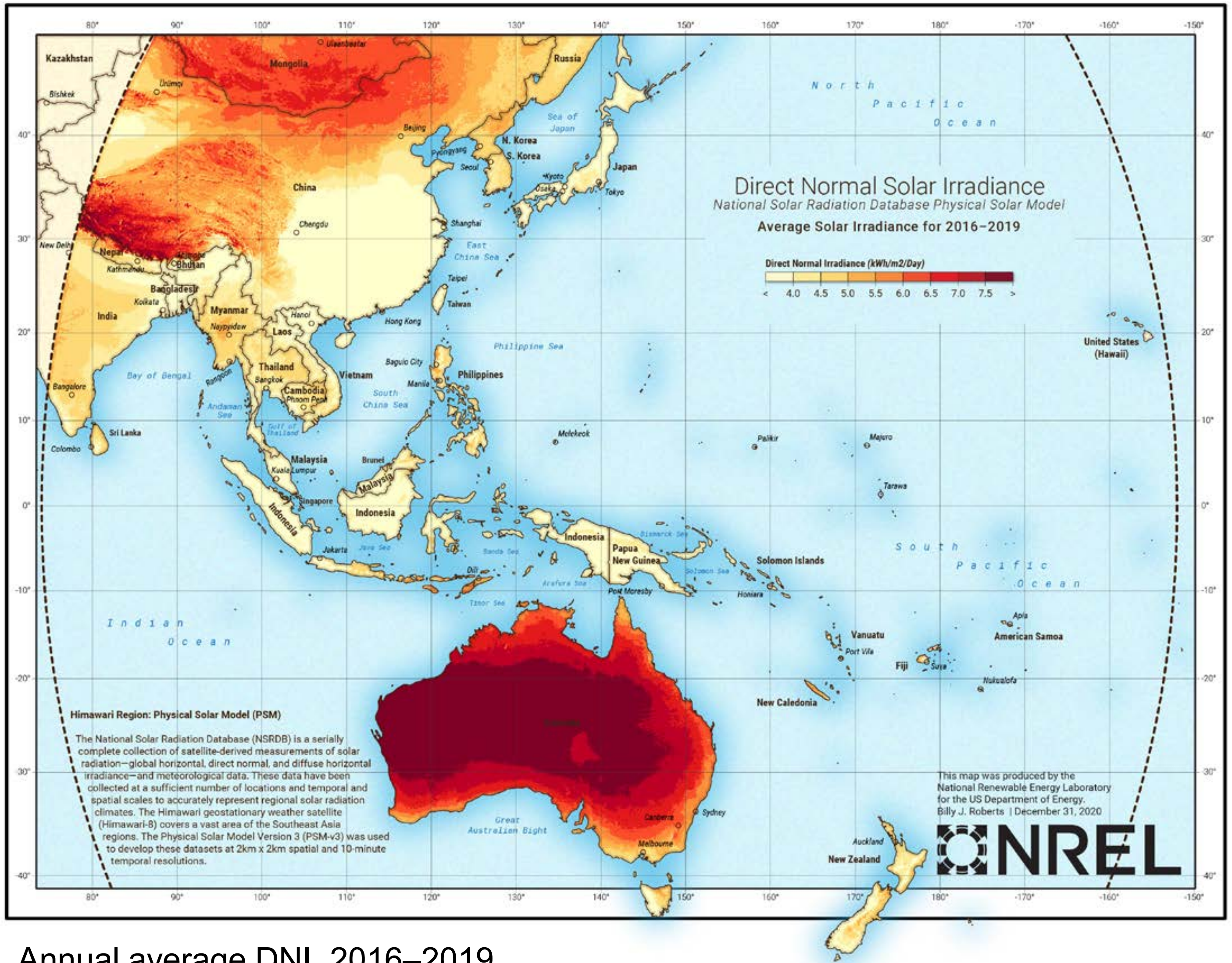


Annual average GHI, 2016–2019. *Illustration by Billy Roberts, NREL*

Harnessing the power of its high-performance computing system, NREL produced 10 years of high-resolution solar irradiance data along with ancillary meteorological variables required to model solar energy generation. NREL also developed a typical meteorological year (TMY) data set.

For more information see: "[Developing Southeast Asia Solar Resource Data to Support the Clean Energy Transition in the Region](#)."

Data Set Description



Annual average DNI, 2016–2019.
Illustration by Billy Roberts, NREL

Geographic Coverage:

East and Southeast Asia and Oceania

Temporal Coverage and Resolution:

High-resolution (Himawari 8):

2016–2020 at 2km, 10 minute

Standard-resolution (Himawari 7):

2011–2015 at 4km, 30 minute

Typical Meteorological Year (TMY):

Compiled from 2011–2020 at 4km, hourly*

* https://www.nrel.gov/docs/fy14osti/60886.pdf

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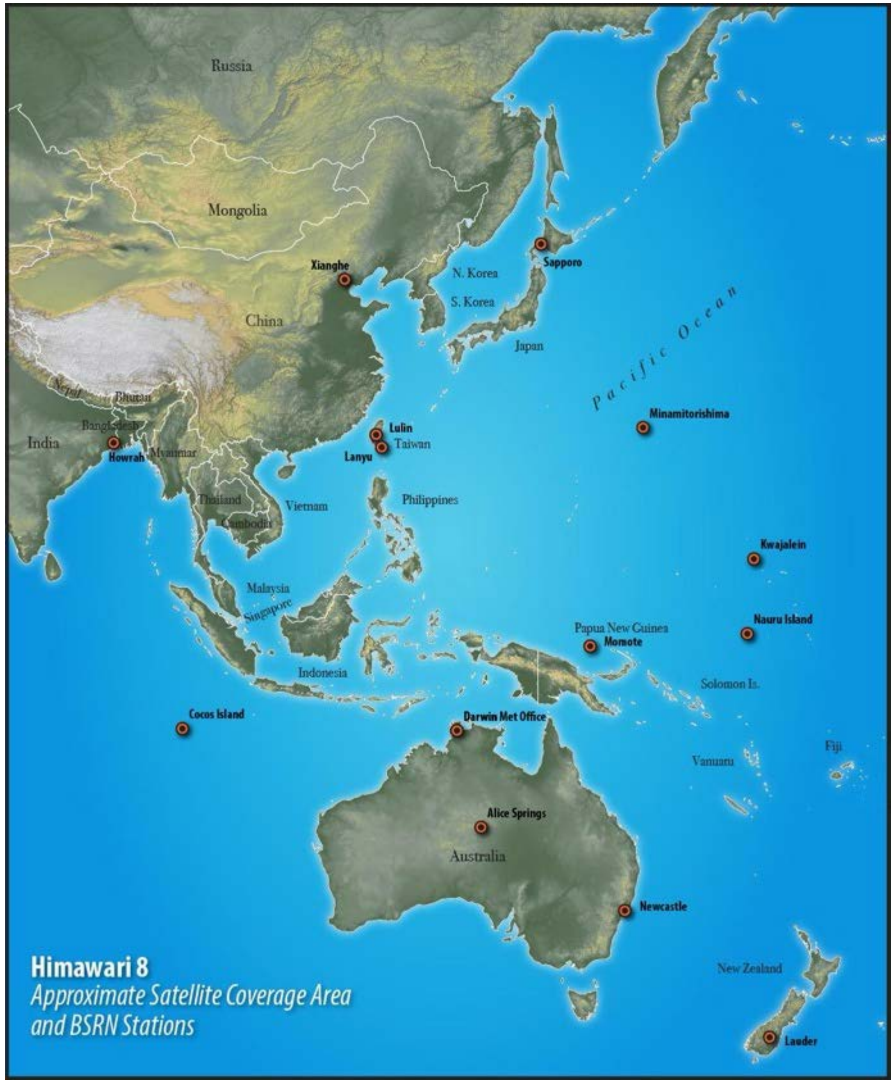
Validation Data and Locations



BSRN measurement locations within Himawari satellite extent. *Illustration by Billy Roberts, NREL*

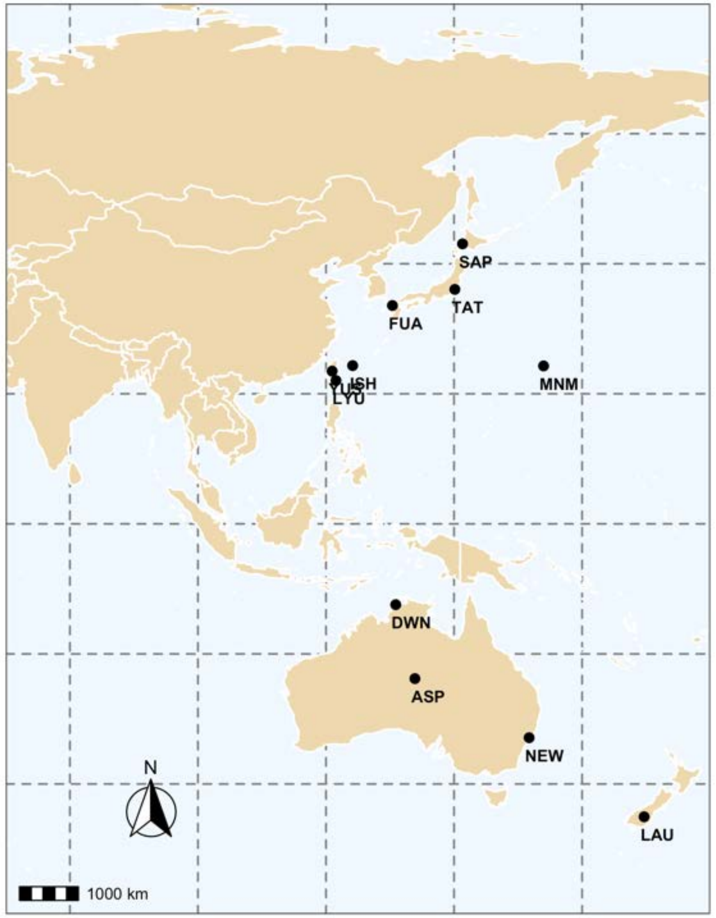
The Baseline Surface Radiation Network (BSRN)* maintains and distributes time series measurements of solar irradiance and weather variables. The global network covers the Himawari satellite extent and provided high-quality validation data for this project. NREL validated the PSM outputs at BSRN locations to understand the uncertainty in the model, which gives confidence in the data quality across the entire spatial extent.

* https://bsrn.awi.de/

Himawari 8 Data Validation Results

Summary of measurement data used for Himawari 8 (2016–2019, 2-km, 10-minute resolution)

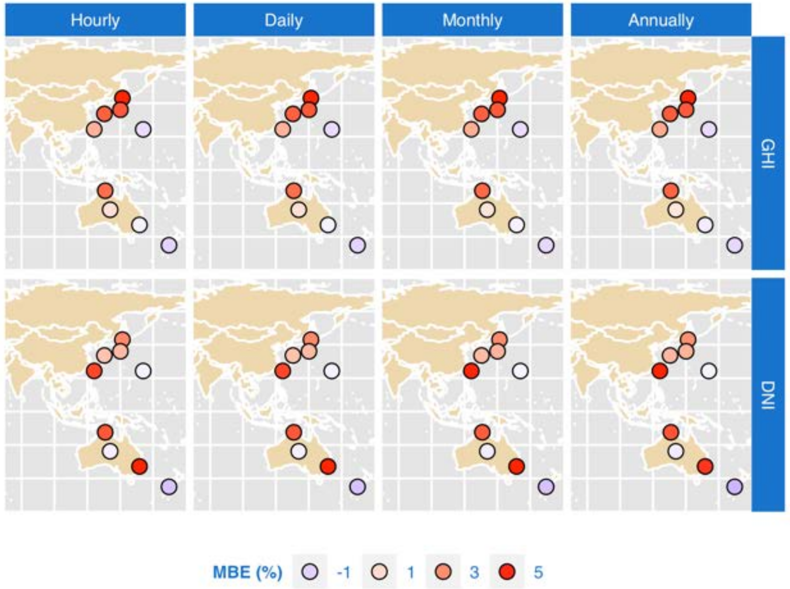
Station name	Abbreviation	Location	Latitude	Longitude	Elevation (m)	Surface type	Topography type	Rural / Urban	Years Used
Alice Springs	ASP	Australia, Northern Territory	-23.798	133.888	547	grass	flat	rural	2015-2018
Darwin Met Office	DWN	Australia	-12.424	130.8925	32	grass	flat	rural	2015-2018
Fukuoka	FUA	Japan	33.5822	130.3764	3	asphalt	flat	urban	2015-2019
Ishigakijima	ISH	Japan	24.3367	124.1644	5.7	asphalt	flat	rural	2015-2019
Lauder	LAU	New Zealand	-45.045	169.689	350	grass	flat	rural	2015-2019
Minamitorishima	MNM	Japan, Minami-Torishima	24.2883	153.9833	7.1	water (ocean)	flat	rural	2015-2019
Newcastle	NEW	Australia	-32.8842	151.7289	18.5	grass	hilly	urban	2017-2018
Sapporo	SAP	Japan	43.06	141.3286	17.2	asphalt	flat	urban	2015-2019
Tateno	TAT	Japan	36.0581	140.1258	25	grass	flat	urban	2017-2019



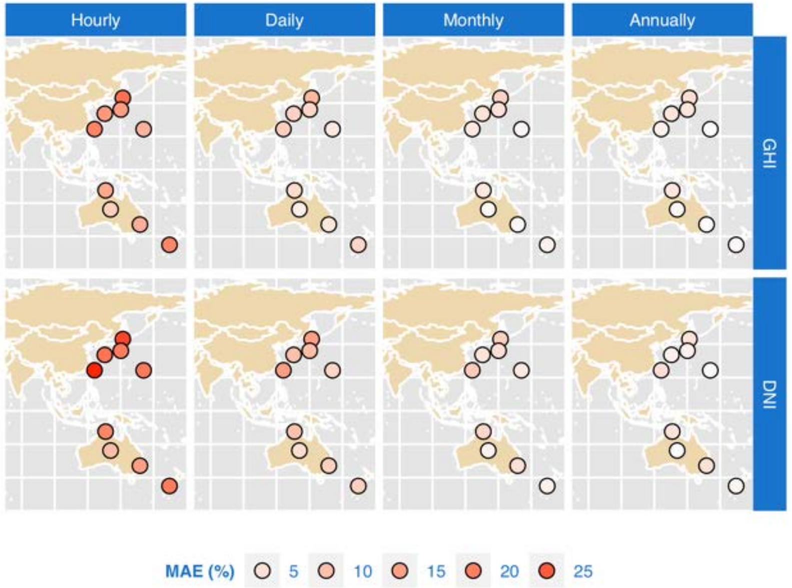
Map showing BSRN locations use for Himawari 8 validation. Illustration by Aron Habte, NREL

Himawari 8* Data Validation Results

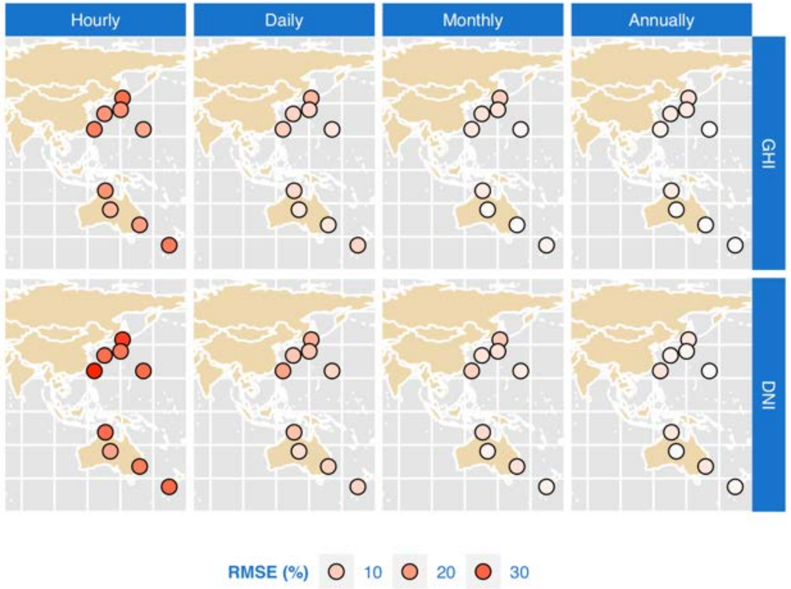
Mean Biased Error (MBE)



Mean Absolute Error (MAE)



Root Mean Squared Error (RMSE)



MBE describes overall the average direction (positive or negative) and magnitude of error in model estimates. MAE measures absolute magnitude of error without indicating direction. RMSE also describes the absolute magnitude of error but is more sensitive to large errors. A greater difference between RMSE and MAE indicates higher variance among the individual errors.

Figures by Aron Habte, NREL

* Covering 2016–2019, 2-km, 10-minute resolution

Key Takeaways:

- MBE for GHI and DNI are below +/- 5% with a tendency to overestimate irradiance overall. MBE is consistent across timeframes (hourly to annual).
- MAE and RMSE show higher error at hourly, and lower error at annual, time steps. MAE and RMSE agree closely across time steps, suggesting relatively low variance among individual errors.

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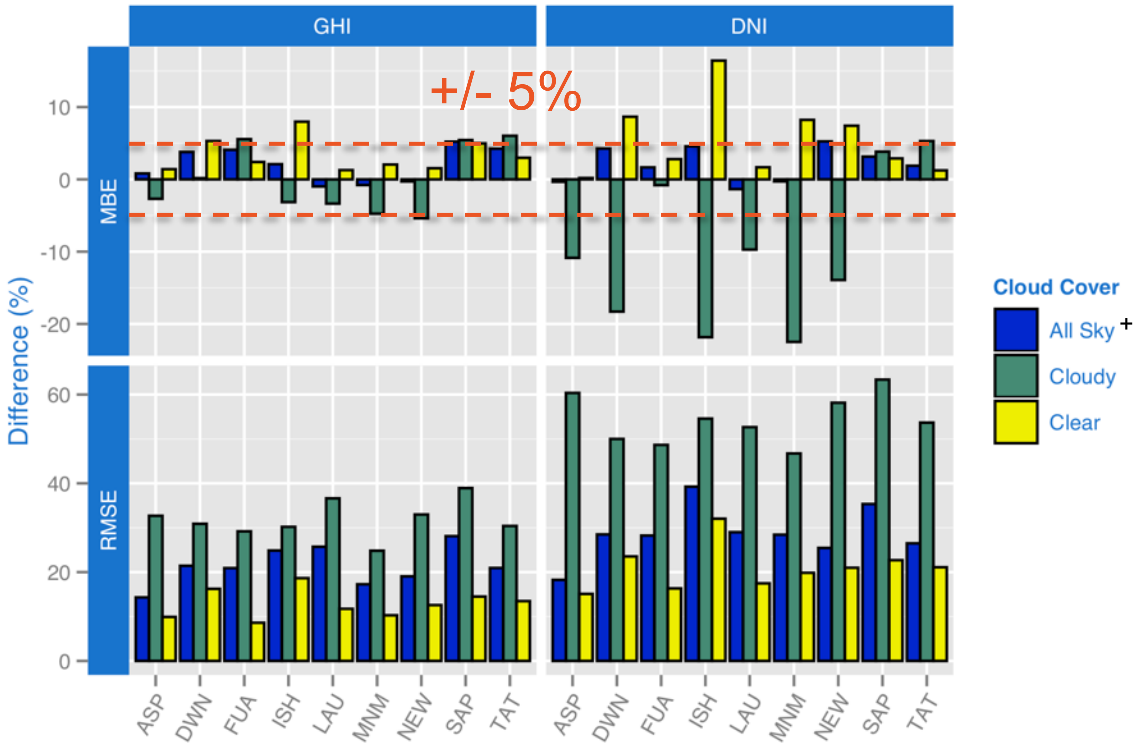
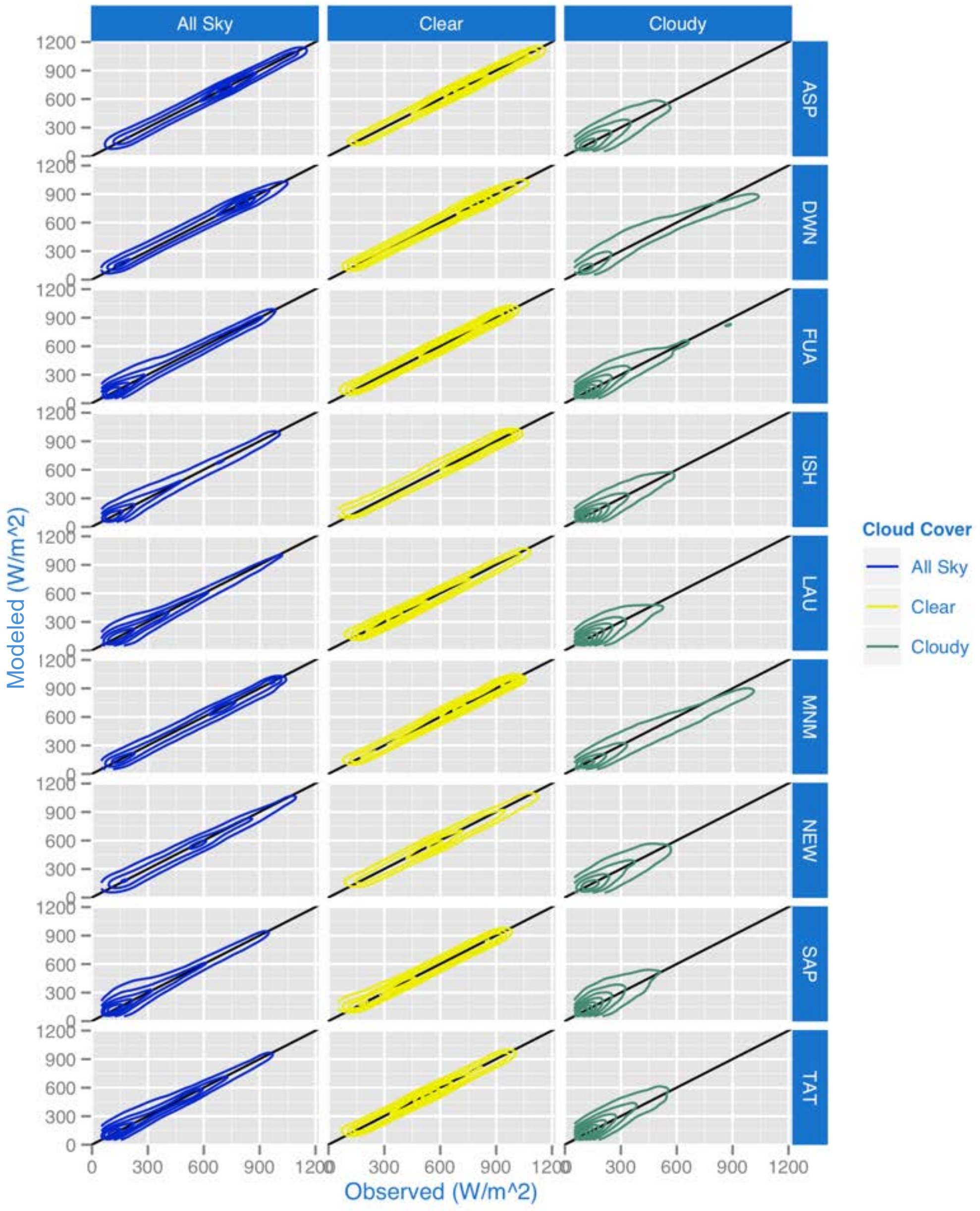
Himawari 8* Data Validation Results





Key Takeaways:

- MBE for all sky conditions are below +/- 5% with a tendency to overestimate GHI and DNI overall. Cloudy conditions have the highest uncertainty, which results in larger, negative errors for DNI estimates.
- Errors (right figure) are approximately normally distributed with the widest spread in cloudy conditions.

Figures by Aron Habte, NREL

* Covering 2016–2019, 2-km, 10-minute resolution.

+ All Sky captures clear, cloudy, and partially cloudy sky conditions.

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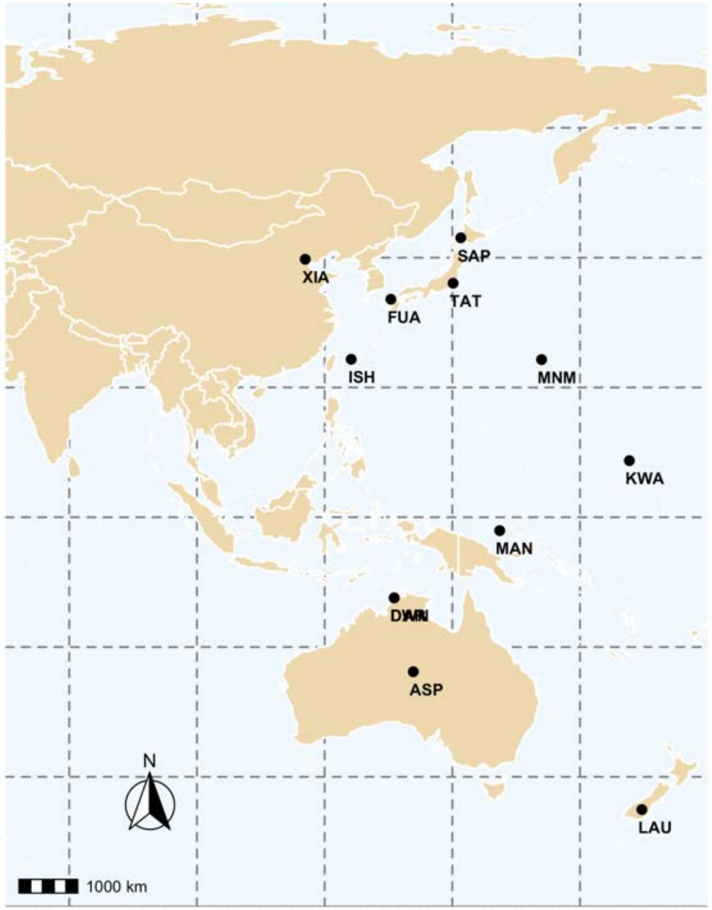
Himawari 7 Data Validation Results

Summary of measurement data used for Himawari 7 (2011–2015, 4-km, 30-minute resolution)

Station name	Abbreviation	Location	Latitude	Longitude	Elevation (m)	Surface type	Topography type	Rural / Urban	Years Used
Alice Springs	ASP	Australia, Northern Territory	-23.798	133.888	547	grass	flat	rural	2011-2015
Darwin	DAR	Australia	-12.425	130.891	30	grass	flat	rural	2011- Jan 2015
Darwin Met Office	DWN	Australia	-12.424	130.893	32	grass	flat	rural	2011-2015
Fukuoka	FUA	Japan	33.5822	130.376	3	asphalt	flat	urban	2011-2015
Ishigakijima	ISH	Japan	24.3367	124.164	5.7	asphalt	flat	rural	2011-2015
Kwajalein	KWA	Marshall Islands	8.72	167.731	10	water, ocean	flat	rural	2011-2015
Lauder	LAU	New Zealand	-45.045	169.689	350	grass	flat	rural	2011-2015
Momote	MAN	Papua New Guinea	-2.058	147.425	6	grass	flat	rural	2011-2013
Minamitorishima	MNM	Japan, Minami-Torishima	24.2883	153.983	7.1	water (ocean)	flat	rural	2011-2015
Sapporo	SAP	Japan	43.06	141.329	17.2	asphalt	flat	urban	2011-2015
Tateno	TAT	Japan	36.0581	140.126	25	grass	flat	urban	2011-2015
Xianghe	XIA	China	39.754	116.962	32	desert, rock	flat	rural	2011-OCT 2015



Map showing BSRN locations use for Himawari 7 validation. Illustration by Aron Habte, NREL

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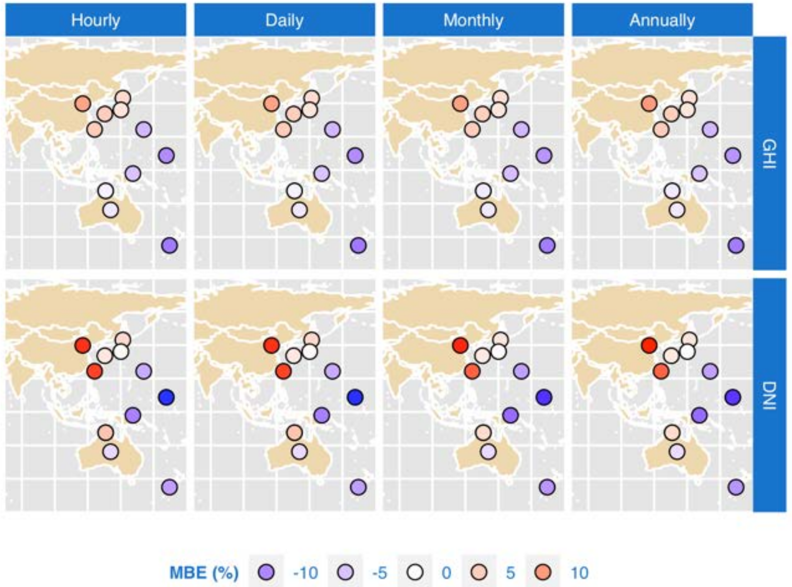
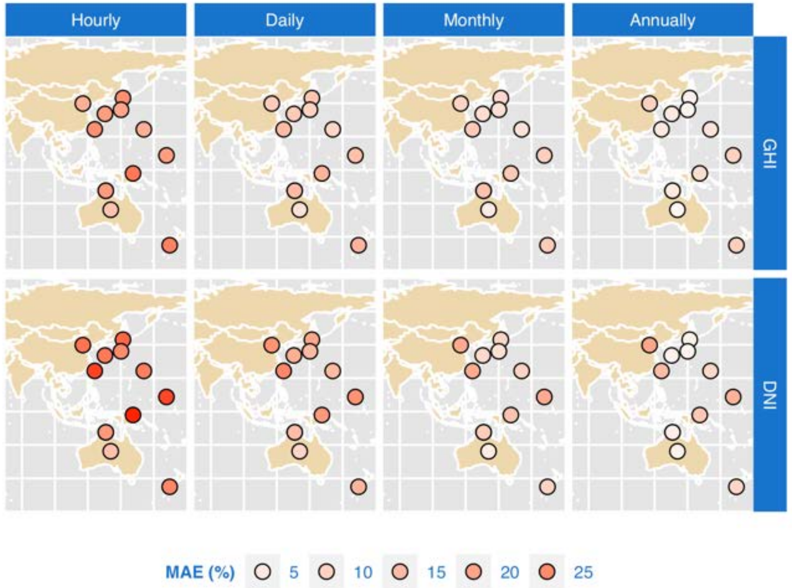
Himawari 7* Data Validation Results

Mean Biased Error (MBE)



MBE describes overall the average direction (positive or negative) and magnitude of error in model estimates. MAE measures absolute magnitude of error without indicating direction. RMSE also describes the absolute magnitude of error but is more sensitive to large errors. A greater difference between RMSE and MAE indicates higher variance among the individual errors.

Mean Absolute Error (MAE)



Figures by Aron Habte, NREL

* Covering 2011–2015, 4-km, 30-minute resolution

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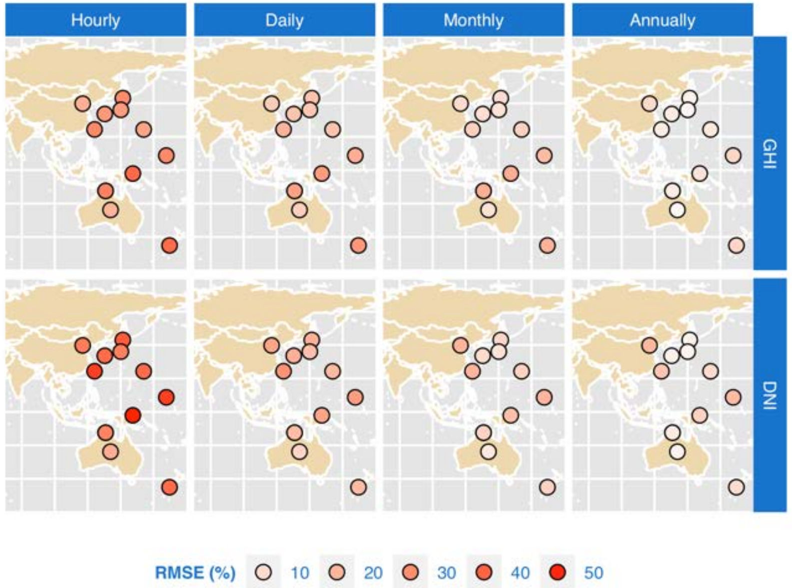
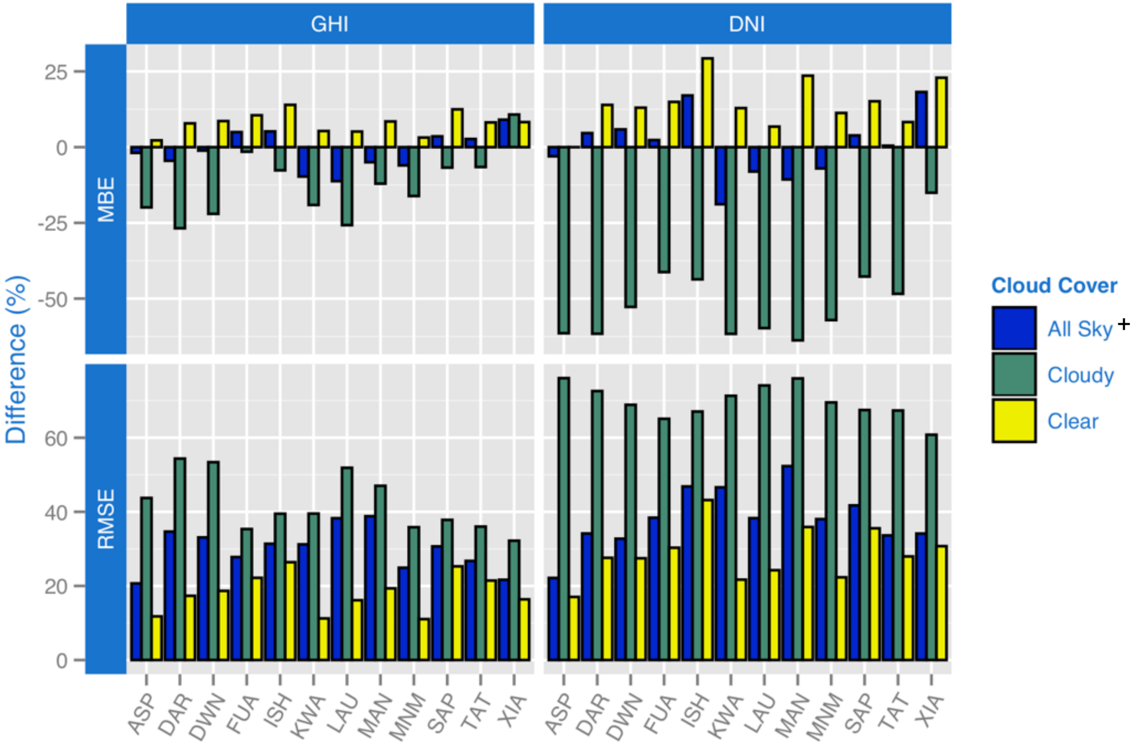
Root Mean Squared Error (RMSE)

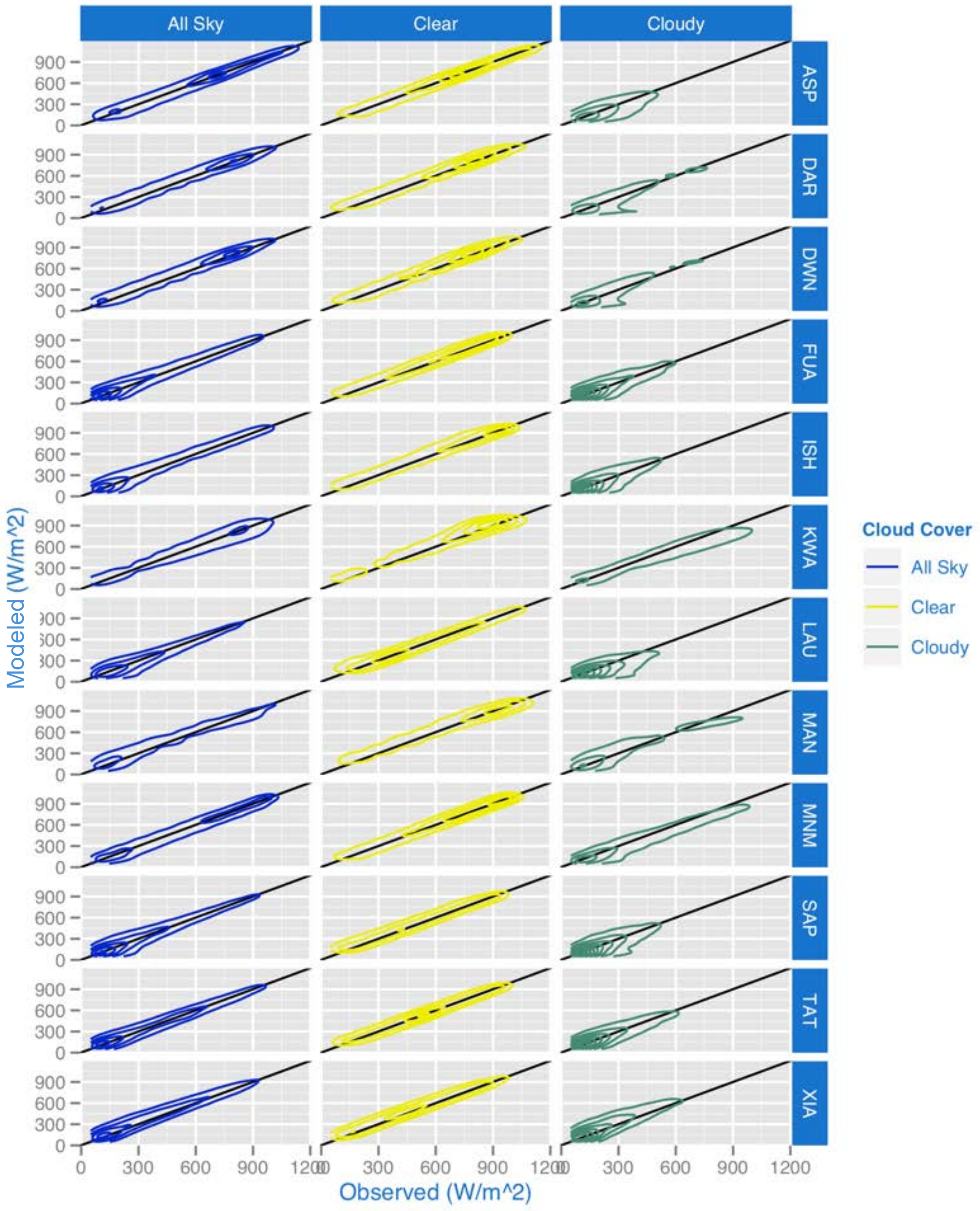


Key Takeaways:

- MBE for GHI and DNI are higher than with Himawari 8 but are more evenly distributed around 0.
- MAE and RMSE show similar trends as with Himawari 8, but with higher magnitude of error.
- Higher error is expected for an older satellite with lower spatial resolution.

Himawari 7* Data Validation Results





Key Takeaways:

- MBE for all sky conditions are generally below +/- 10% with GHI and DNI centered around 0 overall. Cloudy and clear conditions are consistently biased negative and positive, respectively.
- Errors (right figure) are approximately normally distributed with the widest spread in cloudy conditions. Distributions are wider than with Himawari 8.

* Covering 2011–2015, 4-km, 30-minute resolution.

+ All Sky captures clear, cloudy, and partially cloudy sky conditions.

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Figures by Aron Habte, NREL

Model Validation Key Takeaways

- Validation shows strong correlation with ground measurements.
- The levels of accuracy reported here meet or exceed expectations for global modeled solar radiation data sets.
- Himawari 8 had an annual MBE for GHI typically less 5% for all sky (clear and cloudy conditions).
- Himawari 7 is an older satellite with lower resolution and fidelity of the imagery, which resulted in higher all-sky MBE.

Mean Biased Error (MBE) for Himawari 8

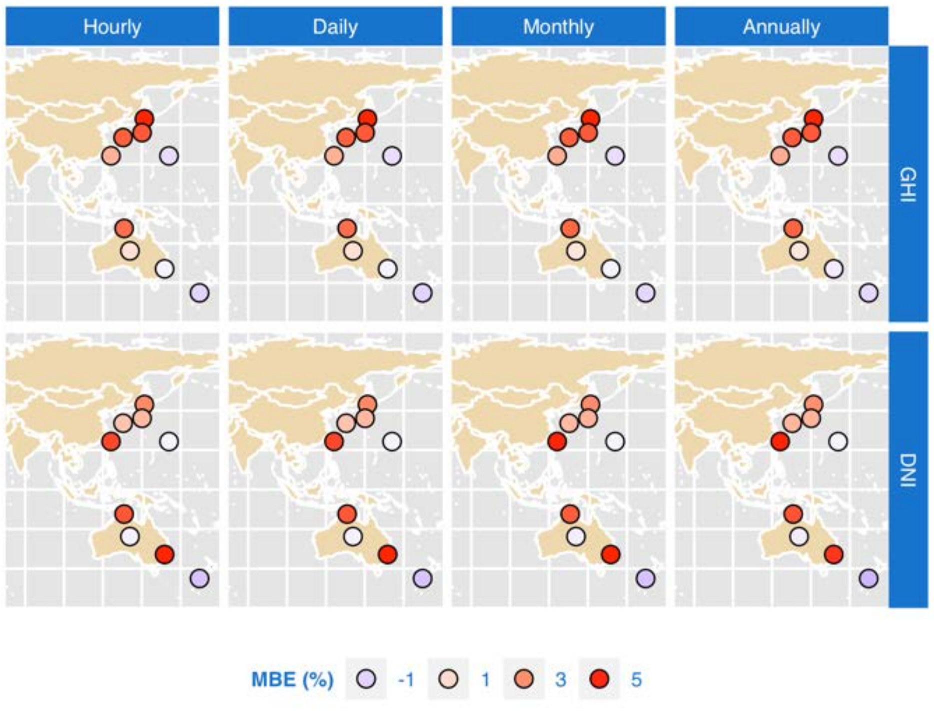

Figure by Aron Habte, NREL

Data Access and Download

The updated RE Data Explorer provides access to this new data set.

- A user-friendly geospatial analysis tool for analyzing renewable energy potential and informing decisions.

www.re-explorer.org

- Performs visualization and analysis of renewable energy potential that can be customized for different scenarios.
- Repository for download of high-quality data and integration with other analytic tools.
- Supports prospecting, integrated planning, policymaking, and other decision-making activities to accelerate renewable energy deployment.

Additional Data Download Options

In addition to the RE Data Explorer (www.re-explorer.org), we provide three other data download options:

1. Data for point locations or small areas can be downloaded through the NSRDB Data Viewer (https://maps.nrel.gov/nsrdb-viewer/).
2. NREL provides an Application Programming Interface (API) to access larger quantities of data through automated approaches (https://nsrdb.nrel.gov/data-sets/api-instructions.html).
3. NREL also provides access through the Highly Scalable Data Service (HSDS) hosted on Amazon Web Services (https://nsrdb.nrel.gov/data-sets/nsrdb-data-hsds-demo.html).

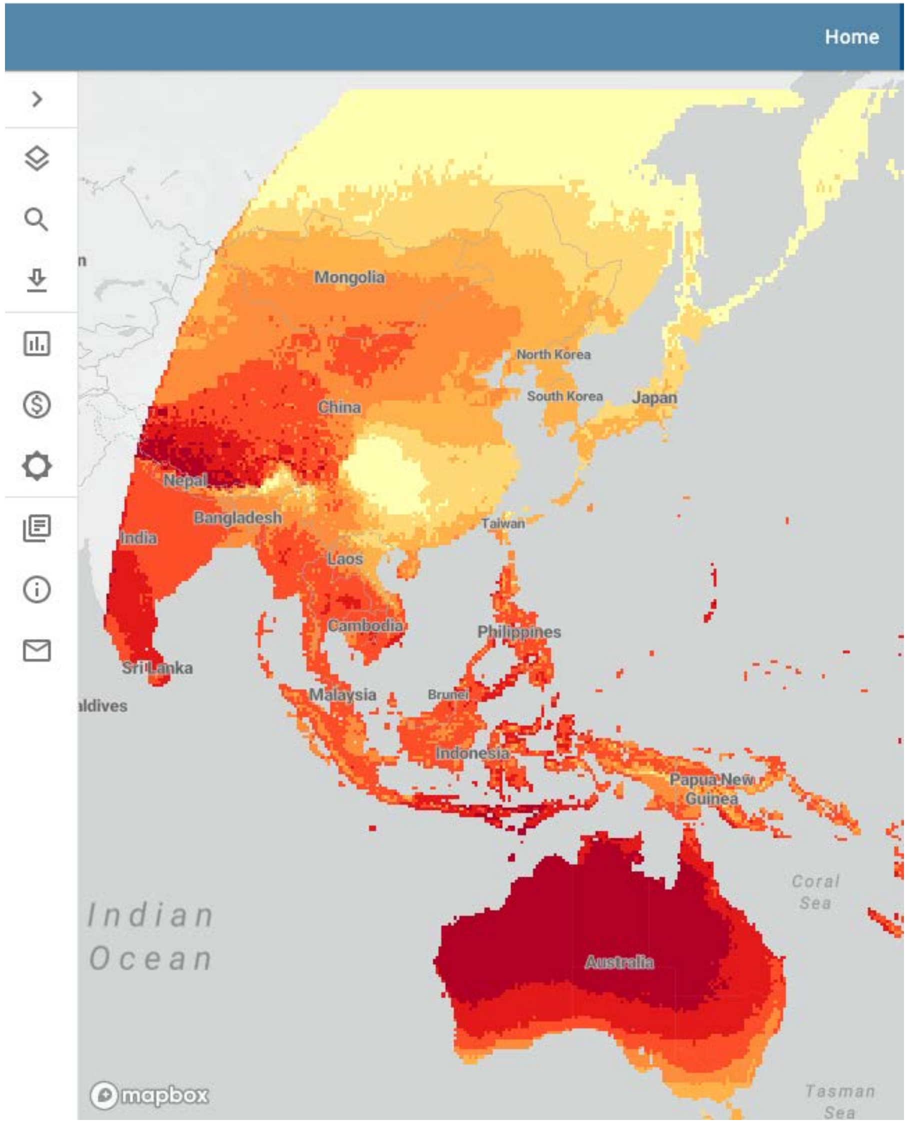

Image from www.re-explorer.org

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Specifically, we thank Dr. Tassos Golnas, technology manager for the Systems Integration team of the DOE, Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Office.

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We thank the BSRN for making high-quality solar radiation data available, because these were crucial for validation efforts. We also thank the National Ice Center for making the IMS data available, and Professor Crystal Schaaf and her team from the University of Massachusetts for developing the MODIS products of surface albedo.

Finally, we appreciate the tireless efforts of NREL's High-Performance Computing and Cloud teams, whose members provided us with the computing resources and cloud architecture to produce and disseminate the data.

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Thank you!

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