Development and Validation of Southeast Asia Solar Resource Data

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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.

**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

Floating PV array on a water retention pond. Photo by Dennis Schroeder, NREL
High-Quality Data for Decisions

Analyses
- mapping and visualization
- systems generations and cost analysis
- technical potential
- capacity expansion
- production cost modeling

High-Fidelity Solar Data

Decisions
- renewable energy target setting
- investment and finance
- early-stage prospecting
- long-term energy planning
- grid integration and system operation

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., CO₂, O₃, H₂O) 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)

**Data Sources**
- **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.

**Model Inputs**
- **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.

**Radiative Transfer Model**
- **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 \( \cdot \) cosine (Solar Zenith Angle).

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

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

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/

BSRN measurement locations within Himawari satellite extent. Illustration by Billy Roberts, NREL
Himawari 8 Data Validation Results

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

<table>
<thead>
<tr>
<th>Station name</th>
<th>Abbreviation</th>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
<th>Surface type</th>
<th>Topography type</th>
<th>Rural / Urban</th>
<th>Years Used</th>
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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.

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.

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

Figures by Aron Habte, NREL
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.

* Covering 2016–2019, 2-km, 10-minute resolution.
* All Sky captures clear, cloudy, and partially cloudy sky conditions.

Figures by Aron Habte, NREL
## Himawari 7 Data Validation Results

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

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**Mean Biased Error (MBE)**

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**Mean Absolute Error (MAE)**

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.

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

Figures by Aron Habte, NREL
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.
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.

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.
- 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.

www.re-explorer.org
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).
References


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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.
Thank you!

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Advanced Energy Partnership for Asia

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