Assessing Uncertainty in Solar Measurements: Key Findings From NLR's SUNI Application Across 89 Stations

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Abstract

- Accurate solar irradiance data are essential for assessing the feasibility and performance of solar energy systems.
- Despite high standards in networks such as the Baseline Surface Radiation Network (BSRN), Atmospheric Radiation Measurement (ARM), and Solar Radiation Research Laboratory (SRRL), data reliability is often compromised by radiometer types, environmental factors, and maintenance gaps.
- Unquantified uncertainties lead to financial and operational risks in solar energy projects that depend on such solar resource assessments.
- The Solar Uncertainty Integrator (SUNI) is a Python-based tool that quantifies measurement uncertainty for global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI) according to the international Guide to the Expression of Uncertainty in Measurement (GUM).
- It accounts for both hardware performance (radiometer specs) and site-specific operational conditions.
- It has demonstrated efficacy using high-frequency (1-minute) data sampled from 80+ global stations.

Method

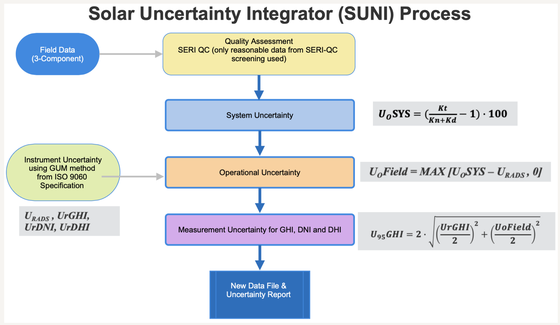
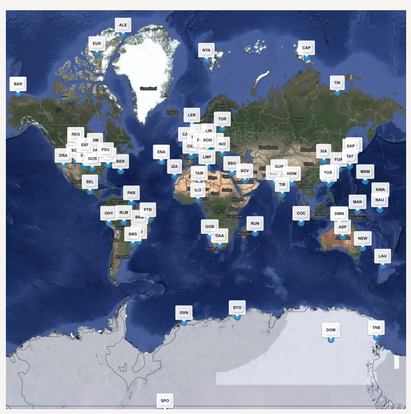


Figure 1. Flowchart of the SUNI process

- SUNI inherent radiometer uncertainty: This is determined by the specific sensor technology and design of the radiometer, categorized according to its ISO 9060 classification.
- Calibration uncertainty: This value represents the calibration uncertainty of the device as established by the manufacturer or service provider under strictly controlled laboratory conditions.
- Operational uncertainty: This reflects the real-world variability caused by installation, maintenance, and weather, and it is calculated by checking the internal consistency of the GHI, DNI, and DHI measurements.
- Inputs: GHI, DNI, and DHI
- Quality control + consistency checks
- Time-resolved uncertainty outputs.

SUNI is publicly available at: https://github.com/NatLabRockies/SUNI.

Sites



Data from 89 stations were analyzed using SUNI:

- National Laboratory of the Rockies (NLR) SRRL
- World Meteorological Organization (WMO) BSRN
- U.S. Department of Energy (DOE) ARM network.

Application and Key Findings

- SUNI does not operate in isolation. Its accuracy heavily depends on a data quality assessment tool—**NLR's SERI QC**.
- SUNI transforms data quality flags into quantitative uncertainty, enabling a continuous and physically consistent assessment of solar measurement reliability.
  - Data quality screening ➔ Flagging and filtering ➔ SUNI process

Data Quality Screening Using NLR's SERI QC and ARM's QCRAD Methods

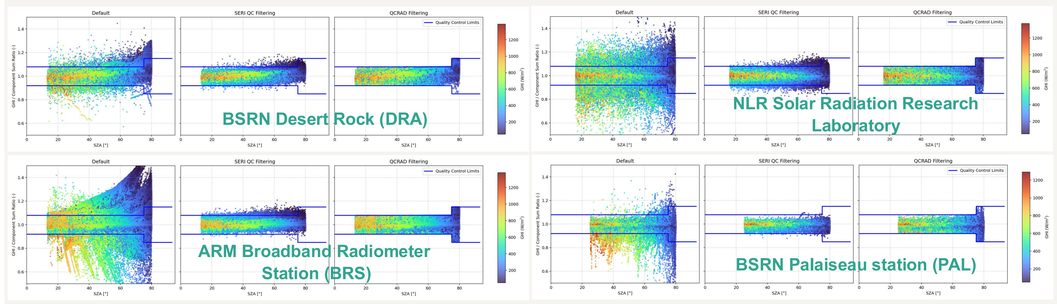


Figure 2. Example of filtering data using data quality assessment tools

- The study employed the BSRN's QCRAD quality control method (Figs. 2–4).
- These figures show unfiltered, SERI QC and QCRAD-filtered data for comparison.
- These methods were toggled on and off in the analysis to ascertain the impact on the uncertainty results (Figs. 3–4).

Uncertainty Results

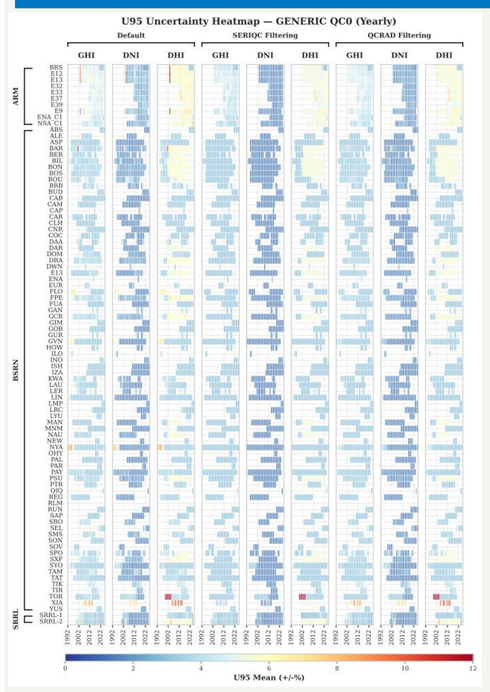


Figure 3. Uncertainty analysis result for all sites

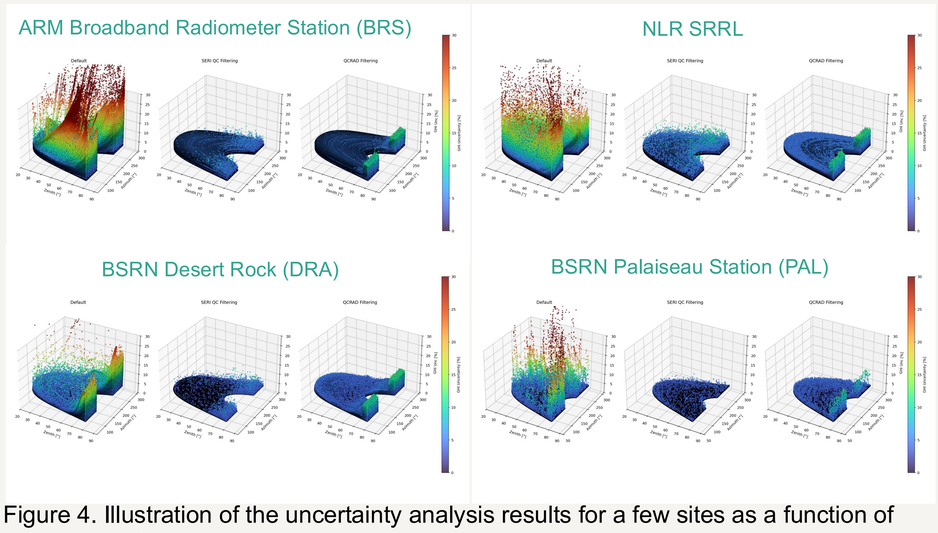


Figure 4. Illustration of the uncertainty analysis results for a few sites as a function of solar geometry

Site	Station	GHI U95 Mean (%)	DNI U95 Mean (%)	DHI U95 Mean (%)	GHI U95 Mean with SERI QC Filtering (%)	DNI U95 Mean with SERI QC Filtering (%)	DHI U95 Mean with SERI QC Filtering (%)	GHI U95 Mean with QCRAD Filtering (%)	DNI U95 Mean with QCRAD Filtering (%)	DHI U95 Mean with QCRAD Filtering (%)
ARM	BRS	4.45	2.50	5.46	3.49	1.43	4.40	3.91	1.75	4.91
BSRN	DRA	3.44	2.01	5.75	2.90	1.31	5.34	3.28	1.57	5.49
BSRN	PAL	2.94	1.35	2.94	2.90	1.30	2.90	2.91	1.31	2.91
SRRL	SRRL-1	3.16	1.67	2.99	2.89	1.36	2.79	3.03	1.47	2.82

Summary

- The SUNI study was developed by NLR to provide a standardized "bulk uncertainty processing" method for solar irradiance data, which is essential for the successful deployment of solar energy systems.
- SUNI calculates uncertainty based on:
  - Radiometer measurement performance and calibrations
  - Detected environmental effects
  - General operational uncertainties.
- SUNI assumes "best practices" in station design and maintenance. It is not designed to provide accurate estimates for data from poorly maintained or improperly installed measurement stations.
- Testing at well-maintained sites shows that almost all measurable uncertainty at these stations is directly attributable to the radiometers themselves.
- The tool is available as a stand-alone application for Windows and Mac or as a Python package for integration into other software.
- It has been successfully used to estimate long-term uncertainty for major networks, including the NLR SRRL, the DOE ARM, and the WMO BSRN.
- It is one of two candidate software tools to be implemented for the BSRN network.

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