Application of Solar Uncertainty Integrator (SUNI) Software to ARM Solar Radiation Measurements

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Abstract

- Reliable solar irradiance data is essential for various applications, especially in the analysis of radiative forcing.
- The Atmospheric Radiation Measurement (ARM) program offers high-quality radiometric data, but the data's integrity is significantly influenced by factors like the type of radiometer used, calibration procedures, installation practices, and operational maintenance, all of which can introduce uncertainty.
- Assessing measurement uncertainty is critical, and NREL has created the Solar Uncertainty Integrator (SUNI) [1] software that complies with the globally recognized *Guide to the Expression of Uncertainty in Measurement* (GUM).
- The SUNI software is tailored to incorporate data quality assessments and measurement uncertainty estimates for global horizontal, direct normal, and diffuse horizontal irradiance data.
- This software processes data at intervals of 1 to 60 minutes, offering an intuitive interface that accounts for various factors affecting data quality at specific sites.
- The SUNI software has been developed in the Python and C++ programs for use in command line interface and a graphical user interface.
- NREL has implemented this method on the 1-minute ARM irradiance measurements.

Method

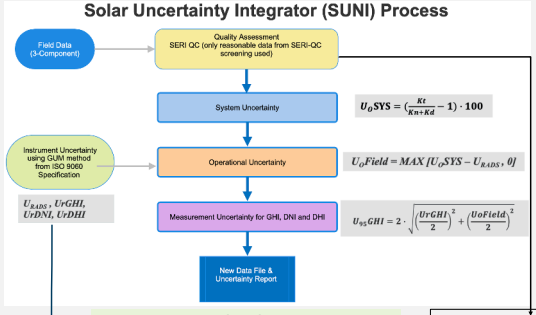
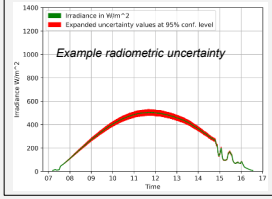


Figure 1: Flowchart of the SUNI process.

- Developed SUNI software package that provides a method to assign expanded uncertainty estimates to three-component measured solar radiation data.
- The system merges static uncertainty information about radiometer performance with the dynamic operational uncertainty information extracted from the data quality assessment.

Instrument Uncertainty



- Calibration
- Spectral error
- Zenith angle
- Temperature dependence
- Nonlinearity
- Aging
- Etc.

Figure 2: Example radiometric uncertainty.

Data Quality Assessment Using SERI QC

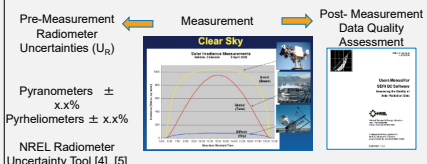
A well-established automated method based on the fraction of normal incidence extraterrestrial irradiance (ETRN) [2]
https://www.nrel.gov/docs/legosti/old/5608.pdf

Variable	Definition
K_t	Global / [ETRN * cos (Z)]
K_n	Direct / ETRN
K_d	Diffuse / [ETRN * cos(Z)]
Z	Solar zenith angle

SERI QC performs the initial evaluation of the incoming data for uncertainty analysis, and its flags provide filtering for suitable data (only three-component data that pass routine checks).

Approach

Integrate the results from instrument uncertainty estimates and automated data quality assessments consistent with the GUM [3].



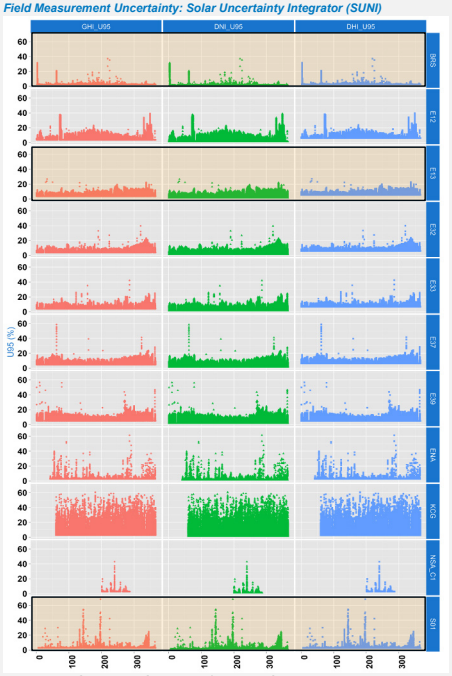
Limitation

The system is designed to accurately evaluate data acquired using best practices[1] for solar measurements. It is not intended to evaluate data from neglected or substandard stations.

- Additional limitations:
  - Requires three-component data (GHI, DNI, DHI)
  - Cannot evaluate at very low irradiance (DNI < 25 W/m^2)
  - Filters out data with blatant errors (high SERI QC flags)
  - Will not evaluate data at high zenith angles (near sunrise/sunset).
- The process works well for the high irradiance.

Results

Field Measurement Uncertainty: Solar Uncertainty Integrator (SUNI)



- BRS, E13, and S01 are collocated stations, but E13 is equipped with Eppley radiometers that demonstrate relatively higher overall uncertainty compared to S01, which is equipped with Hukseflux radiometers, and BRS, which is equipped with Kipp & Zonen radiometers.
- Similar to E13, the remaining ARM's Southern Great Plains (SGP) Extended Facilities (EFs)—such as E12, E32, E33, E37, and E39—are equipped with Eppley radiometers.
- Similar to S01, ENA, NSA, and KCG are equipped with Hukseflux radiometers.
- NSA has a limited amount of data after the radiometer upgrade.
- The atmospheric and environmental conditions at the KCG location are difficult for collecting high-quality radiometric data. This is clearly illustrated in the scatter plot. The uncertainty is higher when compared to other locations with the newly deployed Hukseflux radiometers.

Figure 3: Field measurement uncertainty for the 11 active ARM stations using the 2024 dataset. Note: The x-axis is day of the year.

Table 1. Summary Statistics for Each Constituent Parameter in the Uncertainty Process and the Final U_{95}GHI Values.

Stations	Statistical Metrics			
	U_R GHI (Instrument Uncertainty)	U_{95} GHI (Instrument Uncertainty + Operational Uncertainty)	U_{95}GHI Exceeds U_RGHI (%)	Instrument Manufacturer
BRS	2.4	2.43	1.6	Kipp & Zonen
E13	3.7	4.24	32	Eppley
S01	2.9	2.98	4.7	Hukseflux
E12	3.7	4.35	21	Eppley
E32	3.7	4.37	37.8	Eppley
E33	4	4.52	28.6	Eppley
E37	4.7	5.28	25.9	Eppley
E39	4.9	5.67	32.7	Eppley
ENA	2.7	2.83	8	Hukseflux
KCG	2.8	10.86	76.7	Hukseflux
NSA C1	2.8	3	9.6	Hukseflux

- Table 1 provides insights about the overall uncertainties of the sites. These uncertainties are dependent on the instrument type, environmental conditions, and instrumentation performance at each site.
- The KCG station contains the new Hukseflux radiometers; however, the location has difficult environmental/ meteorological conditions. These conditions are responsible for the higher uncertainty depicted in Table 1.
- The BRS site is equipped with Kipp & Zonen radiometers. Relatively, it shows the lowest uncertainty; however, this could be partially a result of regular maintenance of the station because it is located at the SGP central facility.

Reference

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