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A Method to Estimate Uncertainty in Radiometric Measurement Using the Guide to the Expression of Uncertainty in Measurement (GUM) Method

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Abstract

Radiometric data with known and traceable uncertainty is essential for climate change studies to better understand cloud radiation interactions and the earth radiation budget. Further, adopting a known and traceable method of estimating uncertainty with respect to SI ensures that the uncertainty quoted for radiometric measurements can be compared based on documented methods of derivation. Currently, most radiometric data users rely on manufacturers' specifications of calibration uncertainty to quantify the uncertainty of measurements. However, the accuracy of solar radiation measured by radiometers depends not only on the specifications of the instrument but also on (a) calibration procedure, (b) measurement setup and maintenance, and (c) location and environmental conditions [1]. Therefore, statements about the overall measurement uncertainty can only be made on an individual basis, taking all relevant factors into account. This poster provides guidelines and recommended procedures for estimating the uncertainty in calibrations and measurements from radiometers. The approach follows the Guide to the Expression of Uncertainty in Measurement (GUM)[2].

Traceability Chain of Radiometric Measurements

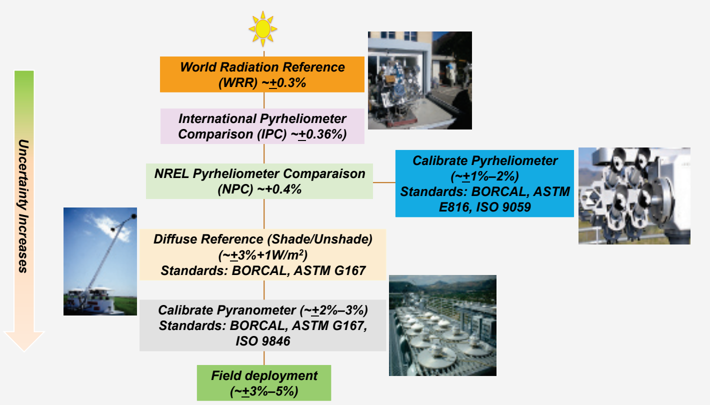

Figure 1: Traceability chain of radiometric data and associated measurement uncertainty level

Method

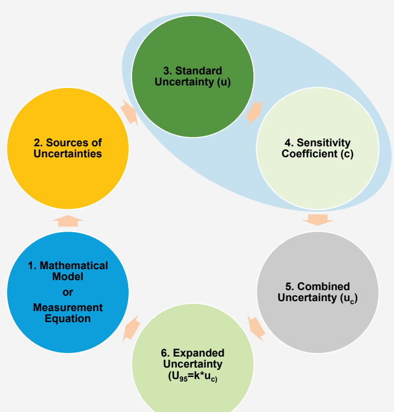

Figure 2: Steps for measurement uncertainty estimation using the GUM method

Measurement Equation—Step 1

$$G = \frac{(V - R_{net} * W_{net})}{R}$$

where:

G = global solar irradiance in watts per square meter (Wm⁻²)

V = thermopile output voltage in microvolts (μV)

R_{net} = net longwave responsivity estimated or determined by blackbody characterization in μV/(Wm⁻²)

W_{net} = net longwave irradiance measured by a collocated pyrgeometer in W/m⁻²

(Pyrgeometers are radiometers that measure atmospheric longwave irradiance.)

R = responsivity determined by calibration in μV/(Wm⁻²).

Sources of Measurement Uncertainties—Step 2

In field deployments, identify sources of uncertainties related to the variables in the measurement equation *(V, R_{net}, W_{net}, and R)* such as those due to,

- Calibration (R), spectral response (R), zenith angle (R), maintenance—soiling (dust, rain, bird droppings, etc.) (R), data logger uncertainty (V), temperature dependence (R), nonlinearity (R), aging (R), etc.

Quantifying Standard Uncertainty—Step 3

Example of Measurement Sources of Uncertainty for Pyranometers

Uncertainty Component	Quantity	Statistical Distribution	Uncertainty Type	Standard Uncertainty (u)	Expanded Uncertainty (U)*
Calibration	R	Normal	Type B	$\frac{U}{1.96} = 2.87\%$	5.62% (calibration done at 45 degrees)
Zenith Response	R	Rectangular	Type B	$\frac{U}{\sqrt{3}} = 1.15\%$	2% (calibration done at 45 degrees)
Spectral Response	R	Rectangular	Type B	$\frac{U}{\sqrt{3}} = 0.58\%$	1% (calibration done at 45 degrees)
Nonlinearity	R	Rectangular	Type B	$\frac{U}{\sqrt{3}} = 0.29\%$	0.5%
Temperature Response	R	Rectangular	Type B	$\frac{U}{\sqrt{3}} = 0.29\%$	1%
Aging per Year	R	Rectangular	Type B	$\frac{U}{\sqrt{3}} = 0.58\%$	1%
Data Logger Accuracy	V	Rectangular	Type B	$\frac{U}{\sqrt{3}} = 5.77uv$	10 μV
Maintenance	R	Rectangular	Type B	$\frac{U}{\sqrt{3}} = 0.17\%$	0.3%

Type B uncertainties—Method of evaluation of a standard uncertainty by means other than the statistical analysis of a series of observations

Type A uncertainties—A standard uncertainty is **derived from measurements** using the statistical analysis of a series of observations, e.g., standard deviation

Note: In the GUM method, when the distribution of the uncertainty is not known, it is common to assume a rectangular distribution.

Sensitivity Coefficient Calculations—Step 4

Use the partial derivative for each variable in the measurement equation to obtain the sensitivity coefficient.

Example: Field Measurement Sensitivity Equations
e.g., sensitivity coefficient of R

Measurement Equation

$$G = \frac{(V - R_{net} * W_{net})}{R}$$

$$c_R = \frac{\partial G}{\partial R} = \frac{-(V - R_{net} * W_{net})}{R^2}$$

Combined Uncertainty—Step 5

The standard uncertainty (*u*) and sensitivity coefficients (*c*) are combined using the root sum of the squares method to calculate the combined uncertainty.

$$u_c = \sqrt{\sum_{i=0}^{n-1} (u_i * c_i)^2}$$

Expanded Uncertainty (U_{95})—Step 6

The expanded uncertainty (U_{95}) is calculated by multiplying the combined uncertainty (u_c) by a coverage factor (*k*=1.96, for infinite degrees of freedom), which represents a 95% confidence level, in W/m².

$$U_{95} = u_c * k$$

The expanded uncertainty (U_{95}) as a percentage is then calculated as

$$U_{95} = \frac{U_{95}}{\text{Measured Irradiance}} * 100$$

Excel spreadsheet—Radiometric Data Uncertainty Estimate Using GUM Method Link: http://www.nrel.gov/midc/srrl_bms/ and look for Excel uncertainty spreadsheet at the bottom of the page.

Example Methods in Improving Measurement Uncertainty Estimates

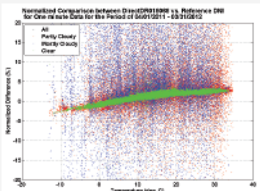

Figure 3: shows temperature dependence of DNI radiometer [3]. This plot will help in confirming the uncertainty value for temperature dependence for that particular instrument (Step 2 and Step 3), and it helps the user to correct this bias due to temperature. Then the overall uncertainty will get reduced.

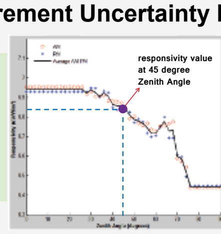

Figure 4:demonstrates the importance and application of an existing but unused approach that ultimately reduces the uncertainty of radiometric measurements. Current radiometric data is based on a single responsivity value that introduces significant uncertainty to the data; however, through using responsivity as a function of solar zenith angle, the uncertainty could be decreased by 50% for some radiometers that have higher zenith dependence [4].

Summary

- Solar resource data with known and traceable uncertainty estimates are essential for climate change studies.
- Identifying and correcting the biases in the radiometric measurement as they apply to each source of uncertainties would assist in reducing the overall measurement uncertainty.
- Adopting such a standardized method will ensure that the uncertainty quoted for data collected by radiometers can be compared based on documented methods of derivation and provide global uniformity and acceptance.

References

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[2] Joint Committee for Guides in Metrology Working Group 1. *Guide to the Expression of Uncertainty in Measurement.* 2008. Accessed March 5, 2015: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf.

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[4] Reda, I. *Method to Calculate Uncertainty Estimate of Measuring Shortwave Solar Irradiance Using Thermopile and Semiconductor Solar Radiometers.* NREL/TP-3B10-52194. Golden, CO: National Renewable Energy Laboratory, 2011; 20 pp.

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