

Practical Calibration Procedures for Solar Radiation Instruments in Algeria

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ABSTRACT

Reliable measurement of solar irradiance forms the cornerstone of performance evaluation and efficiency optimization in solar energy systems. This work outlines a comprehensive, practical methodology for the calibration of solar irradiance sensors, providing a systematic, step-by-step framework to ensure high-quality solar radiation data. The described approach covers instrument selection criteria, proper installation practices, routine maintenance, and calibration procedures using reference standards (ISO 9847). Specific focus is placed on pyranometer calibration through shading and Unshading methods, zero-offset verification, and sensitivity checks. This practical framework outlines the essential procedures for calibrating pyranometers and pyrhemometers used in solar irradiance measurements in Algeria. The study emphasizes the critical importance of regular calibration of solar radiation instruments, highlighting a sensitivity degradation of pyranometers that can reach approximately 4% per decade in regions characterized by harsh climatic conditions.

I. Introduction

Algeria is among the world's most endowed nations in terms of solar energy potential, possessing some of the highest solar irradiation levels globally, particularly within the Mediterranean basin. Its geographic position, especially the vast Saharan territory, provides an exceptional solar resource. Average daily solar irradiation exceeding 5.5 kWh/m² across most of the country and can reach 7 kWh/m² in the southwestern region [1]. Recognizing this strategic advantage, the Algerian government has launched an ambitious renewable energy program, targeting 22,000 MW of installed renewable capacity by 2030, with solar power as the cornerstone of this national energy transition [2], [3].

However, the accurate assessment and harnessing of these vast resources face significant technical challenges. Developing reliable solar energy projects, whether photovoltaic or concentrated solar power, requires precise solar irradiance data with high temporal and spatial resolution. Current assessments in Algeria often rely on satellite-derived data or sparse ground measurements, which may lack the accuracy required for bankable project development and optimal system performance prediction [4].

The Adrar region in southwestern Algeria is a prime example of this potential and its associated challenges. Characterized by extremely high irradiation, minimal cloud cover, and extensive available land, this region has become a focal point for solar research and commercial projects. However, the accurate irradiance measurement in this arid environment presents unique challenges, including dust accumulation, extreme temperatures, and limited technical support infrastructure, factors that can significantly compromise data accuracy if not properly managed [3].

The quality of solar irradiance measurements fundamentally depends on the proper selection, installation, calibration, and maintenance of measurement instruments. High-precision devices such as pyranometers and pyrhemometers require meticulous handling and regular calibration to guarantee data reliability. The World Meteorological Organization (WMO) maintains the World Radiometric Reference (WRR) in Davos, Switzerland, as the global benchmark for solar radiation measurements [5]. Regional centers, like the U.S. National Renewable Energy Laboratory (NREL) and Italy's Joint Research Centre, provide traceable calibrations for national meteorological services. In the Algerian context, where environmental conditions can be particularly demanding, establishing robust measurement protocols becomes even more critical. The absence of standardized procedures and the limited local technical expertise in high-precision solar measurement have been identified as significant barriers to the accurate assessment of the country's solar resource[6].

This article addresses these challenges by presenting a comprehensive practical approach to the measurement and calibration of solar irradiance instruments[7], [8], [9], specifically tailored to the Algerian context. The study builds on field experience gained at the URER/MS research station in Adrar, incorporating lessons learned from operating solar monitoring equipment in Saharan conditions. The proposed framework encompasses the full measurement chain—from instrument selection and installation to maintenance and calibration—while explicitly accounting for the specific environmental constraints' characteristic of Algeria's high-irradiance regions [6], [10], [11], [12], [13].

The importance of this work extends beyond academic interest, as it directly supports Algeria's renewable energy ambitions by providing technical guidance for the establishment of reliable solar monitoring stations. Accurate ground measurements not only validate satellite data but also enable the precise performance assessment of existing solar installations and the optimal design of future projects. Furthermore, the development of local expertise in solar instrument calibration and maintenance contributes to building national capacity in the growing solar energy sector.

This paper is structured as a practical and systematic guide for researchers, engineers, and technicians engaged in solar resource assessment across Algeria. By addressing the operational aspects of solar irradiance measurement with specific context of Algerian environmental conditions, the study aims to enhance the accuracy of national solar resource databases. Ultimately, this contribution supports the effective implementation of Algeria's renewable energy strategy and reinforces the country's emerging role as a regional leader in solar power development.

II. Materials and Methods

The method used in this work is based on experimental calibration of solar radiation instruments using reference Pyranometers and Pyrhemometers. The pyranometers under calibration are part of the meteorological station installed at the Renewable Energy Research Unit in the Saharan Environment (URER/MS), a branch of the Renewable Energy Development Center (CDER) in Algiers. The station is located in Adrar (27.9° N, -0.3° E, 263 m a.s.l.) in southern Algeria, within a typical Saharan desert environment characterized by exceptionally high solar potential and frequent dust events.

II.1. Data and Measurement Stations for under calibration pyranometers

The solar radiation station installed at (URER/MS) in Adrar, is equipped with the following devices:

- Pyranometers (Kipp & Zonen, Type CM11) for GHI measurements.
- Pyrhemometers (Eppley NIP) mounted on solar trackers for DNI.
- Pyranometer equipped with a shadow band/ring assembly for diffuse irradiance (DHI) measurement
- All sensors are connected to a Data logger type fluke 2625 with 1-minute temporal resolution, connected

to the computer by an RS232 cable.

A second automated station, part of the enerMENA network[13], has been operational at URER/MS since 2012. The installation was conducted by Algerian company NEAL in cooperation with CSP Services. it was equipped with:

- Pyranometers CMP 21 with the CVF3 ventilation module
- Pyrhelimeter CHP 1 and a shade assembly, are mounted on an automatic Kipp & Zonen Solys-2 tracker, equipped with GPS guidance with an uncertainty $<0.05^\circ$.
- Data acquisition type CR1000 connect using a modem for GSM connection.

II.2. Data Acquisition and Processing

Solar irradiance measurements were systematically collected, from two primary sources: a permanent station providing a continuous dataset from 2010 to the present, and a complementary automatic measurement campaign conducted from 2013 to 2017 to enhance data reliability. A rigorous quality control and quality assurance (QC/QA) protocol was implemented, combining automated algorithms with manual inspection to identify and flag suspect data [14], [15]. The data validation procedure followed international standards ISO 9060 for solar instrument classification and World Meteorological Organization (WMO) [16] guidelines for meteorological data quality control. Missing values resulting from equipment maintenance or power outages were explicitly documented, while outliers caused by instrumental drift, shading effects, or environmental factors were systematically removed following established statistical thresholds.

Data acquisition process follows the standardized radiometric measurement chain protocol illustrated in Figure 1. All measurements were recorded at one-minute intervals to ensure high temporal resolution.

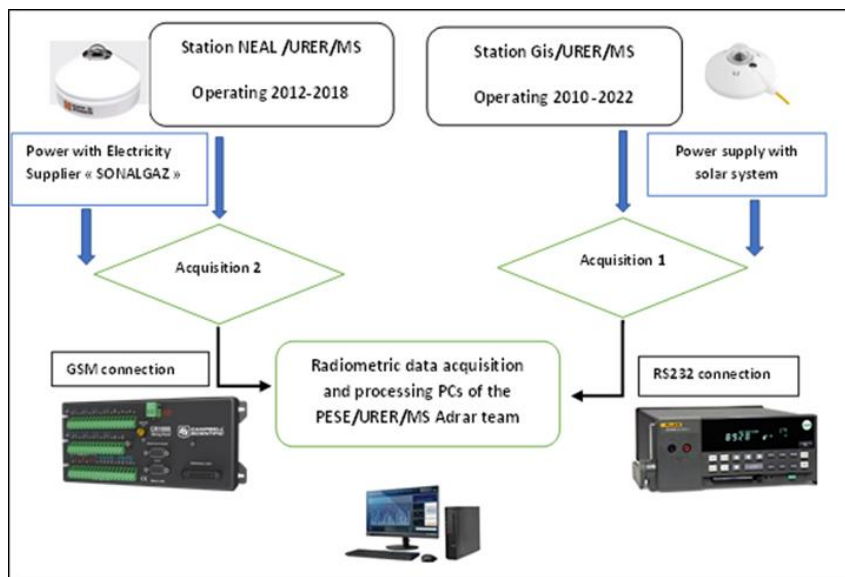


Figure 1. Radiometric measurement chain at URER/MS

The data processing and validation workflow, implements a comprehensive quality assurance protocol combining automated computational methods with systematic visual inspection and daily monitoring of instrumental conditions.

The data processing sequence comprises multiple stages:

- Initial processing employs a Fortran program that filters raw CSV data, eliminating invalid entries and restructuring the dataset into standardized daily files (.dat format) covering exclusively solar exposure periods (sunrise to sunset)

- Secondary processing involves executing a validation algorithm that identifies and rectifies missing data points, systematically replacing null values (-9999) through appropriate gap-filling methodologies.
- The ordinary station (Gis/URER/Ms) (Fig. 2.) conducts comprehensive radiometric assessments including:
- Direct measurement of global solar radiation across multiple geometric planes (horizontal, latitude-tilted, vertical, and variable inclination surfaces)
- Continuous monitoring of diffuse radiation components
- Computational derivation of direct normal irradiance through the established formula (1):
- $$direct = (G_h - Dfh) * \sin(h) \quad (1)$$

where G_h represents global horizontal radiation, Dfh denotes diffuse horizontal radiation, and h indicates solar elevation angle



Figure 2. The ordinary station (Gis/URER/Ms)

Complementarily, the automatic station (NEAL/URER/Ms) (Fig. 3.) performs fundamental radiometric measurements consisting of:

- Global horizontal irradiance quantification.
- Diffuse radiation assessment.
- Direct beam radiation measurement using a dedicated pyrheliometer.



Figure 3. The automatic station (NEAL/URER/Ms) right

II.3. Calibration of Solar Irradiance Instruments

1) Pre-Calibration Phase (Preparation)

Step 1: Pre-Calibration Documentation & Planning

- Review instrument maintenance history and previous calibration certificates.
- Schedule calibration at the regional center of calibration at ONM (Office national de la Meteorologie) in Tamanrasset city 3-6 months in advance.
- Plan for minimum 2-week instrument absence from monitoring station.

Step 2: Pre-Transport Preparation

- Clean optical surfaces using approved methods (distilled water, soft cloth)
- Perform preliminary field checks (zero offset, visual inspection)
- Document current instrument performance baseline.
- Possible spare part for measuring instruments (cable, pyranometer dome)
- Package instruments in original factory containers with shock-absorbing materials.

2) Calibration Execution

Calibration of pyranometers and pyrhemometers was performed using reference instruments traceable to the World Radiometric Reference (WRR) maintained at the PMOD/WRC Davos [17]. Cross-calibration sessions were performed at regional center for calibration of Solar Irradiance Instruments of the National Meteorological Office (ONM) in Tamanrasset (22.8° N, 5.5° E, 1377 m a.s.l.), and at The pyranometer calibration laboratory belonging to CDER (Renewable Energy Development Center) in Algiers (36.8° N, 3° E, 345 m a.s.l.), which is accredited by the Algerian Accreditation Body (ALGERAC) in accordance with the ISO/IEC 17025:2017 standard.

Step 3: Reference Standard Verification

- ONM and CDER technicians verify regional reference standards (Fig. 4.) traceable to WMO at the PMOD/WRC Davos, every 5 years (WMO AHF29225 Standard)[18].



Figure 4. CDER station on the left and WMO AHF29225 regional standard Tamanrasset ONM station on the right

- Confirm environmental and weather conditions meet WMO requirements:
 - Clear sky conditions (cloud cover < 2 oktas).
 - Solar elevation > 30 degrees.
 - Low aerosol optical depth (<0.2).
 - Wind speed < 5 m/s.

Step 4: Pyranometer Calibration Procedure

A. Outdoor Comparison Method:

- Mount test pyranometer alongside reference standard pyranometer or pyrhemometers (Fig. 5.)
- Align both instruments horizontally using precision level.
- Using Shading / Unshading Methods for Pyranometer Calibration with a shading device (like a shading ring or ball).
- Collect simultaneous data for 5-7 consecutive clear days (A thousand values of output voltages are available for reference and test pyranometer).
- Record data at 1-minute intervals from 3 hours before to 3 hours after solar noon.



Figure 5. Outdoor Calibration Method (ONM Tamanrasset)



Figure 6. shading ring

The Shading / Unshading Methods for Pyranometer Calibration is used to calibrate diffuse and global solar radiation measurements by employing either two pyranometers or a single pyranometer equipped with a shading device, such as a shading ring or shading ball (Fig. 6.).

1. Shading Method: The pyranometer is shaded (using a shading ring) so that direct sunlight is blocked. It measures only the diffuse solar irradiance (DHI). This helps determine how much of the solar radiation is scattered by the atmosphere.

2. Unshading Method: In this phase, the shading device is removed, allowing the pyranometer to measure global solar irradiance (GHI), which represents the sum of direct and diffuse components. By comparing the shaded (DHI) and unshaded (GHI) measurements, and using reference instruments or theoretical models, the calibration constant (sensitivity) of the pyranometer can be accurately determined.

B. Calibration Factor Calculation:

In Algeria, two types of calibration are used: one by comparison with a reference pyrhelimeter and the other by comparison with a reference pyranometer:

B1. Comparison with a reference pyrhelimeter

Used in OMM Tamanghasset, the method requiring consistently clear, cloud-free skies.

The Global (G), Direct (I), and Diffuse (D) irradiances are related by the equation:

$$G = I \cdot \sin(h) + D \quad (2)$$

where h represents the solar elevation angle.

To calibrate a pyranometer, simultaneous measurements of the energy irradiances or electrical signals for G, I, and D are required.

- I is measured by the reference pyrhelimeter.
- G and D are measured by recording the output voltages U_G and U_D respectively, delivered by the pyranometer under calibration.

The estimation of the calibration coefficient K for a given global irradiance value is performed in three steps corresponding to three instants t1, t2, t3 (with t3 - t1 $\approx$ 5 minutes):

- I and UD are measured at instant t2.
- U_G is calculated by averaging measurements taken at instants t1 and t3.

The fundamental relationship is derived as follows [19]:

$$G - D = I \cdot \sin(h) \text{ or } \frac{(U_G - U_D)}{K} = I \cdot \sin(h) \quad (3)$$

Therefore, the calibration coefficient K is calculated using:

$$k = \frac{(U_G - U_D)}{I \cdot \sin(h)} \quad (4)$$

Important Note: The pyranometer is shaded by a small sun-blocking disk only at instant t2 to measure the diffuse component. It is also noted that the method used to calculate the solar elevation angle (h) significantly influences the final uncertainty.

B2. Comparison with a reference pyranometer

At the Renewable Energy Development Center (CDER) in Algiers, the reference pyranometer used for the calibration is of the same type as the instrument under test. Unlike previous methods, this approach does not require clear-sky conditions, making it simpler to implement.

The calibration coefficient K is determined as the ratio R between the output voltage U_G of the sensor being calibrated and the output voltage U_R delivered by the reference, where K_R represents the calibration coefficient of the reference instrument[19]:

$$k = \frac{U_G}{G} = \frac{U_G}{U_R} K_R = R \cdot K_R \quad (5)$$

This direct comparison method allows for calibration under various sky conditions, making it more flexible and practical for routine calibration work.

B3. Uncertainty Analysis:

- Calculate standard deviation of daily calibration factors
- Determine expanded uncertainty (typically ± 1.5 -2.5% for secondary standards)

Step 5: Pyrheliometer Calibration Procedure

a. Direct Beam Comparison:

- Mount test pyrheliometer and reference instrument on precision solar tracker
- Ensure precise sun tracking (tracking error $< 0.1^\circ$)
- Collect direct normal irradiance data during peak sun hours

b. Calibration Sequence:

- Perform calibration at multiple solar zenith angles (30° , 45° , 60°)
- Verify angular response characteristics
- Apply air mass correction using Langley plot method when applicable

c. Responsivity Calculation:

Responsivity ($\mu\text{V}/\text{W}/\text{m}^2$) = (Output Voltage) / (Direct Normal Irradiance)

3) Post-Calibration Phase

Step 6: Certification and Documentation

The calibration certificate (Fig. 7.) contain:

- Calibration factor or responsivity value
- Measurement uncertainty
- Traceability to WMO standards
- Environmental conditions during calibration
- Date of calibration and next due date



Figure 7. Certificate of calibration

Step 7: Post-Calibration Verification

- Re-install instruments at UREMS station
- Conduct side-by-side comparison with operational instruments
- Verify consistency with pre-calibration baseline
- Update data processing algorithms with new calibration factors

Step 8: Implementation and Data Correction

- Apply new calibration factors to historical data if significant drift detected.
- Update quality control protocols with new uncertainty values.
- Document calibration impact on data quality.

4) Quality Assurance Measures

a. Regular Inter-Calibration Checks:

- Perform field comparisons every 6 months between calibrated and operational instruments.
- Monitor calibration drift through periodic zero offsets checks.
- Maintain calibration history database for trend analysis.

b. Environmental Considerations for Calibration:

- Account for high dust load conditions in Adrar region
- Consider temperature extremes in uncertainty calculations
- Document cleaning frequency impact on calibration stability
- Account for Solar Elevation Angle and Solar Irradiance

In (Table 1.) an example of Geographical and Environmental Characteristics of the Calibration Site located in CDER (Centre de Développement des énergies renouvelables) (Algiers) on May 2024.

Table 1. Environmental Characteristics of the Calibration Site (Algiers)

Parameter	Mean	Minimum	Maximum
<i>Latitude</i>	36.8° N	—	—
<i>Longitude</i>	3° E	—	—
<i>Altitude (m)</i>	345	—	—
<i>Ambient Temperature (°C)</i>	24.4	17.0	31.0
<i>Solar Elevation Angle (°)</i>	45.8	20.2	71.4
<i>Solar Irradiance (W/m²)</i>	953	786	1030

d. **Compliance with WMO Standards:**

- Follow WMO-No. 8 "Guide to Meteorological Instruments"[18]
- Adhere to ISO 9060:2018 classification requirements[20]
- Maintain traceability to World Radiometric Reference (WRR) and International Committee for Weights and Measures – Mutual Recognition Arrangement (CIPM MRA).
- The calibration is performed according to the operating procedure MODLT01.02, version 02, in accordance with ISO 9847:2023, type B1[8].

e. **Typical Calibration Timeline:**

according to (Table 2.)

Table 2. Typical Steps and Timeline for Calibration

<i>Time</i>	<i>Activity</i>
<i>T-180 days</i>	<i>Schedule calibration appointment</i>
<i>T-7 days</i>	<i>Pre-calibration performance check</i>
<i>T-0</i>	<i>Ship instruments to ONM Tamanrasset</i>
<i>T+1 to T+10</i>	<i>Calibration execution</i>
<i>T+14</i>	<i>Receive calibrated instruments</i>
<i>T+15 to T+21</i>	<i>Post-calibration verification</i>
<i>T+30</i>	<i>Full implementation completed</i>

This systematic approach ensures that URER/MS maintains measurement accuracy within WMO requirements and provides traceable, reliable solar radiation data for research and energy applications. The 3–5-year calibration cycle aligns with WMO recommendations for secondary standard pyranometers operating in desert environments.

III. Results and Discussion

III.1. Calibration Performance

The calibration process exhibited a highly linear response across all tested instruments, showing near-perfect correlation between the reference and field sensor outputs. This exceptional performance is characterized by a measurement uncertainty of $\pm 0.2 \mu\text{V}/(\text{W}/\text{m}^2)$ and a standard deviation ranging from 0.02 to 0.04 $\mu\text{V}/(\text{W}/\text{m}^2)$, confirming excellent precision and repeatability.

Using the historical sensitivity records of the pyranometers (CM11) operated at URER/MS Adrar and calibrated at the ONM calibration center (Fig. 8), the comparative analysis illustrates the temporal evolution of the calibration coefficient (sensitivity, expressed in $\mu\text{V}\cdot\text{W}^{-1}\cdot\text{m}^2$) for several radiometric sensors over successive calibration campaigns conducted between 2003 and 2019. For all instruments, a progressive decrease in sensitivity with time is observed, although the magnitude of this decline varies among sensors.

The earliest calibration (December 2003) generally exhibits the highest sensitivity values, whereas more recent calibrations (2017–2019) show lower sensitivities, reflecting the effects of instrument aging and the gradual degradation of optical and electronic components, such as sensor coatings, domes, and thermopiles. Despite this downward trend, the sensitivity variations remain smooth and gradual, with changes typically ranging between 1–

2% between successive calibration campaigns and an overall reduction of approximately 3–4% per decade (2009–2019). This behavior indicates good long-term stability and adequate maintenance of the instruments.

Minor fluctuations or partial recoveries observed during intermediate calibration periods (e.g., 2009–2011) may be attributed to recalibration adjustments, differences in environmental exposure, or instrument refurbishment. Overall, the observed interannual sensitivity variations emphasize the critical importance of regular recalibration to maintain the accuracy, reliability, and traceability of solar radiation measurements, particularly for long-term climatological monitoring and solar energy applications.

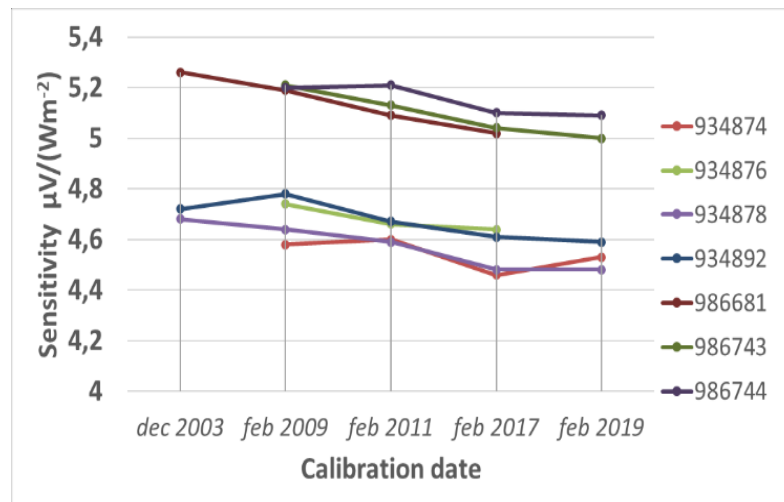


Figure 8. Variation of the coefficient of calibration pyranometers (CM11) operated at URER/MS Adrar

III.2. Influence of Environmental Conditions and Period of Use on Sensor Sensitivity

The sensitivity of pyranometers is strongly influenced by both environmental conditions and the duration of instrument use. Prolonged exposure to harsh climatic environments such as:

- High solar irradiance.
- Elevated temperatures
- Large diurnal thermal cycles
- Dust deposition, humidity, and wind-blown sand

can accelerate the aging of optical and electronic components. In arid regions such as Adrar region, frequent dust accumulation on sensor domes reduces optical transmittance, while repeated thermal stress affects the stability of thermopile junctions and internal electronics, leading to a gradual decline in sensitivity.

In addition, the period of continuous operation plays a key role in sensitivity drift. Long-term use results in cumulative degradation of protective coatings, dome materials, and sealing systems, which may alter the sensor's radiative response. This degradation typically manifests as a progressive and irreversible decrease in sensitivity over time, even under regular maintenance conditions. Although routine cleaning and periodic recalibration can partially mitigate these effects, they cannot fully prevent long-term drift.

Overall, the combined impact of environmental exposure and operational duration highlights the necessity of regular calibration intervals, especially for instruments deployed in extreme climates. Such practices are essential to ensure the accuracy, consistency, and traceability of solar radiation measurements used in climatological studies and solar energy assessment.

III. Conclusion

This study presents a comprehensive and practical methodology for calibrating solar irradiance instruments in desert environments. The results clearly show that systematic and well-documented calibration procedures significantly enhance data quality. A sensitivity degradation of approximately 3–4% per decade is observed for pyranometers operated in southern regions (Adrar region). The approach provides a robust and transferable

foundation for solar resource assessment, photovoltaic system performance monitoring, and climate modeling both in North Africa and in arid regions worldwide.

Future efforts will focus on extending the calibration period to capture long-term climatic variability, implementing automated cleaning systems to minimize dust-related effects, and analysing sensor drift over extended timescales.

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