

Evaluation of net shortwave radiation measurements at the Argentine-German Geodetic Observatory (AGGO)

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Abstract Net shortwave radiation (SW) measurements recorded at the Argentine-German Geodetic Observatory (AGGO), Argentina, are analyzed over two time periods (2016–2018 and 2019–2023) measured with a CNR2 net radiometer installed as part of AGGO's meteorological monitoring system. The observed SW time series are compared with estimates from ERA5 reanalysis. A quality assessment reveals the presence of systematic shadowing effects that affect the measurements after approximately 14 local time and persist throughout the entire observation period. These effects are identified using direct inspection of the time series and a shadow map analysis based on the ratio between cumulative measured SW and reference radiation estimates. After filtering out shadow-affected data, the agreement between the SW measurements and the ERA5 dataset improves substantially. As an exploratory exercise, global horizontal irradiance (GHI) is estimated from the filtered SW data using a simplified approach based on a constant surface albedo. The resulting GHI estimates show reasonable agreement with ERA5 and CAMS satellite-based data, with CAMS exhibiting the best overall performance. Although AGGO is primarily designed for geodetic applications, this study demonstrates the scientific value of its solar radiation observations, even when their limitations are identified, and provides a valuable opportunity to assess surface radiation measurements in the Southern Hemisphere.

Keywords Net shortwave radiation, AGGO, reanalysis, ERA5, CAMS

Evaluación de las mediciones de radiación neta de onda corta en el Observatorio Argentino-Alemán de Geodesia (AGGO)

Resumen Se analizan las mediciones de radiación neta de onda corta (SW) registradas en el Observatorio Argentino-Alemán de Geodesia (AGGO), Argentina, a lo largo de dos períodos (2016–2018 y 2019–2023), obtenidas mediante un radiómetro neto CNR2 instalado como parte del sistema de monitoreo meteorológico de AGGO. Las series temporales observadas de SW se comparan con estimaciones provenientes del reanálisis ERA5. La evaluación de calidad revela la presencia de efectos sistemáticos de sombra que afectan las mediciones a partir de aproximadamente las 14 horas locales y persisten durante todo el período de observación. Estos efectos se identifican mediante la inspección directa de las series temporales y un análisis de mapas de sombra basado en la razón entre la radiación SW acumulada medida y las estimaciones de radiación de referencia. Tras filtrar los datos afectados por sombra, la concordancia entre las mediciones de SW y el conjunto de datos ERA5 mejora de manera sustancial. Como ejercicio exploratorio, la irradiancia global horizontal (GHI) se estima a partir de los datos filtrados de SW mediante un enfoque simplificado basado en un albedo superficial constante. Las estimaciones resultantes de GHI muestran una concordancia razonable con ERA5 y con los datos satelitales de CAMS, siendo CAMS el que presenta el mejor desempeño global. Si bien AGGO está diseñado principalmente para aplicaciones geodésicas, este estudio demuestra el valor científico de sus observaciones de radiación solar, aun cuando se identifican sus limitaciones, y ofrece una valiosa oportunidad para evaluar mediciones de radiación en superficie en el hemisferio sur.

Palabras clave Radiación de onda corta neta, AGGO, reanálisis, ERA5, CAMS

INTRODUCTION

The Argentine-German Geodetic Observatory (AGGO) is one of the most comprehensive geodetic observatories worldwide, and its strategic location in the Southern Hemisphere makes it a key component of the Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG). (Mikolaj et al., 2019; Antokoletz et al., 2020; Brunini et al., 2023). At the global scale, AGGO contributes to the establishment of geodetic reference frames.

AGGO is located in Buenos Aires Province near the city of La Plata, in east-central Argentina, and is jointly operated by the German Federal Agency for Cartography and Geodesy (BKG) and

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the National Scientific and Technical Research Council of Argentina (CONICET). [Figure 1](#) (left) shows AGGO's geographical location (34.87° S, 58.13° W) within the Buenos Aires Province and Argentina. Its observational infrastructure includes Global Navigation Satellite System (GNSS), Very Long Baseline Interferometry (VLBI), and Satellite Laser Ranging (SLR) systems, as well as a gravity laboratory hosting a high-precision Superconducting Gravimeter (SG) and an Absolute Gravimeter (AG), complemented by seismological and timing facilities. This combination of techniques places AGGO among the most significant contributors to the global geodetic Earth observation network.

In addition to the instrumentation dedicated to geodetic observations, AGGO operates a set of automatic meteorological stations that provide continuous measurements of atmospheric conditions. These include air temperature, relative humidity, atmospheric pressure, wind speed, precipitation, and net solar shortwave and longwave radiation. While several studies have focused on the analysis of geodetic observations collected at AGGO (Oreiro et al., [2018](#); Antokoletz et al., [2017](#), [2020](#), [2024](#); Tocho et al., [2020](#); Pendiuk et al., [2020](#), [2023a](#), [2023b](#)) comparatively few studies have addressed the meteorological data sets (Antico et al., [2024](#)). Among the meteorological variables, this study focuses on net shortwave radiation (SW).

Although net radiation measurements are not the primary focus of AGGO, we consider it scientifically important to analyze and document any observational data set that has been acquired through sustained effort. The installation, operation, maintenance, and calibration of meteorological instrumentation require financial resources, technical expertise, and long-term institutional commitment. Therefore, such measurements deserve careful analysis and documentation. Making these data available to the community, together with a clear assessment of their limitations and uncertainties, contributes to improving data availability and spatial coverage in the region.

Net radiation represents the energy available at the Earth's surface resulting from the balance between incoming and outgoing radiative fluxes in both the shortwave and longwave spectral ranges. It is the radiant energy available at the surface to drive biological and physical processes, playing a key role in numerous biological, hydrological, agricultural, and environmental processes, and is typically used in surface energy balance and land-surface models (e. g., evapotranspiration, climate studies) (Carmona et al., [2017](#); Foyo-Moreno et al., [2025](#); Zeng et al., [2026](#)). Despite its importance, direct measurements of net radiation remain scarce worldwide. Such measurements are uncommon, often limited to specific conditions or short-term monitoring (Carmona et al., [2017](#); Xu et al., [2022](#); Zeng et al., [2026](#)). This scarcity highlights the value of existing net radiation measurements.

SW is defined as the difference between the downwelling shortwave radiation ($SW_{\downarrow}$), which is equivalent to the global horizontal irradiance (GHI), and the upwelling shortwave radiation ($SW_{\uparrow}$), which is reflected by the surface. Assuming a surface albedo α , the reflected component can be expressed as $SW_{\uparrow} = \alpha \times GHI$. In principle then, GHI could be recovered from SW through

$$GHI = \frac{SW}{1 - \alpha}. \quad (1)$$

In this work, SW measurements recorded at AGGO are analyzed, and their agreement with the corresponding estimates from the ERA5 reanalysis (ECMWF-European Centre for Medium-Range Weather Forecasts-Reanalysis v5) is assessed (Copernicus Climate Change Service, [2023](#)). In addition, the feasibility of using these measurements to derive GHI through the very simple approach given by [equation 1](#) and assuming a constant value for α is explored, given the relevance of this variable for solar resource assessment in the region. The derived GHI is compared with ERA5 data and satellite-based solar radiation products from CAMS (Copernicus Atmosphere Monitoring Service).

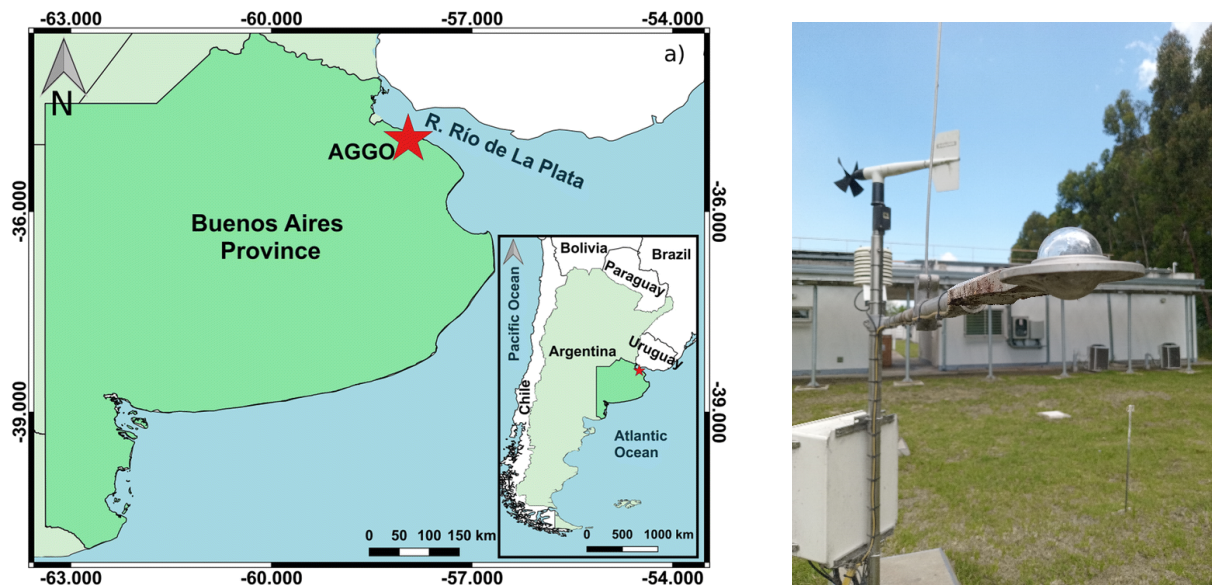


Figure 1. Left: Location of AGGO (red star) in Buenos Aires Province (mint green area), within Argentina (pale green area in the inset at the lower-right corner of the map). Right: CNR2 net radiometer at the WS3-GFZ meteorological station installed at AGGO. Note: Left panel reproduced from Pendiuk et al. (2020).

DATA

Radiation measurements from AGGO

The SW time series, with a temporal resolution of 15 minutes, were obtained from two independent sources, both corresponding to the AGGO site (34.87°S , 58.13°W). One is hosted by the GFZ Helmholtz Centre for Geosciences with data available for the period 2016–2018 (Mikolaj et al., 2018). The other is hosted by AGGO with data available since 2017 to the present. We considered the period 2019–2023 in the latter case due to the fact that the data from the 2017–2018 exhibits a discontinuity prior to 2019, along with a significant temporal gap separating this sub-period from the subsequent data. We called SW1 and SW2 the time series covering 2016–2018 and 2019–2023, respectively.

The instrumentation was implemented by the GFZ. In both cases, net radiation is measured using a CNR2 net radiometer (Campbell Scientific) at the WS3-GFZ meteorological station, illustrated in Figure 1, and installed on a mast 1.5 m above the surface.

The CNR2 net radiometer design is such that both the upward facing and the downward facing instruments measure the energy that is received from the hemisphere. The short-wave sensor is a pyranometer with a field of view of 180 degrees on the upper sensor that measures the incoming short-wave radiation from the sky ($\text{SW}_{\downarrow}$), and 150 degrees on the lower detector for measuring the reflected short-wave radiation by the surface ($\text{SW}_{\uparrow}$). The spectral range covers 310 to 2800 nm. The long-wave sensor is a pyrgeometer that has a field of view of 150 degrees for both the upper and lower detectors, and the spectral range covers 4.5 to 42 μm . Short-wave radiation ($\text{SW} = \text{SW}_{\downarrow} - \text{SW}_{\uparrow}$) and long-wave radiation are measured separately.

Radiation data from ERA5 and CAMS

The ERA5 data used in this study, which is equivalent to SW for comparative purposes, is the surface net short-wave solar radiation (ssr), in J/m^2 (Hersbach et al., 2020). It is defined as the amount of shortwave solar radiation that reaches a horizontal plane at the surface of the Earth (both direct and diffuse components) minus the amount reflected by the Earth's surface, which is governed by the albedo. This reanalysis dataset provides hourly accumulated estimates of ssr with a latitude-longitude resolution of 0.25° . From the four ERA5 grid points surrounding AGGO, an Inverse Distance Weighting (IDW) interpolation was applied to obtain the corresponding time series at the exact location. To

convert the units of J/m^2 to W/m^2 the accumulated ssr value were divided by 3600 seconds.

For the comparative analysis with GHI obtained from SW, ERA5 and CAMS data were considered. In the case of ERA5 the data used is the surface solar radiation downwards (ssrd) that represents the shortwave solar radiation reaching a horizontal surface at the Earth's surface and refers to the sum of direct and diffuse solar radiation in the plane. It is considered a good approximation of the modeled value of radiation that would be measured by a pyranometer integrating the spectral band of 300–4000 nm. The additional radiation in the longer near infrared range (3000–4000 nm), not included in the pyranometer measured values, can contribute about 1% of the total solar energy reaching the Earth's surface, which is practically negligible (Silvero et al., 2025). The same interpolation and unit conversion procedures as ssr was applied to ssrd .

GHI from CAMS satellite-based model, GHI_{CAMS} , was retrieved from the official SoDaPro site (Qu et al., 2017; Schroedter-Homscheidt et al., 2022). In this case, the time series is obtained for the exact location of AGGO. GHI refers to the all-sky global irradiation, that is the surface solar downward irradiation integrated over the 285–2800 nm spectral band on a horizontal surface. Here, the spectral band closely matches the measured spectral range.

METHODOLOGY

Quality control of SW observations

SW1 begins in May 7, 2016 and covers until November 28, 2018. The station records data every 15 minutes which amounts to a total of 89856 data considering 4 values per hour of each day of the period considered. The missing data amounts to 349 in total, that is less than 1%. SW2 covers the complete period January 1, 2019–December 31, 2023, which amounts to a total of 175296 data. The missing data in this case amounts to 4740, that is $\sim 3\%$.

To begin, we applied a quality control following Long and Shi (2008), based on the extremely rare limits defined in the Baseline Surface Radiation Network (BSRN) quality control procedures, which accounts for the possibility of transient effects such as cloud enhancement events (CEE). Separate limits are given for $\text{SW}_{\downarrow}$ and $\text{SW}_{\uparrow}$, but not for the difference, that is not for SW. So we applied a 0.82 factor correction to $\text{SW}_{\downarrow}$ extremely rare limit curve. The factor 0.82 follows from equation 1 assuming a surface albedo of $\alpha = 0.18$. This value is obtained from the National Solar Radiation Database (NSRD) (Sengupta et al., 2018) for AGGO location. In addition, it is very close to representative surface albedo of $\alpha = 0.2$, which has been traditionally employed as a standard value in solar radiation studies (Sengupta et al., 2024). Although the albedo depends on the specific surface type beneath the instrument and may differ from a site-average value, we adopt this value. A sensitivity analysis addressing this assumption is also presented.

Figure 2 shows the SW1 and SW2 data and the extreme rare limits as a function of the zenith angle (Z). Nighttime values are slightly negative, oscillating around -2 W/m^2 and only rarely reaching values as low as -15 W/m^2 , thus they were set to zero in Figure 2. Only around 5 points in each dataset exceeds the extreme rare limits, by less than 10 W/m^2 for $Z \sim 80^\circ$. They are highlighted with a red rectangle in the figure. They were retained since, as explained later, only values with $Z < 75^\circ$ are considered in this study.

Visual inspection of SW observations and filtering

Figure 3 shows SW1 and SW2 as a function of local time (LT) for each analyzed period, after eliminating negative values. In both cases, and especially for SW2, the diurnal cycle is asymmetric around local noon, with a pronounced reduction in SW at times later than noon. This pattern is consistent with shadowing effects on the sensor, likely caused by a fixed obstacle. To investigate this further, Figure 4 and Figure 5 present selected days as example, illustrating an abrupt decline in SW after ~ 14 LT. For reference, a theoretical clear-sky SW curve is included, derived from the Haurwitz (1945) GHI simple

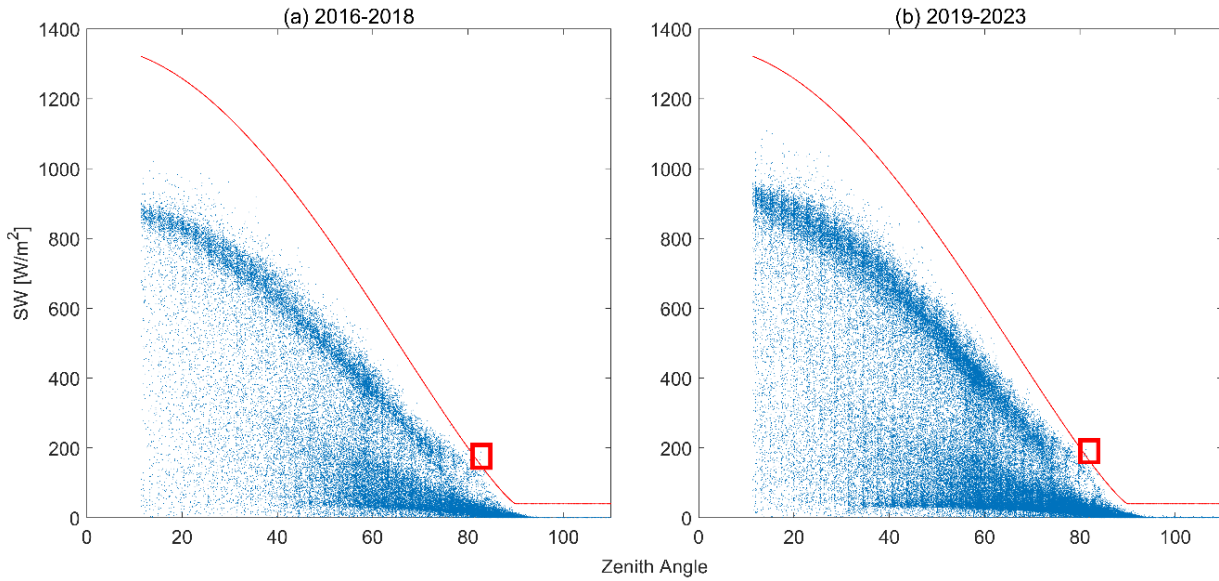


Figure 2. Net shortwave, SW, radiation measured at AGGO (34.87°S, 58.13°W) with a CRN2 Net Radiometer with 15-minute frequency (blue dots): a) SW1 for period 2016–2018 and b) SW2 for period 2019–2023. Red line corresponds to the extreme rare limit for GHI (Long & Shi, 2008) multiplied by 0.8. Red rectangle encircles SW data that exceeds the extreme rare limits.

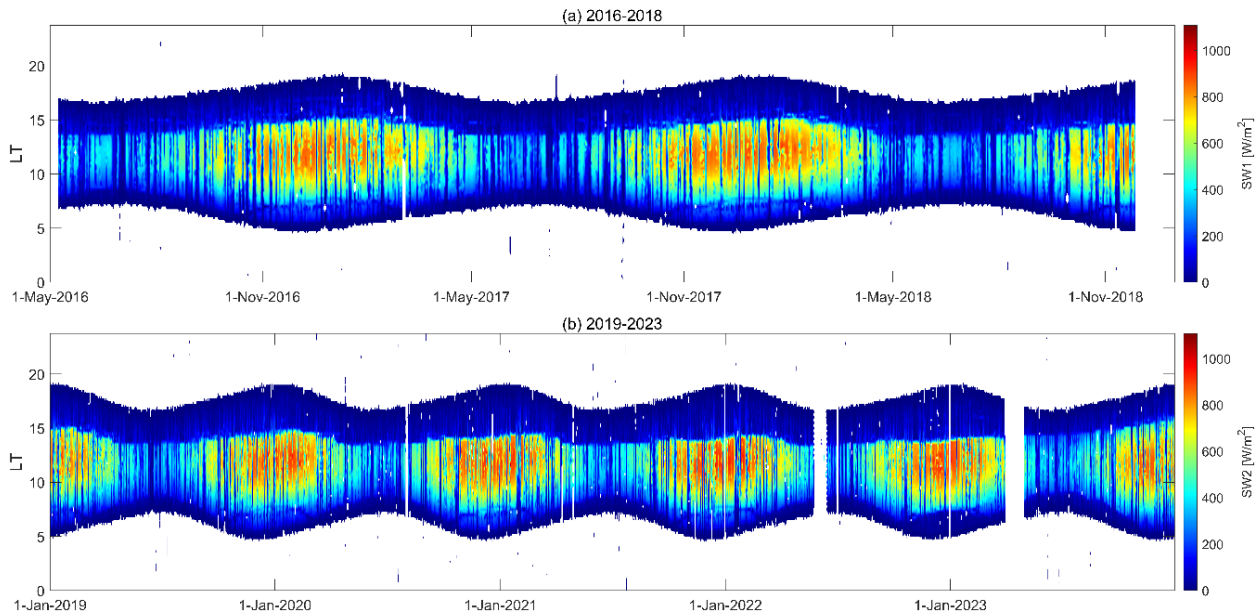


Figure 3. Net shortwave radiation (SW) measured at AGGO with 15-minute frequency: a) SW1 for period May 2016–November 2018, and b) SW2 for period January 2019–December 2023.

formula (Stein et al., 2012) scaled by a factor of 0.82, given by

$$\text{GHI} = 1098 \cos(Z) e^{-0.057/\cos(Z)}. \quad (2)$$

To further corroborate and detect potential shadowing or masking effects affecting the SW measurements, a shadow map, shown in Figure 6, was constructed. The approach follows the methodology described in the SODA (Solar Radiation Data) validation guidelines (“Get an insight of the quality of your ground measurements”, <https://www.soda-pro.com/help/validation/get-an-insight-of-the-quality-of-your-ground-measurements>), also based on the framework presented by Lorenz et al. (2022). The shadow map represents the base-10 logarithm of the ratio between two cumulative radiation time

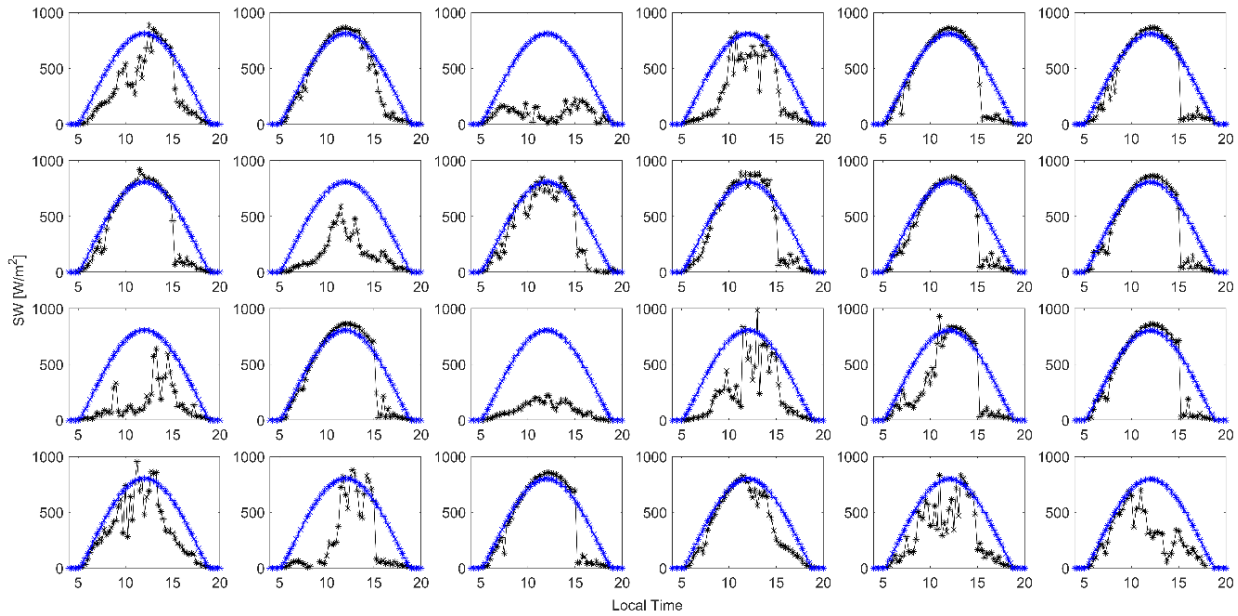


Figure 4. Time series of net shortwave radiation (SW) measured at AGGO at 15-min resolution (black) from SW1 dataset, for the first 24 days of January 2017 (consecutive days displayed from left to right, starting on the top row). Theoretical reference values are shown in blue.

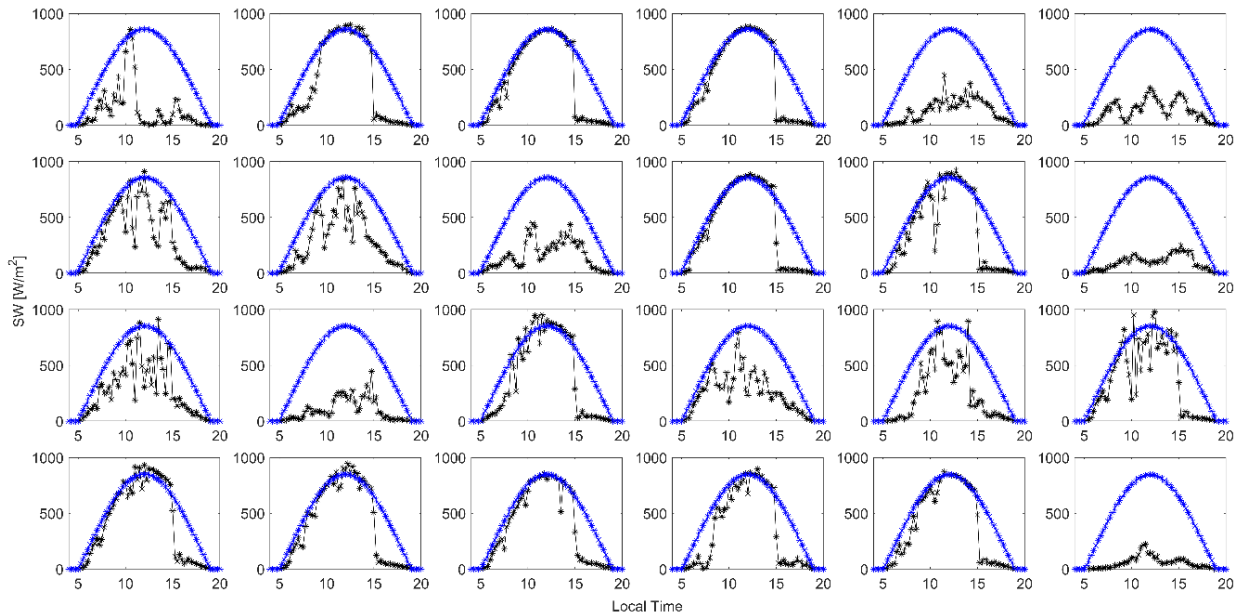


Figure 5. Time series of net shortwave radiation (SW) measured at AGGO at 15-min resolution (black) from the SW2 dataset, for the first 24 days of January 2019 (consecutive days displayed from left to right, starting on the top row). Theoretical reference values are shown in blue.

series, in this case SW measurements and a reference dataset assumed to be free of local shadowing effects that is *ssr* from ERA5, which was resampled to a 15-minute resolution by value repetition. The values are binned as a function of the solar position, with solar elevation ($90 - Z$) on the y-axis and solar azimuth on the x-axis. Each bin therefore corresponds to a specific solar position and contains the cumulative contribution of radiation measured when the sun is located within that angular range. This representation is effective for visualizing persistent potential shadowing effects, since systematic reductions in the measured radiation appear as coherent structures in specific regions of the elevation-azimuth space. However, it is sensitive to the temporal resolution of the measurements and, because it relies on cumulative values, shadowing effects present during limited periods may

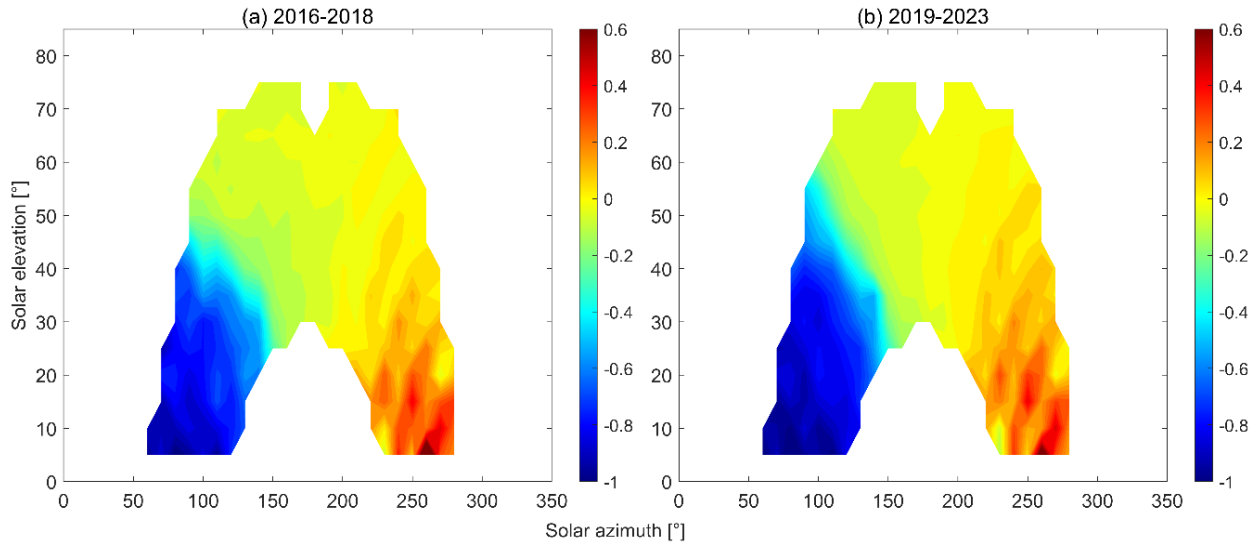


Figure 6. Shadow map showing the base-10 logarithm of the ratio between cumulative SW measured at AGGO and cumulative SSR from ERA5, grouped by solar azimuth and elevation [°], for a) 2016–2018 period (SW1), and b) 2019–2023 period (SW2).

be partially masked when longer time intervals are analyzed. The ideal value for each bin is zero, indicating that, on average, SW equals SSR. Clusters of strongly negative values indicate the presence of shading effects.

Based on this map, elevation and azimuth angles were identified for which the map's values are lower than a threshold set to -0.5 , and the corresponding SW data were removed. A total of 10874 and 22991 data points were removed in SW1 and SW2 series, respectively, which correspond to $\sim 25\%$ in each case. Figure 7 shows the SW1 and SW2 time series after removing shadowed values. The original time series are also shown in order to corroborate that the removed values are those previously identified by visual inspection in Figure 3.

Hourly averages of SW1 and SW2 were estimated then without applying a minimum data requirement, after deleting shadowed values and also considering the original time series for comparison purposes. That is, the hourly value was calculated even with one data in the 4 values per hour interval. Data were restricted to $Z < 75^\circ$, since at larger zenith angles the increased atmospheric path length and reduced irradiance levels lead to larger relative uncertainties.

Statistical comparison

Measured SW values were compared to SSR obtained from ERA5 considering hourly mean values and $Z < 75^\circ$, using three comparative statistic parameters (Gueymard, 2014; Nollas et al., 2022; Medina et al., 2023): mean relative absolute error (MRAE), mean relative error (MRE) and squared correlation coefficient (r^2), defined by

$$\text{MRAE} (\%) = 100 \frac{1}{n} \sum_{i=1}^n \left| \frac{y_i - x_i}{x_i} \right|, \quad (3)$$

$$\text{MRE} (\%) = 100 \frac{1}{n} \sum_{i=1}^n \frac{y_i - x_i}{x_i}, \quad (4)$$

and

$$r^2 = \frac{[n(\sum_i x_i y_i) - (\sum_i x_i)(\sum_i y_i)]^2}{[n(\sum_i x_i^2) - (\sum_i x_i)^2] [n(\sum_i y_i^2) - (\sum_i y_i)^2]}, \quad (5)$$

where x_i corresponds to the measured values (SW), y_i to the reanalysis values (SSR), and n to the

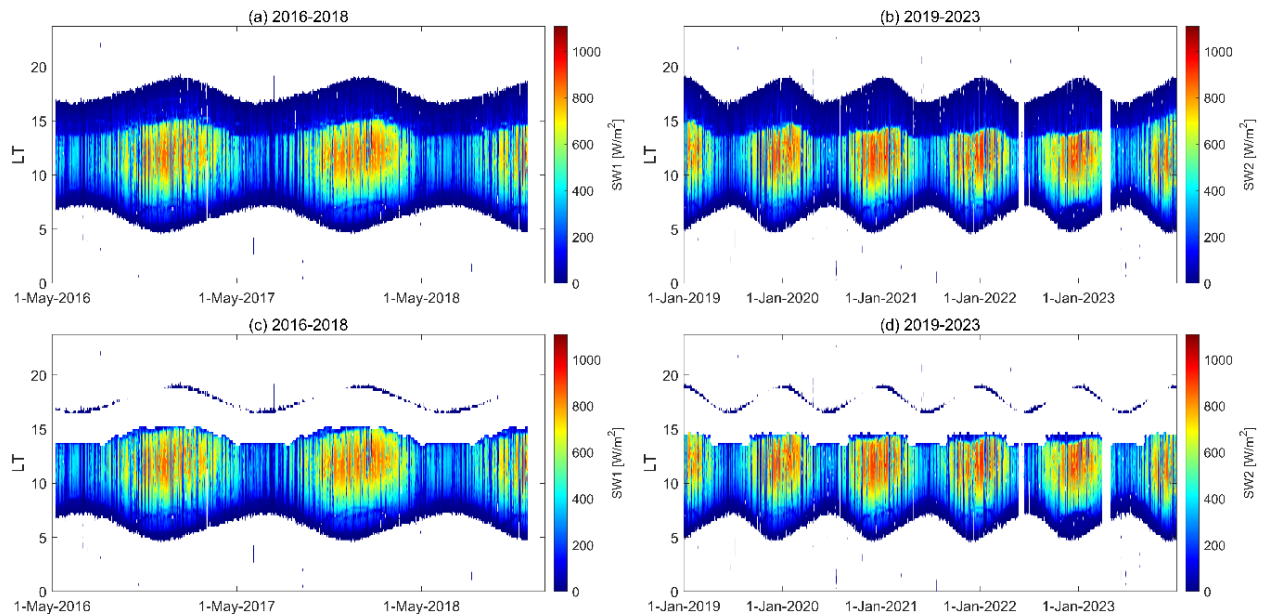


Figure 7. Net shortwave radiation, SW, measured at AGGO with 15-minute frequency: a) original SW1, b) original SW2, c) SW1 after deleting shadowed values, and d) SW2 after deleting shadowed values.

number of data points in the time series. MRAE is a measure of the mean deviation of ssr from SW in percentage. The optimal value is 0 indicating that both series are identical. MRE measures the average bias of ssr over or underestimating SW depending on its sign: positive or negative, respectively, in percentage. Its optimal value is 0, but in this case it does not indicate that both series are identical, since there can be a compensation of errors. r^2 measures the explained variance in SW by ssr time variation. So, it measures how similar is the variability in one series to that of another. It is bounded by 1 and 0, where 1 is the optimal value indicating that both time series varies identically.

Daily and monthly mean values are not analyzed, because the removal of shadow-affected data leaves most days with incomplete diurnal coverage, limited to the morning hours up to solar noon and only one or two hours afterward.

Simplified estimation of GHI from net shortwave radiation and comparison with reanalysis and satellite data

A simplified way of obtaining GHI from SW is using [equation 1](#) and assuming a constant representative surface albedo of $\alpha = 0.18$, as previously mentioned (Sengupta et al., [2018](#), [2024](#)). In this way, hourly mean GHI values were obtained considering SW2 hourly mean time series after filtering out shadowed affected values, as an exploration analysis.

The resulting GHI estimates were compared with ssr d from ERA5 and GHI_{CAMS} from CAMS using the three statistical metrics (MRAE, MRE, and r^2) defined in [equations 3 to 5](#).

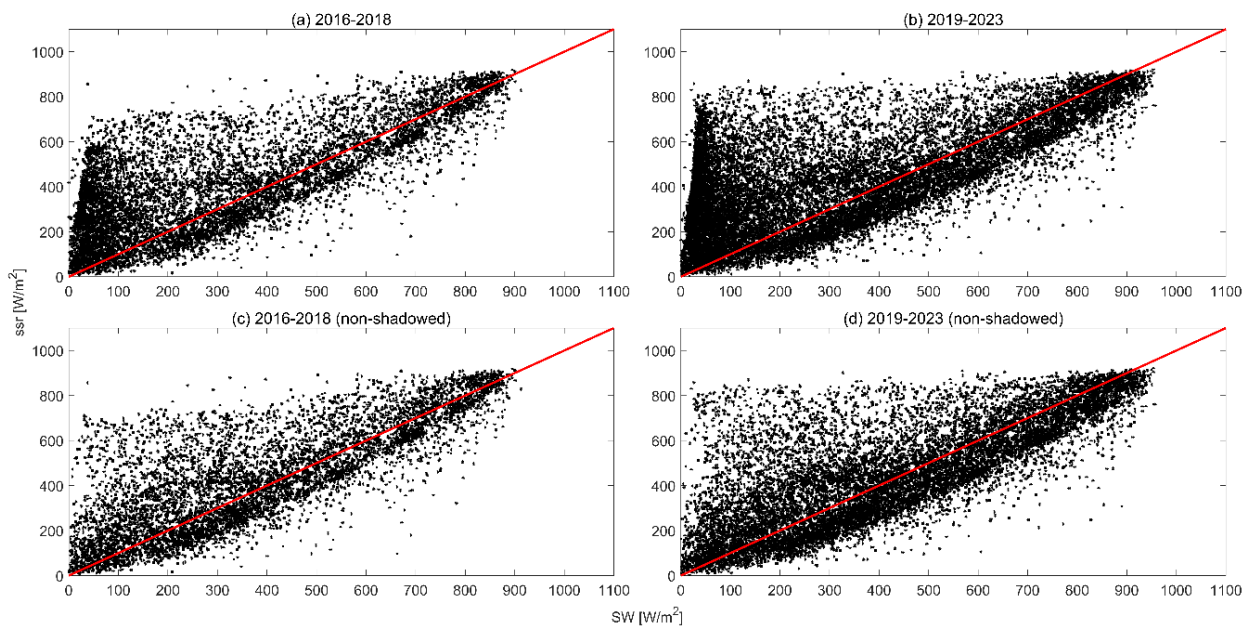
RESULTS AND DISCUSSION

SW and ERA5 comparative analysis

[Table 1](#) lists the values of MRAE, MRE, and r^2 between SW and ssr for the filtered dataset after shadowing detection, as well as for the unfiltered dataset. This comparison highlights how the inclusion of shadow-affected hourly values can significantly distort a comparative analysis of this type. [Figure 8](#) shows the dispersion between SW and ssr , together with the first bisector in each graph. This figure highlights the overestimation already evident from MRE values.

Table 1. Comparative statistics: MRAE, MRE, and r^2 , of SW1 and SW2 with ssr from ERA5 considering hourly mean values original time series and after filtering for shadowing effects.

	SW1 – ssr (ERA5)		SW2 – ssr (ERA5)	
	Original	Filtered	Original	Filtered
MRE (%)	182	63	246	53
MRAE (%)	196	81	261	74
r^2	0.56	0.64	0.44	0.58

**Figure 8.** Dispersion diagrams for hourly values of SW with ssr from ERA5 for SW1 (panels a and c) and SW2 (panels b and d) considering original dataset (upper panels) and dataset after deleting shadowed values. The red line corresponds to the first bisector meaning perfect match.

It is noteworthy that the error metrics decrease to one third or less once the time series is filtered for shadowing effects. This behavior is also evident in the scatter plot, where the removed points are those located far from the 1 : 1 line, corresponding to low SW and high ssr values, respectively. Regarding r^2 , it is largely driven by both the diurnal and seasonal variability of solar radiation, which are generally well reproduced by reanalysis and satellite-based products, even under partly cloudy conditions. Hourly radiation typically follows a characteristic daily cycle, with minimum values in the morning and late afternoon and maximum values around local noon. However, in this study the diurnal cycle is not well represented, as a fraction of the data, particularly in the afternoon, is removed due to shadowing effects, resulting in incomplete daily coverage. This weakens the contribution of the diurnal variability to r^2 and leads to lower overall values compared to those commonly reported in the literature. Nevertheless, the seasonal variability remains well defined in the dataset and is reasonably captured by the model, which explains why a consistent, although reduced level of correlation is still observed.

In order to analyze the ERA5 performance throughout the year, the comparative statistics were estimated separately for each season for both SW1 and SW2. The results are presented in Figure 9, together with the corresponding values obtained when all data are considered jointly (listed in Table 1). The seasons are defined as summer (DJF), autumn (MAM), winter (JJA), and spring (SON). The results indicate that ERA5 performance, in terms of errors, is worst during spring (SON), while the lowest errors occur in most cases during winter (JJA). Regarding r^2 , values computed using the full dataset are systematically higher than those obtained when analyzing each season separately. This behavior is mainly due to the fact that, when all data are considered together, the seasonal cycle

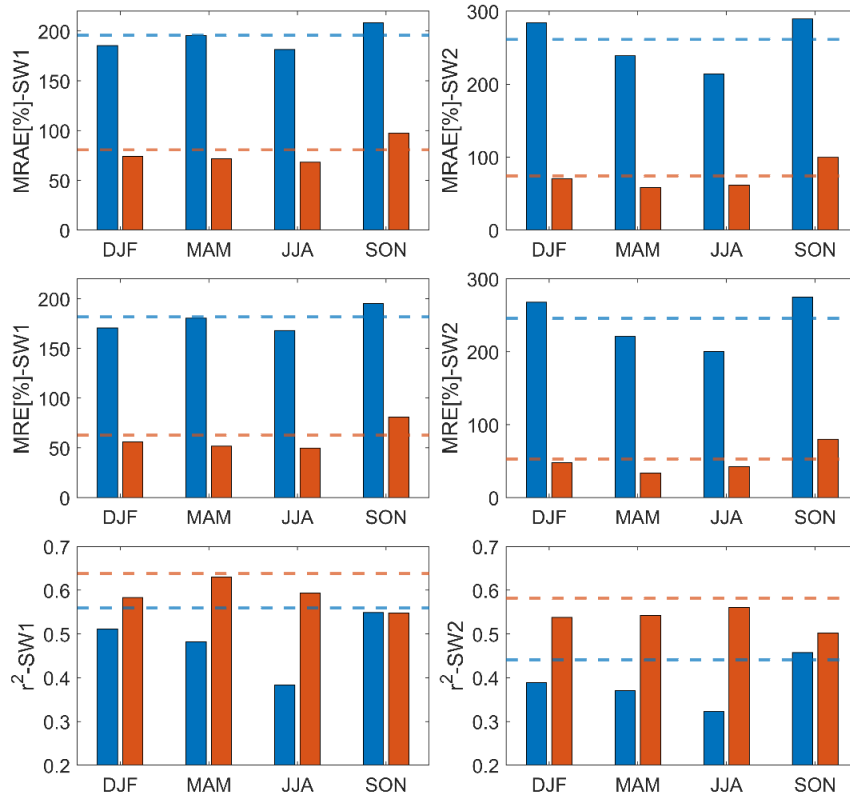


Figure 9. Seasonal performance metrics for SW1 (left panels) and SW2 (right panels) relative to ERA5 ssr. The upper, middle, and lower panels show MRAE (%), MRE (%), and r^2 , respectively. Bars correspond to seasonal values—summer (DJF), autumn (MAM), winter (JJA), and spring (SON)—computed from hourly data for the original time series (blue bars) and after filtering for shadowing effects (red bars). Dashed horizontal lines indicate the corresponding values obtained using the complete dataset (all seasons combined).

improves the correlation, as already mentioned. In contrast, when seasons are analyzed individually, the seasonal component is largely removed leading to lower r^2 values.

Derived GHI from SW1, ERA5 and CAMS comparative analysis

Table 2 lists the values of MRAE, MRE, and r^2 between GHI obtained from SW1 and values obtained from ERA5 (ssrd) and from CAMS (GHI_{CAMS}). Figure 10 shows the dispersion between GHI and ssrd, and between GHI and GHI_{CAMS} .

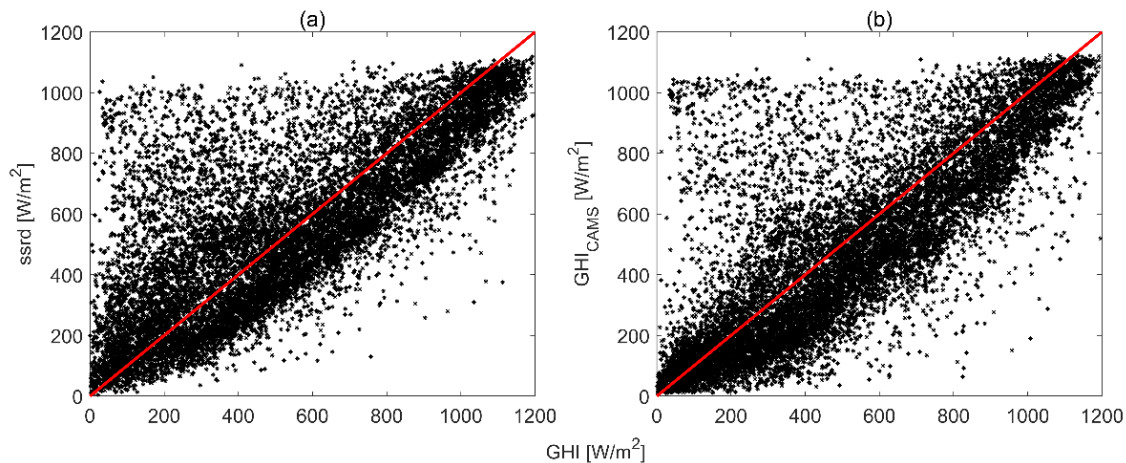
r^2 between GHI and ssrd is identical to that between SW and ssr, as expected, since GHI has the exact time variation of SW being the same time series multiplied by a constant (0.82^{-1}), while almost the same happens with ERA5 database. The latter can be noticed from Figure 11, which shows the ssr/ssrd ratio (practically equivalent to $(1 - \alpha)$ value, as recommended by Hagan (2015) considering the time series after removing hours with $Z > 75^\circ$). Even though a weak seasonal variation can be noticed, it is almost constant with a mean value of 0.82, coincident to the value here considered, and standard deviation of 0.01.

With respect to the error metrics, MRAE decreases slightly and MRE decreases more markedly for ERA5 when GHI is considered, compared to the previous comparison based on SW. In the case of CAMS, the agreement with GHI is even better than that obtained with ERA5 and is also characterized by a higher r^2 value.

A sensitivity analysis was performed to assess the impact of the selected α value used to derive GHI from SW. Specifically, α was varied between 0.12 and 0.5 in steps of 0.005, and the corresponding comparative metrics were computed between GHI estimated as $SW/(1 - \alpha)$ and ssrd and GHI_{CAMS} .

Table 2. Comparative statistics: MRAE, MRE, and r^2 , of GHI derived from SW1 with ssrd from ERA5 and GHI_{CAMS} from CAMS considering hourly mean values after filtering for shadowing effects.

	GHI – ssrd (ERA5)	GHI – GHI_{CAMS} (CAMS)
MRE	54	20
MRAE	76	53
r^2	0.58	0.64

**Figure 10.** Dispersion diagrams for hourly values of GHI with a) ssrd from ERA5, and with b) GHI_{CAMS} from CAMS. The red line corresponds to the first bisector meaning perfect match.

As expected, there is no variation in r^2 , since scaling a time series by a constant factor does not modify its temporal variability, but only its amplitude; therefore, its correlation with another series remains unchanged. In contrast, both MRE and MRAE show a clear dependence on α , as can be seen in Figure 12. MRE is particularly sensitive: as α increases, the bias is progressively reduced (i.e., the overestimation decreases), eventually reaching zero and becoming negative. This behavior is explained by the fact that increasing α reduces the denominator in $SW/(1 - \alpha)$, which in turn increases the estimated GHI relative to the reference datasets. MRAE also varies with α , initially decreasing as the estimated SW-derived GHI approaches the reference values. In the case of CAMS, after reaching a minimum, MRAE increases again for larger α , due to the same mechanism as in the case of MRE: as α increases further, the estimated GHI values become progressively larger, leading to larger absolute errors.

Discussion

The analysis of SW measurements at AGGO reveals a recurrent reduction after approximately 14 LT, consistently observed across both analyzed periods. The persistence of this pattern strongly suggests that it is not related to atmospheric variability, but rather to fixed local obstructions affecting the radiometer's field of view. The shadow map analysis provides an effective way to identify these effects in solar azimuth-elevation space. The clustering of negative values in specific regions of the shadow map indicates that the reduction in SW is linked to the solar position, consistent with shading by nearby structures.

After removing shadow-affected data, the agreement between the AGGO SW measurements and ERA5 ssr improves substantially, as reflected by the reduction in error metrics. This highlights how even a relatively limited fraction of systematically biased data can significantly distort comparative analyses if it is not properly identified and filtered. The remaining discrepancies can be attributed to a combination of factors, including differences in spatial representativeness between point measurements and gridded products, uncertainties in surface properties such as albedo, and the intrinsic limitations of reanalysis and also satellite-derived radiation estimates in general.

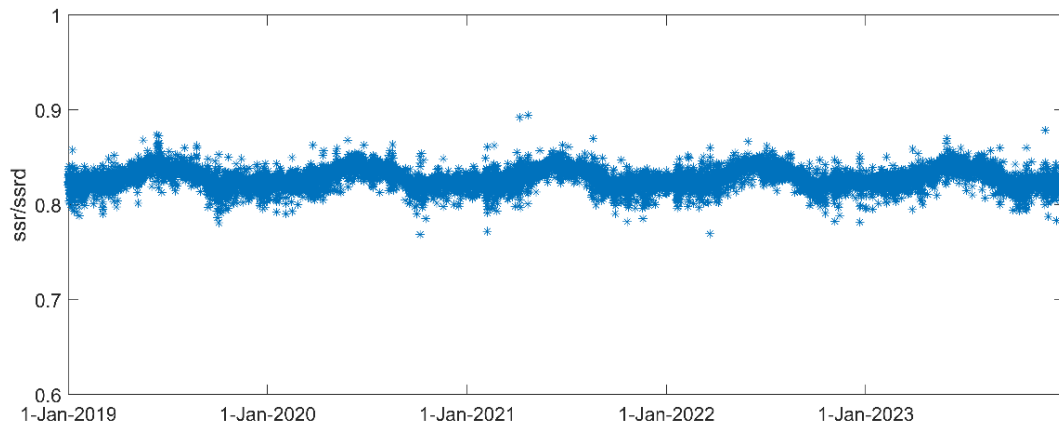


Figure 11. ERA5 based $ssr/ssrd$ ratio, equivalent to $(1 - \alpha)$ value, considering hourly mean values along the period January 2019–December 2023, after removing hours with $Z > 75^\circ$. $ssr/ssrd$ mean value of 0.82 and standard deviation of 0.01.

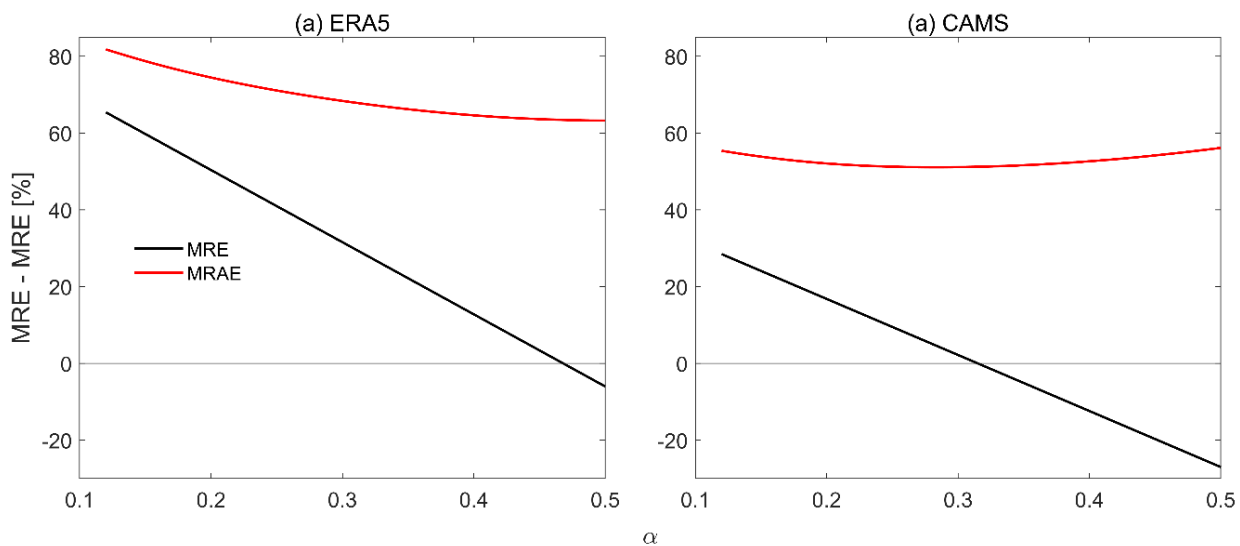


Figure 12. MRE (%) and MRAE (%) of GHI obtained as $SW/(1 - \alpha)$ with a) $ssrd$ from ERA5, and b) GHI_{CAMS} from CAMS, in terms of α .

The exploratory estimation of GHI from SW further illustrates the potential usefulness of the AGGO dataset beyond its original purpose. Although the adopted approach is simple and relies on a constant representative albedo, the resulting GHI estimates show a reasonable agreement with ERA5 and, in particular, with CAMS. The better performance of CAMS is consistent with other studies which find that satellite-derived products are better than reanalysis products (Yang & Bright, 2020; Mabasa et al., 2021; Yang et al., 2023; Silvero et al., 2025). In terms of the errors, a comparison can be made with values obtained by Silvero et al. (2025) who analyzed Tucumán (26.8° S, 65.1° W) for the period 2006–2023, and Mabasa et al. (2021) who analyzed 13 radiometric stations in South Africa located between 23° S and 35° S, for the period 2016–2019. Both studies used hourly mean data and included the external databases considered here.

Table 3 shows the comparative statistical values. In the case of Mabasa et al. (2021) the range of the 13 values obtained for each statistic is given. Based on the listed values, the agreement with Tucumán can be considered very good in terms of the error metrics, particularly MRAE. For South Africa, the error values are noticeably smaller, but they remain comparable to those obtained in this study. The main difference arises in the r^2 values, which are markedly lower in the case of AGGO.

Table 3. Comparative statistic values of GHI measurements at AGGO, Tucumán and 13 South African stations, with ERA5 and CAMS considering hourly mean values: MRAE, MRE and r^2 . Values for Tucumán and South Africa are from Silvero et al. (2025) and Mabasa et al. (2021), respectively.

	AGGO	Tucumán	South African stations
GHI – ssrd (ERA5)			
MRE (%)	50	47	$-3 \leq \text{MRE} \leq 6$
MRAE (%)	74	66	$6 \leq \text{MRAE} \leq 13$
r^2	0.58	0.80	$0.96 \leq r^2 \leq 0.99$
GHI – GHI_{CAMS} (CAMS)			
MRE (%)	17	9	$-4 \leq \text{MRE} \leq 11$
MRAE (%)	52	58	$6 \leq \text{MRAE} \leq 38$
r^2	0.64	0.88	$0.87 \leq r^2 \leq 0.99$

CONCLUSIONS

To summarize, this study presents the first detailed analysis of net radiation measurements performed at AGGO using SW datasets spanning 2016–2018 and 2019–2023. The measurements were evaluated through comparison with ERA5 and CAMS.

A persistent shadowing effect affecting the measurements after approximately 14 LT was identified using both direct inspection of the time series and a shadow map analysis in solar azimuth-elevation space. These effects are systematic and stable over time, indicating a local geometric origin rather than atmospheric variability. Filtering the shadow-affected data leads to a substantial improvement in agreement with the external datasets, demonstrating the importance of careful quality assessment prior to any comparative analysis.

An exploratory estimation of GHI from the filtered net shortwave radiation was also performed using a simplified approach based on a constant surface albedo. Despite its simplicity, the estimated GHI shows reasonable consistency with ERA5 and CAMS, with CAMS exhibiting the best overall agreement. This result suggests that, when properly filtered and interpreted, AGGO net radiation measurements may provide useful complementary information for regional radiation studies.

Finally, the meteorological instrumentation at AGGO provides net radiation measurements that are commonly used in geodetic and gravimetric studies to support corrections related to atmospheric loading, thermal effects, and surface energy exchanges. From this perspective, the afternoon shadowing effect may have a limited impact on the primary objectives of the observatory. Given the effort and resources invested in long-term observational infrastructures at AGGO, a transparent assessment of data quality remains essential. Even when limitations are identified, documenting and publishing such analyses enhances data traceability and contributes to the availability of high-quality observational information in the Southern Hemisphere where long-term radiation measurements remain relatively scarce. Future work may focus on refining radiation estimates using more detailed surface characterization and on further integrating AGGO meteorological observations into climate and solar energy oriented studies.

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DATA AVAILABILITY

Net shortwave solar radiation is freely available from AGGO website and can be retrieved from <ftp://ftp.aggo-conicet.gob.ar/MeteoData>, with data available since 2017 to the present. Net shortwave solar radiation for the period 2016–2018 is retrievable from <https://dataservices.gfz-potsdam.de/panmetaworks/showshort.php?id=escidoc:3748903> (Mikolaj et al., 2018).

ERA5 data: Copernicus Climate Change Service, Climate Data Store, (2023): *ERA5 hourly data on single levels from 1940 to present*. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), <https://doi.org/10.24381/cds.adbb2d47> (Accessed on 11-Dec-2025) (<https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview>)

CAMS satellite-based model was retrieved from the official SoDaPro site at <https://www.tsv.soda-pro.com/web-services/radiation/cams-radiation-service>

CAMS solar radiation time-series. Copernicus Atmosphere Monitoring Service (CAMS) Atmosphere Data Store (ADS) (Accessed on 11-Dec-2025) (<https://ads.atmosphere.copernicus.eu/datasets/cams-solar-radiation-timeseries?tab=overview>)

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