Research, Society and Development, v. 11, n. 16, e543111638179, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i16.38179

Quality checks procedure for erroneous measurements detection of spectral components of solar irradiances

Procedimento de checagem de qualidade para detecção de medidas errôneas das componentes espectrais da irradiância solar

Procedimiento de control de calidad para la detección de medidas erróneas de los componentes espectrais da irradiância solar

Received: 11/18/2022 | Revised: 12/04/2022 | Accepted: 12/10/2022 | Published: 12/17/2022

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Abstract

The shortwave solar radiation that arrives under the Earth's surface is spectrally composed of the ultraviolet, photosynthetically active, and near-infrared components. Having information about the availability of these parameters in different locations allows public agencies and scientific institutions to plan, execute, and manage energy projects in Brazil. Therefore, this information can be obtained from weather measurements with wide temporal and spatial coverage. However, the solar radiation measuring process is not an easy task, due to the uncertainties caused by instrumentation and operational problems. Thus, the aim of this study was to implement a procedure for erroneous measurements detection of ultraviolet, photosynthetically active, and near-infrared solar irradiances, collected in Botucatu (SP) - Brazil during the years 2001 to 2006, in sub-hourly temporal resolution (5 minutes in Wm^{-2}), to certify the quality of the obtained measured values. For this purpose, analyzes were carried out by two quality check analyzes, the first one to verify whether the measurements were within physically possible limits and the second one whether they were within extremely rare but accepted limits. It was possible to identify that the near-infrared solar irradiance had the highest number of erroneous measurements flagged (0.310% of the total values), followed by photosynthetically active (0.162% of the total values) and, with less flags, from ultraviolet (0.047% of the total values). Measurements of spectral components of solar irradiances that were not flagged as erroneous by the quality checks procedure are considered valid, and can be used in future scientific investigations.

Keywords: Ultraviolet solar irradiance; Photosynthetically active solar irradiance; Near-infrared solar irradiance; Quality control; Measurements outliers.

Resumo

A radiação solar de ondas curtas que chega sob a superfície da Terra é composta espectralmente pelas componentes ultravioleta, fotossinteticamente ativa e infravermelha-próxima. Ter informações sobre a disponibilidade desses parâmetros em diferentes localidades permite que órgãos públicos e instituições científicas planejem, executem e gerenciem projetos energéticos de forma mais adequada no Brasil. Tal que, pode-se obter tais informações a partir de medições meteorológicas com ampla cobertura temporal e espacial. Porém, o processo de medição da radiação solar não é uma tarefa fácil de ser executada, se comparado a outras variáveis climáticas, devido às incertezas causadas pela instrumentação e problemas operacionais. Neste sentido, o objetivo deste estudo foi implementar um procedimento para detecção de medições errôneas das irradiâncias solares ultravioleta, fotossinteticamente ativa e infravermelha-próxima, coletadas em Botucatu (SP) - Brasil durante os anos de 2001 a 2006, em resolução temporal sub-horária (5 minutos em Wm-2), a fim de certificar a qualidade dos valores obtidos nesse período. Para tanto, foram realizadas duas análises de checagem de qualidade, a primeira para verificar se as medições estavam dentro dos limites fisicamente possíveis e a segunda para identificar se estavam dentro dos limites extremamente raros, mas aceitos. Foi possível identificar que a irradiância solar infravermelha-próxima teve o maior número de medições sinalizadas como errôneas (0,310% do total de valores), seguida da fotossinteticamente ativa (0,162% do total de valores) e, com menos sinalizações, da ultravioleta (0,047% do total de valores). As medições das componentes espectrais da irradiância solar que não foram sinalizadas como errôneas são consideradas válidas e podem ser usadas em futuras investigações científicas.

Palavras-chave: Irradiância solar ultravioleta; Irradiância solar fotossinteticamente ativa; Irradiância solar infravermelha-próxima; Controle de qualidade; Outliers em medições.

Resumen

La radiación solar de onda corta que llega en la superficie de la Tierra está compuesta espectralmente por los componentes ultravioleta, fotosintéticamente activo e infrarrojo cercano. Tener información sobre la disponibilidad de estos parámetros en diferentes lugares permite a los departamentos públicos y instituciones científicas a planificar, ejecutar y gestionar adecuadamente proyectos de energía en Brasil. De manera que, se puede obtener dicha información a partir de mediciones meteorológicas con amplia cobertura temporal y espacial. Sin embargo, el proceso de medición de la radiación solar no es una tarea sencilla, en comparación con o de otras variables climáticas, debido a las incertidumbres provocadas por la instrumentación y problemas operativos. En ese sentido, el objetivo de este estudio fue implementar un procedimiento para la detección de mediciones erróneas de la irradiancia solar ultravioleta, fotosintéticamente activa y del infrarrojo cercano, colectadas en Botucatu (SP) - Brasil durante los años 2001 a 2006, en resolución temporal subhoraria (5 minutos en Wm-2), con el fin de certificar la calidad de los valores obtenidos en este periodo. Para ello se realizaron dos análisis basados en la relación física, el primero para verificar si las medidas se encontraban dentro de los límites físicamente posibles y el segundo para identificar si se encontraban dentro de los límites extremadamente raros pero aceptados. Se pudo identificar que la irradiancia solar del infrarrojo cercano tuvo el mayor número de mediciones señalados como erróneos (0,310% del total de valores), seguida de la fotosintéticamente activa (0,162% del total de valores) y, con menos erros, la ultravioleta (0,047% del total de valores). Las mediciones de los componentes espectrales de la radiación solar que no se marcaron como erróneas se consideran válidas y se pueden utilizar en futuras investigaciones científicas.

Palabras clave: Irradiância solar ultravioleta; Irradiância solar fotosintéticamente activa; Irradiância solar del infrarrojo cercano; Control de calidad; Valores atípicos en las mediciones.

1. Introduction

The shortwave solar irradiance that arrives under the Earth's surface, the global solar radiation, has three primary incoming fluxes, depending on their wavelength, the ultraviolet spectral component with a wavelength of 0.29 to 0.40μm, the photosynthetically active spectral component with a wavelength of 0.40 to 0.70μm and the near-infrared spectral component with wavelength of 0.70 to 2.80μm, according to Escobedo et al. (2011). The ultraviolet spectral component has been used in the treatment of contaminants in residual decomposition of water (Terra et al., 2020), mainly by solar concentrators, and has been used in skin cancer and eye cataracts investigations (Escobedo et al., 2011; Rossi, et al., 2018). The photosynthetically active spectral component is used by the biochemical processes of plants to carry out photosynthesis, what makes it important for agricultural crops (Vignola et al., 2012). Such as, the near-infrared spectral component is used in remote sensing applications to retrieve the total atmospheric water vapor column (Larsen and Stamnes, 2005), as it is being investigated for having a positive impact on vegetative growth in greenhouses (Lamnatou & Chemisana, 2013).

In this sense, having information on the spectral components (ultraviolet, photosynthetically active and near infrared) of solar irradiance fluxes that reaches the Earth's surface allows to conduct scientific investigations in the health, climatology, meteorology, and agriculture areas. This information can be obtained from weather measurements with a wide temporal and spatial scope. However, the process of solar irradiance measuring is not easy, due to uncertainties caused by instrumentation problems, operational negligence, and other environmental difficulties (Younes et al., 2005). According to the World

Meteorological Organization - WMO (2012), instrumentation problems are the main cause of uncertainty in solar irradiance measurements, so that they are originate by sensor construction aspects, such as the response of cosine, azimuth and temperature, spectral selectivity, and instrument stability (Younes et al., 2005). However, operational negligence and environmental difficulties, such as dirt on the sensor dome, incorrect instrument leveling and the occurrence of artificial shadows on the sensor, can also cause uncertainties (Muneer, Younes and Munawwar, 2007).

The uncertainties in the process of solar irradiance measuring have impact on the obtained values, and may result in erroneous measurements, with large deviations, or suspected of being incorrect, with small variations. So that, the uncertainties in measurements can be reduced and investigated based on quality control processes, which include procedures for detecting erroneous measurements. A procedure for detecting erroneous measurements has the purpose of identifying, using different methods, measurements that are suspected of being incorrect and flagging them, so that a decision can be made about it later (Journée and Bertrand, 2011). Therefore, the aim of this study was to implement a procedure for detecting erroneous measurements of ultraviolet, photosynthetically active and near infrared solar irradiances, collected in Botucatu (São Paulo) - Brazil, in sub-hourly temporal resolution (5 minutes) in Wm^{-2}. The procedure will allow to identify values suspected of being incorrect based on modified quality checks of the Baseline Surface Radiation Network (BSRN) quality check rules, created by the World Radiation Monitoring Center (WRMC).

2. Methodology

2.1 Location and Climate

The study was conducted based on Agrometeorology and Solar Radiometry Laboratory measurements (Latitude 22º 54' S, Longitude 48º 27' W and 786m of Altitude) by the School of Agricultural Sciences of the São Paulo State University - UNESP of Botucatu (São Paulo) - Brazil. Botucatu is a city located in the south-central region of the São Paulo state (SP) with a temperate climate characterized by a dry winter (June to August) and a hot and humid summer (December to February). The city has intense agricultural activities with large plantations of sugar cane and eucalyptus, as well as moderate commercial and industrial activities (Codato et al., 2008; Dal Pai et al., 2016). The geographic formation of Botucatu is characterized by hills that comprise two levels of altitude, in the range of 400 to 500 meters in the lowest region, and from 700 to 900 meters in the highest region (Silva et al., 2017).

The historical series of weather measurements (1971 to 2013) obtained by the Lageado Weather Stations (2022), allow to classify the Botucatu (São Paulo) - Brazil climate as Cwa (mesothermal) according to the Köppen climatic criteria. Thus, the city has a temperate and hot climate with well-defined seasons, with the following characteristics (Figure 1):

a) February is the hottest month with an average of 22.5 ºC and July is the coldest with an average of 16.8 ºC.

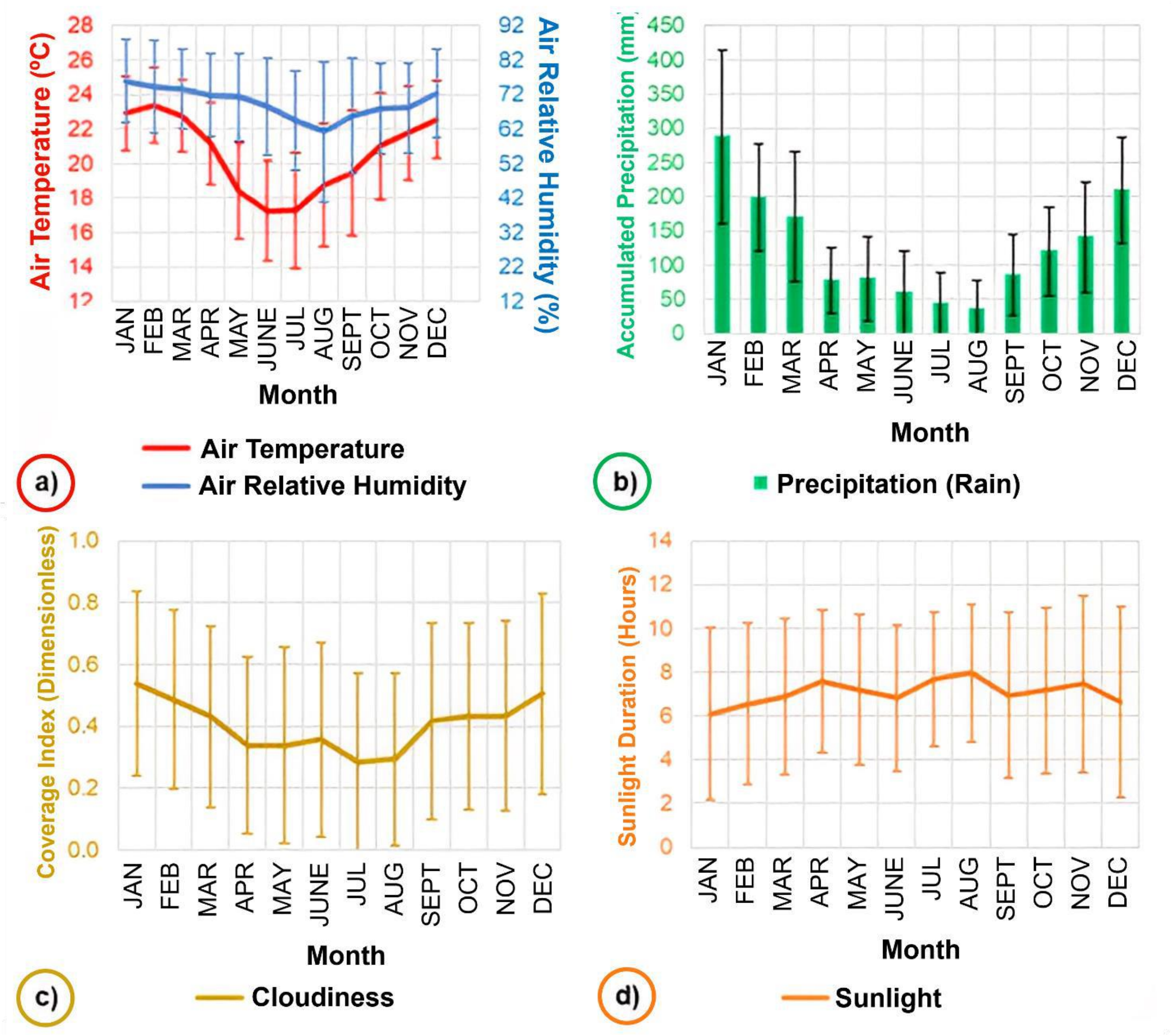
b) January is the month with the highest humidity (average of 75.6%) and August the least (average of 61.20%).

c) January is the rainiest month with 300 mm on precipitation average and August the least with 50 mm on average.

d) January is the cloudiest month with an average index of 0.54 and July the least with an average index of 0.28.

e) Sunlight duration had a minimum average value of 6.1 hours in January and a maximum of 7.9 hours in August.

Figure 1 - Historical Weather Measurements (1971 to 2013) by the Lageado Weather Station (2022).



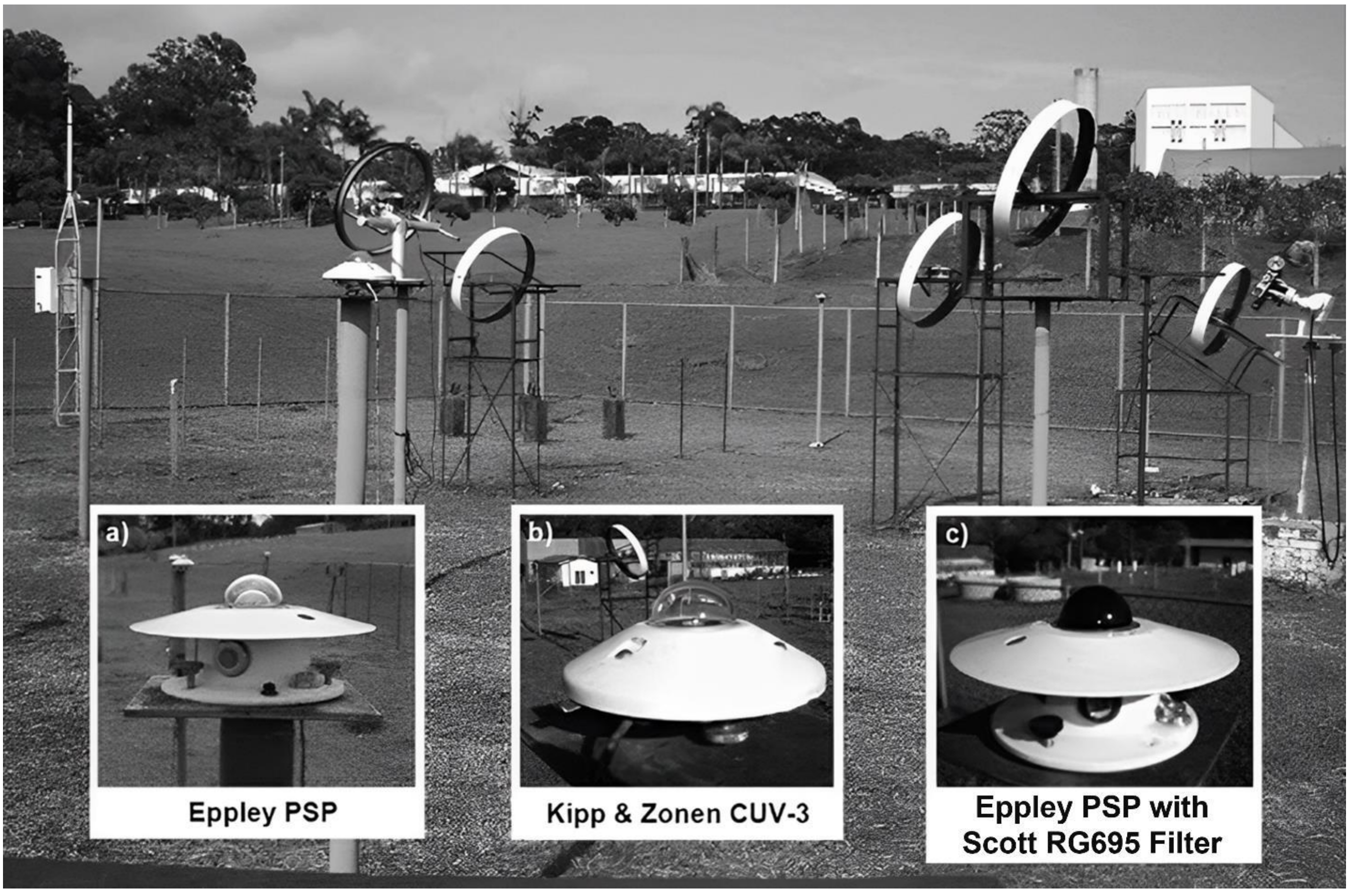
Source: Authors.

2.2 Instruments and Measurements

Diurnal measurements from 2001 to 2006 of ultraviolet (UV) solar irradiance spectral component, measured by a Kipp & Zonen CUV-3 radiometer (Figure 2b), near-infrared (NIR), measured by an Eppley PSP pyranometer with selective transmission dome (Scott Filter RG695) in the spectral range of 0.7 to 3.0μm (Figure 2c), and photosynthetically active (PAR), also known as visible spectral component, obtained indirectly from the difference between global (G), measured by an Eppley PSP pyranometer (Figure 2a), and the sum of ultraviolet and near-infrared (Equation 1), were used. The instruments calibration used during the measurement period was carried out every two years following to the recommendations of the World Meteorological Organization (WMO, 2012), as well as the calibration factor of the Kipp & Zonen (2004) CUV-3 radiometer had to be multiplied by 0.92 to correct possible transmission filter influences on the sensitive element (Escobedo et al., 2011).

$$\mathbf{PAR} = G - (UV + NIR) \tag{1}$$

Figure 2 - Radiometers of the Agrometeorology and Solar Radiometry Laboratory (UNESP) - Botucatu (SP) - Brazil.



Source: Escobedo et al. (2011).

The technical operating instruments properties, such as the factory calibration factor, spectral interval, response time, linearity, cosine response and the temperature of the sensitive element are shown in Table 1. During the measurement experiment period a data logger model CR23X Micrologger by Campbell Scientific (2006) was used. It was configured to scan the spectral components of solar irradiances measurements every 5 seconds and store their average values each 5 minutes, generating 288 measurements points for one day interval. Daily measurements were recorded on an external memory module model SM192 from Campbell Scientific (1993) and weekly were transferred to a data server through an SC532 interface and PC208W software from Campbell Scientific (2001). In this case, there was no computational system to store and process the measurements in a structured way on the data server.

Table 1 - Operational properties of instruments for solar irradiances measurements.

INSTRUMENT FEATURES	**SOLAR IRRADIANCE**		
	GLOBAL	**ULTRAVIOLET**	**NEARINFRARED**
Manufacturer (Model)	Eppley (PSP)	Kipp & Zonen (CUV-3)	Eppley (PSP)
Calibration Factor	7,45 $\mu V/Wm^{-2}$	312 $\mu V/Wm^{-2}$	8,12 $\mu V/Wm^{-2}$
Spectral Range	285 a 2800nm	290 a 400nm	695 a 2800nm
Response Time	1s	5ms	1s
Linearity	± 0,5% de 0 a 2800 Wm^{-2}	< 1%	± 1% de 0 a 700 Wm^{-2}
Cosine Response	± 1% (0° < Z < 70°) ± 3% (70° < Z < 80°)	± 10%	± 5%
Temperature Response	± 1% de -20°C a 40°C	± 0,1/K	± 1% de -20°C a 40°C

Source: Kipp and Zonen (2004), Escobedo et al. (2011) and Eppley (2011).

2.3 Erroneous Measurements Detection Procedure

The quality control process of a measurement system is composed of operational procedures such as instrument calibration, visual inspections, preventive maintenance, erroneous measurements detection and validation. These procedures must be performed routinely to ensure that the instrumentation is correct operation, as well as being able to generate quantitative documents about the quality of the measured values (The Meteorological Resource Center, 2002). A procedure for erroneous values detecting for solar irradiance measurements should be performed based on the application of sequential tests with rules to validate the measures based on some principles, such as (Ohmura et al., 1998): physically possible limits, to analyzes ranges of values; relationship between the quantities measured in other sensors, to analyzes values differences; models for comparison, to analyzes relative deviation, and seasonal variations.

The procedure for detecting erroneous measurements based on two quality was adapted from the quality control methodology created by Long and Dutton (2002) and used in the Baseline Surface Radiation Network. The Baseline Surface Radiation Network is a project of the Data and Analysis Panel from the Global Energy and Water Exchange and is aimed at detecting important changes in the radiation on the Earth's surface which may be related to climate changes, through radiation measurements stations available around the world. The first methodology for data quality control recommended by Baseline Surface Radiation Network is a visual check of the measurement time series graphs to find outliers. The second data quality control methodology is the quality checks tests to prove that the data do not exceed the physically possible limit, do not exceed the extremely rare limit, and is consistent when compared to other measures (WMO, 2013).

Thus, the methodology of Long and Dutton (2002) is used by data scientists at Baseline Surface Radiation Network to identify measured values that exceed the physically possible and extremely rare limits of global, sky-diffuse, and direct-beam solar irradiances. In this case, this methodology was adapted to verify measured values of the ultraviolet, photosynthetically active, and near-infrared solar irradiances were within the physically possible limits (first quality checks applied by the Equations 2, 3 and 4), as well were verified if the measured values were within the extremely rare limits (second quality checks applied by Equations 5, 6 and 7). The measured values that are outside the limits by the first quality checks, should be considered erroneous and are flagged, such that the second quality checks should not be applied. The measured values that are outside the limits of the second quality checks must also be flagged as erroneous.

a) Physically Possible Limits (First Quality Check):

$$-4\ Wm^{-2} \leq \mathbf{UV} \leq I_{CS}\, E_0\, 1{,}5\, Cos(Z)^{1,2} + 100\ Wm^{-2} \quad (2)$$

$$-4\ Wm^{-2} \leq \mathbf{PAR} \leq Ics\, E_0\, 1{,}5\, Cos(Z)^{1,2} + 100\ Wm^{-2} \quad (3)$$

$$-4\ Wm^{-2} \leq \mathbf{NIR} \leq I_{CS}\, E_0\, 1{,}5\, Cos(Z)^{1,2} + 100\ Wm^{-2} \quad (4)$$

b) Extremely Rare Limits (Second Quality Check):

$$-2\ Wm^{-2} \leq \mathbf{UV} \leq I_{CS}\, E_0\, 1{,}2\, Cos(Z)^{1,2} + 50\ Wm^{-2} \quad (5)$$

$$-2\ Wm^{-2} \leq \mathbf{PAR} \leq Ics\, E_0\, 1{,}2\, Cos(Z)^{1,2} + 50\ Wm^{-2} \quad (6)$$

$$-2\ Wm^{-2} \leq \mathbf{NIR} \leq Ics\, E_0\, 1{,}2\, Cos(Z)^{1,2} + 50\ Wm^{-2} \quad (7)$$

In the Equations 2, 3, 4, 5, 6 and 7, the UV is the ultraviolet solar irradiance, PAR is the photosynthetically active solar irradiance and NIR is the near-infrared solar irradiance measured on a horizontal Earth surface (Wm^{-2}). I_{CS} is the solar constant (Wm^{-2}) calculated for each spectral component of the solar irradiance, E_0 (Equation 8) is Sun-Earth distance correction factor (dimensionless), and Z (Equation 9) is the solar zenith angle (degrees).

$$\mathbf{E_{XC}} = 1 - 0{,}0009467\ sen\ (F) - 0{,}01671\ cos\ (F) - 0{,}0001489\ (2\ F) - 0{,}00002917\ sen\ (3\ F) - 0{,}0003438\ cos\ (4\ F) \quad (8)$$

$$\mathbf{Z} = sen\ (\delta)\ sen\ (\phi) + cos\ (\delta)\ cos\ (\phi)\ cos\ (\omega) \quad (9)$$

Such that, F is 360 D/365, where D is the day of the year from the 1st to the 365th, δ is the solar declination in degrees (Equation 10), ϕ is the geographic latitude of Botucatu (São Paulo) - Brazil in degrees (22.85º) and ω is the hour angle in degrees (Equation 11), so that Hd is the expression of hour and tenth of hour of day in decimal format. All the equations for obtaining these values (geospatial ephemeris) were obtained according to the expressions proposed by Iqbal (1983).

$$\boldsymbol{\delta} = 0{,}3964 + 3{,}631\ sen\ (F) - 22{,}97\ cos\ (F) + 0{,}03838\ sen\ (2\ F) - 0{,}3885\ cos\ (2\ F) + 0{,}07659\ sen\ (3\ F) - 0{,}1587\ cos\ (3\ F) - 0{,}01021\ cos\ (4\ F) \quad (10)$$

$$\boldsymbol{\omega} = (12 - Hd)\ 15 \quad (11)$$

The solar constants of the ultraviolet, photosynthetically active, and near-infrared spectral components of the solar irradiances were calculated based on the percentage that each one represents of the global solar irradiance, considering a horizontal surface (Table 2). So that, the ultraviolet spectral component represents 5.7%, the photosynthetically active spectral component represents 38.8% and the near-infrared spectral component represents 55.5%, according to Corrêa (2011).

Table 2 - Solar constant of global, ultraviolet, photosynthetically active, and near-infrared spectral components.

SOLAR IRRADIANCES	SOLAR CONSTANT (I_{CS})
Global	1361 Wm^{-2}
Ultraviolet	77,577 Wm^{-2}
Photosynthetically Active	528,068 Wm^{-2}
Near-Infrared	755,355 Wm^{-2}

Source: Corrêa (2011).

3. Results and Discussion

The ultraviolet solar irradiance had the highest measurements number in 2003 and the lowest in 2001. The photosynthetically active solar irradiance had the highest measurements number in 2006 and the lowest in 2004. The near-infrared solar irradiance has the highest measurements number in 2006 and the lowest in 2004. Considering the total measurements number, the photosynthetically active and ultraviolet solar irradiances have the highest and lowest amount, respectively (Table 3). During the period of the measurement 288 values were acquired per day, considering a year with 365 days, and considering only the daytime period it was expected that each year will have around 52560 measured values. In this sense, considerable gaps were found in the measurement series of the three spectral components of solar irradiance. The biggest failure was 3.44% of missing values of the ultraviolet solar irradiance in 2001, followed by near-infrared solar irradiance in 2004 with a failure of 1.30% of missing measurements and, with less failures, the photosynthetically active solar irradiance which presented a gap of 0.64% of the expected values for the year 2004.

Table 3 - Total number of measured values of solar irradiance from 2001 to 2006.

YEAR	SOLAR IRRADIANCE		
	ULTRAVIOLET	PHOTOSYNTHETICALLY ACTIVE	NEAR-INFRARED
2001	42301	51704	50474
2002	50419	50810	49445
2003	51861	51873	50622
2004	51640	50590	48644
2005	51809	50851	50369
2006	50210	52413	51060
TOTAL	**298240**	**308241**	**300614**

Source: Authors.

In the first quality checks of erroneous measurements detection, where the spectral components measurements of solar irradiance are checked if they are physically possible according to calculated limits (Table 4), the ultraviolet solar irradiance did not have a value flagged as erroneous. The photosynthetically active solar irradiance had the highest number of measurements considered erroneous in 2002 with 146 flagged values, which represent 0.287% of the total values measured in that year, and in 2001 the lowest number, without considering the years not flagged, with 2 values that represent 0.004% of the total values measured in that year. The near-infrared solar irradiance had the highest number of erroneous measurements in 2004 with 713 flagged values, which represent 1.466% of the total in that year, and the lowest number in 2002, again without considering the not flagged years, with 11 flagged values, representing 0.022% of the total for that year. Long and Dutton (2002) suggest adapting the values used to obtain the physically possible limits (Equations 2, 3 and 4) according to the location, however, in a first experiment, the default parameters to obtain the limits were used in this study.

Table 4 - Number of solar irradiances measurements flagged as erroneous by the first quality checks.

YEAR	**SOLAR IRRADIANCE**					
	ULTRAVIOLET		**PHOTOSYNTHETICALLY ACTIVE**		**NEAR-INFRARED**	
	TOTAL	**%**	**TOTAL**	**%**	**TOTAL**	**%**
2001	0	0,000	2	0.004	0	0.000
2002	0	0,000	146	0.287	11	0.022
2003	0	0,000	0	0.000	0	0.000
2004	0	0,000	0	0.000	713	1.466
2005	0	0,000	38	0.075	0	0.000
2006	0	0,000	0	0.000	0	0.000

Source: Authors.

Measurements previously flagged by the procedure were not considered for the next quality checks. Thus, in the second quality checks of erroneous measurements detection, where the limits considered extremely rare are verified (Table 5), the ultraviolet solar irradiance had only 140 values flagged as erroneous in 2006, representing 0.279% of all points measured in that year. The photosynthetically active solar irradiance had the highest number of erroneous measurements in 2002, as well as in the previous quality checks (analysis of the physically possible limits), with 256 measurements flagged, representing 0.504% of the values acquired in that year, and in 2004 it had the lowest number, without considering the year 2006 which did not have flagged measured values, including 1 measure, representing 0.001% of the total obtained in that year. The near-infrared solar irradiance had the highest number of erroneous measurements in 2004, as well as in the previous quality checks, comprising 208 flagged values, which represent 0.428% of the total measured in that year, but the other years did not receive flags, which indicates that no more erroneous measurements were identified.

Table 5 - Number of solar irradiances measurements flagged as erroneous by the second quality checks.

YEAR	SOLAR IRRADIANCE					
	ULTRAVIOLET		PHOTOSYNTHETICALLY ACTIVE		NEAR-INFRARED	
	TOTAL	%	TOTAL	%	TOTAL	%
2001	0	0.000%	13	0.025%	0	0.000%
2002	0	0.000%	256	0.504%	0	0.000%
2003	0	0.000%	2	0.004%	0	0.000%
2004	0	0.000%	1	0.002%	208	0.428%
2005	0	0.000%	41	0.081%	0	0.000%
2006	140	0.279%	0	0.000%	0	0.000%

Source: Authors.

In a general context, near-infrared solar irradiance was the one that generated the greatest number of erroneous measurements in the period from 2001 to 2006, with 932 values flagged by this procedure, representing 0.310% of the total measured values for all years. Followed by photosynthetically active solar irradiance with 499 erroneous measurements, which represent 0.162% of the total for all years. Thus, ultraviolet solar irradiance was the one that generated the least number of erroneous measurements, with only 140 measured values flagged, which represent 0.047% of the total for all years (Table 6). In the first quality checks of erroneous measurements detection (analysis of the physically possible limits) near-infrared solar irradiance had the highest and ultraviolet the lowest number of measured values flagged, representing 0.241% and 0.000% of the total values measured for all years, respectively. In the second quality checks of erroneous measurements detection (analysis of the extremely rare limits) the photosynthetically active solar irradiance had the highest and ultraviolet the lowest number of flagged measured values, representing 0.102% and 0.047% of the total for all years, respectively.

Table 6 - Final number of solar irradiances measurements flagged as erroneous.

PROCEDURE STEPS	SOLAR IRRADIANCE					
	ULTRAVIOLET		PHOTOSYNTHETICALLY ACTIVE		NEAR-INFRARED	
	TOTAL	%	TOTAL	%	TOTAL	%
TOTAL MEASUREMENTS	298240	100,0	308241	100,00	300614	100,00
FIRST QUALITY CHECKS	0	0.000%	186	0.060%	724	0.241%
SECOND QUALITY CHECKS	140	0.047%	313	0.102%	208	0.069%
ERRONEOUS MEASUREMENTS	140	0.047%	499	0.162%	932	0.310%

Caption: Total Measurements - Total number of values measured from 2001 to 2006; First Quality Checks - Rules for analysis of physically possible limits; Second Quality Checks - Rules for analysis of extremely rare limits; and Erroneous Measurements - Total number of values flagged as erroneous from 2001 to 2006. Source: Authors.

There is no in-depth information about the problems that affected the measurement system during the years 2001 to 2006, despite the existence of electronic instrumentation for acquire the spectral components measurements of solar irradiance, there was not a computational management system of the information generated in the period of experiment execution. According to Escobedo et al. (2011), technical problems related to the power supply of instruments in all years of operation of the measurement system were reported, with greater emphasis for the years 2004 and 2005, where 80 and 35 days were disregarded, respectively, and with minor problems for the years 2001, 2002 and 2003, with 1, 15 and 6 days disregarded for each year, respectively, in their study. This problem caused measurement errors, but other error identification methods were used by the authors, such as eliminating measurements at the beginning and end of the day, due to possible shading effects caused by physical objects in the measurement field (Escobedo et al., 20011). Due to the rural location in which measurements were obtained, problems with power supply were common.

It was possible to understand, by exploring the measurements, that most of the erroneous values were above the maximum limit of variation for each of the quality checks. Values greater than the physically possible and extremely rare limits, in this case, indicate a large measurement error, probably caused by a break in the cabling, bad connection of the wires in the datalogger or malfunctioning of the sensor. However, to correctly identify the problem, it would be necessary to have a record of the routine maintenance of the measurement system. It was considered to compare the measurements with the values obtained for the top of the atmosphere. However, this requires more investigation, in exceptional occasions the correct measurements of solar irradiance can exceed the values of the top of the atmosphere due to severe refractive processes, multiple reflections between clouds and shiny surfaces and temperature jumps (WMO, 2013). As in this study, only daytime measurements of solar irradiance were used, therefore, few values below zero were signaled during the day. In general, negative measurements occur at night due to heat loss in the sensor element (thermal offset) and are therefore disregarded in energy studies.

4. Conclusion

The implementation of the erroneous measurement detection procedure for the spectral components of solar irradiance series obtained from 2001 to 2006 by the Agrometeorology and Solar Radiometry Laboratory of the School of Agricultural Sciences (UNESP) of Botucatu (São Paulo) - Brazil, allowed the following conclusions:

a) The near-infrared solar irradiance had the highest number of measurements flagged as erroneous (0,310% in relation to the total values). An exploratory analysis made it possible to identify that all flagged measures were above the maximum limits of variation for each quality checks adopted.

b) Ultraviolet solar irradiance had the lowest number of measurements flagged as erroneous (0.162% of the total values). As previously highlighted, in an exploratory analysis it was found that all flagged values were above the upper limits of variation defined in each of the adopted quality checks.

c) All measurements flagged as erroneous of the spectral components of solar irradiance are considered invalid to be used in future studies. Such that, the number of erroneous measurements detected is low and would not harm the transformation of these measurements to the hourly and daily temporal resolutions.

d) Although the procedure comprises quality checks capable of detecting large measurement errors, mainly related to the possible physical limit, it was identified the need to use a method capable of identifying small erroneous variations in measurements, as a way of complementing the proposed quality checks procedure.

For future quality control studies of the spectral component of solar irradiance measurements, it is suggested the application of a visual check graphs to detect measures that deviate from the standards, then use the quality checks procedure presented in this study to detect large errors and an analysis of the statistical variation of measured series to detect minor errors.

Acknowledgments

The authors would like to thank the São Paulo Research Foundation (FAPESP), the Coordination of Superior Level Staff Improvement (CAPES), the National Council for Scientific and Technological Development (CNPq) and the School of Agricultural Sciences (UNESP) of Botucatu (São Paulo) - Brazil for financial support (scholarships). As well as Professor Dr. João Francisco Escobedo for the valuable knowledge generated over the years on ultraviolet, photosynthetically active, and near-infrared spectral components of solar irradiance.

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