

UV solar radiation in Brazilian cities: A perspective to the ideal time for healthy solar exposure

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ABSTRACT

The UV solar represents less than 10% of the total solar radiation. The main biological effects of UV are the health benefits - vitamin D synthesis, and health risks - damage to cells and DNA as erythema and skin cancer. The aim of this article is to investigate the relationship between UV and global radiation in low and mid-latitudes Brazilian cities and impacts on the ideal time for exposure to vitamin D synthesis. UV radiation have been used to demonstrate the hourly and seasonal variation in João Pessoa/PB (7° S) and Florianópolis/SC (27° S). Results show a high positive correlation between global and UV radiation. In low latitude, the UV present higher differences compared with the one in mid-latitude that there was greater hourly variability. The peak of UV happened around midday (11 am to 1 pm) in both cities with a higher difference in João Pessoa. According to period that could be produce the vitamin D (SEA>20°), it starts before 7 am in all seasons in João Pessoa and at 7 am in the summer and 9 am in the winter in Florianópolis. This study evaluates the periods of low and high UV and alerts to the period of sun exposure aimed at the production of vitamin D and skin damage, since the literature recommends avoiding exposure after 10 am. This investigation contributes to a better understanding of the incidence of UV and adaptations in locations with similar latitudes and climatic characteristics.

KEYWORDS: Global and Ultraviolet Radiance. Latitudes. Daily and seasonal patterns.

1 INTRODUCTION

Solar radiation is the main source of energy on our planet. Ultraviolet radiation (UV) is a part of the electromagnetic spectrum (wavelength range between 100 and 400 nm). It can be classified into three sections: UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm). The UVC band and approximately 90% of the UVB are absorbed by the ozone layer, precipitation, oxygen, and carbon dioxide, which are present in the upper layers of the atmosphere (van der Leun, 2004). However, UVA makes up the largest spectrum that reaches the surface of the Earth, suffering minimal interference from atmospheric components.

Responsible for biological and photochemical transformations in the human body, solar UV establishes a fundamental role in health. Direct effects contribute to the skin (MULLENDERS, 2018), and eye disease (DELCOURT *et al.*, 2014). Excessive exposure to UV rays also implies damage to the DNA of skin cells, such as erythema or sunburn, and, in more severe cases, the development of skin cancer (AUTIER; DORÉ, 2020). On the other hand, UV is essential for vitamin D production in humans and biological factors associated with body clock regulation.

Erythema irradiance involves part of the UVA and UVB range, with the parameter for evaluating UV levels in the skin being represented by the Ultraviolet Index (IUV). The UVI was established as an international standard by the World Health Organization with guidelines for safe sun exposure, defined as a dimensionless, integral, and positive value ranging from 1 (minimal risk) to 11+ (extreme risk) (WHO, 2002). UVI is a simple tool to help people adopt safe behavior regarding UV radiation, specifically to avoid sunburn.

Vitamin D synthesis in the skin due to solar UVB (280–315 nm) radiation is the main source characterized by its spectral action weighted by the response of human skin. There is a specific range of UVB radiation that is weighted for its spectral action to produce vitamin D. The synthesis occurs when a photon of UVB radiation reaches the skin cells. Provitamin D (7-dehydrocholesterol, 7-DHC) is converted to previtamin D in the skin through exposure to UVB radiation. The previtamin D is then isomerized by body heat to form vitamin D₃. Subsequently,

vitamin D3 is transported through the bloodstream to the liver, where it is converted to 25-hydroxyvitamin D (25(OH)D). In the kidneys, the active form of vitamin D, 1,25-dihydroxyvitamin D (1,25(OH)2D), is regulated. The standard measure of vitamin D status is the concentration of 25(OH)D in the blood, without distinction between D2 obtained through diet and supplementation, and D3 from sun exposure (MACLAUGHLIN; ANDERSON; HOLICK, 1982).

Factors that affect vitamin D synthesis are atmospheric and environmental determinants and personal parameters. The first factor interferes with the intensity of ultraviolet radiation through meteorological (ozone, cloudiness, air pollution, aerosol, and albedo), location (latitude), seasonal, and time variables. Personal parameters involve endogenous characteristics such as genetics (age, skin phototype or liver, kidney, bone, and autoimmune diseases) and obesity, and behavioral, cultural, and lifestyle aspects such as percentage of exposed skin, frequency of exposure, clothing, and use of photoprotection (ENGELSEN, 2010; GRANT; BHATTOA; PLUDOWSKI, 2017; HOLICK, 2004). A common “rule of thumb” is that below UV indices (UVI) of 1 to 3 it is impossible to reach an adequate vitamin D status (MCKENZIE; LILEY; JOHNSTON, 2009; WEBB; ENGELSEN, 2008).

UV radiation levels vary by the wavelength range and the position of the sun in the sky or solar elevation angle (SEA). The latter is formed between the horizon line and the radius of the sun and is defined as a function of the latitude and solar declination of the location. Its complementary angle is the solar zenith angle (MADRONICH, 1993). UV incidence starts shortly after sunrise when low solar elevation angles ($\sim 0^\circ$) are predominant even with lower intensity. With SEA close to 90° , UV photons travel shorter distances and have a low probability of absorption by ozone. As this angle approaches the zenith, the proportion of UVB increases in relation to the combined UV band (UVA+UVB), reaching its maximum irradiance at solar noon (WEBB; ENGELSEN, 2008). McKenzie *et al.* (2009) adopted SEA greater than 20° (zeniths below 70°) as a reference for UVB incidence, while Engelsen (2010) assumes that vitamin D synthesis starts with lower intensity for angles greater than 15° and more evident around noon, when they reach values greater than 75° . The model by Webb *et al.* (2011) considered relevant the solar elevation angle above 45° .

Although there is a consensus among dermatologists related to sun exposure risks such as sunburns and eye disease, the literature highlights the midday (near solar time) as the most favorable period to stimulate vitamin D synthesis, as it has a higher incidence of UVB. Therefore, between 10 am and 3 pm is the ideal time for exposure, and excessive exposure with photoprotection is advisable (GRANT; BHATTOA; PLUDOWSKI, 2017; HOLICK, 2004). Vitamin D production, as a function of latitude, season, and skin type, in the spring period (March), and solar noon (SEA = 48°) to Boston (42.5°N) was evaluated. Using the FastRT UV tool, the exposure time sufficient for a standard dose of vitamin D – 1000UI daily (Standard Vitamin D Dose or SDD) for four latitudes, under the incidence of the UVB on a horizontal surface – was simulated. For low latitudes (11.5°N) and phototype I skin exposed at 9 am, they estimated that synthesis occurs after 18 minutes in winter and 9 minutes in summer. For type IV skins, the time doubles to 35 minutes and 19 minutes in the same seasons. Above 60°N , a longer exposure time is recommended (Webb & Engelsen, 2008).

Mckenzie *et al.* (2009) related the solar zenith angle (SZA) of the variables, Ultraviolet Index (UVI), Shadow Rules, and the ratio between UV irradiance for vitamin D and erythema

within the context of Lauder, New Zealand (45° S, 170°L and altitude 370m). The time of sun exposure sufficient to reach the daily dose of vitamin D (1000UI) without sunburns in photo-type II skin was evaluated. It was observed that the variable percentage of exposed skin is inversely proportional to the time required to produce vitamin D. At solar noon during the summer period (SZA<30° or solar elevation >60°) only 1 minute and 10 minutes were needed for 100% and 10% of the body exposed to the sun, respectively, whereas the skin damage started only after 18 minutes. For other phototypes (FITZPATRICK, 1988), a reduction for type I was ± 0.7, double for type IV, and 5 to 10 times for types V to VI. The effect of the shadow rule, which corresponds to the relationship between human height and the dimension of its shadow in the horizontal plane - tangent to the SZA - demonstrated that the lower the shadow factor, the greater the UVI and the less time of sun is needed to synthesize vitamin D.

In recent decades, there has been a progressive increase and great concern related to the amount of UV radiation reaching the surface of the Earth because of the depletion of the stratospheric ozone layer. Vitamin D deficiency has become a worldwide public health problem (HOSSEIN-NEZHAD; HOLICK, 2013). Due to its large territorial extension between latitudes 4°N to 34°S, Brazil is considered a tropical reference and forms part of this epidemiological scenario with high levels of vitamin D deficiency and insufficiency, especially in the south and southeast regions (FONTANIVE *et al.*, 2020; PEREIRA-SANTOS *et al.*, 2018; SANTOS *et al.*, 2012; UNGER *et al.*, 2010).

To evaluate the impacts on health, the World Health Organization recommends monitoring UV incidence for guidance through public health agencies (WHO, 2002). Brazilian governmental and non-governmental initiatives have been put into action to increase public awareness of photoprotection behaviors (BRASIL, 2013; SCHALKA; STEINER, 2014). However, despite its relevance, the survey of UV radiation is still infrequent in most meteorological stations in Brazil, due to the expensive instruments, and maintenance.

As an alternative to address this shortage, national surveys have related the combined (UVA and UVB) UV radiation and the global broadband radiation (280 to 2800nm), which is a measure more easily found in automatic stations. Brazilian investigations showed that the hourly UV irradiance constitutes 5.2% of the global solar irradiance with $R^2 = 0.92$ and errors $MBE\% = 3.09\%$ and $RMSE\% = 15.80\%$ for the city of Recife/PE (LEAL, 2011; TIBA; LEAL, 2012; TIBA; SILVA LEAL, 2017). This estimative reduced to 2.8% in Maceió/AL with $R^2=0.99$ (PORFIRIO *et al.*, 2010) and 4.1% in Botucatu/SP with $R^2 = 0.97$, with errors $MBE\% = -1.67$ and $RMSE\% = 9.94$ (ESCOBEDO *et al.*, 2009). The international studies are more evident in the Northern Hemisphere, especially in mid and high latitude locations (CANADA; PEDROS; BOSCA, 2003; HABTE *et al.*, 2018; MEHNATI *et al.*, 2021; QIN *et al.*, 2020; WRIGHT *et al.*, 2020). Thus, this article aims to investigate the significant relationship between ultraviolet solar and global radiation in Brazilian cities in low and middle latitudes and impacts on the ideal time for exposure to vitamin D synthesis.

2 MATERIALS AND METHOD

2.1 Description of locations

For this study, two representative locations in Brazil were chosen (Figure 1). João Pessoa/Paraíba (7° S, 34° W, 43m) is situated in the northeast region. The meteorological

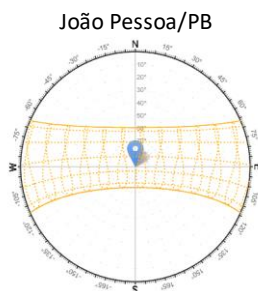
parameters in João Pessoa/PB reach the average temperature of 27°C ($\pm 2.5^\circ\text{C}$), relative humidity of 74% ($\pm 11.6\%$), and global radiation of 1,502.8 KJm⁻², with the peak in January (INMET, 2013). Florianópolis/Santa Catarina (27° S, 48°W, 15m) is located on the coast of the southern region. In Florianópolis the average temperature is 21.6°C ($\pm 4.3^\circ\text{C}$), there is a relative humidity of 78% ($\pm 12.5\%$), and 1,070.7 KJm⁻² of global radiation (INMET, 2020).

Figure 1 – Location of (a) João Pessoa/PB and (b) Florianópolis/SC

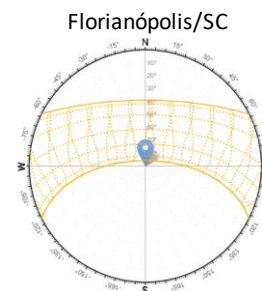


Figure 2 shows the solar charts and some particularities of the sites. Although they are both coastal locations, their climatic characteristics are distinct. The Koeppen classification defines João Pessoa as a humid tropical climate with its wettest period in June. Florianópolis has a humid subtropical climate, with hot summers and cold winters. The climate on the city is determined by tropical and polar air masses, abundant rainfall, with the peak temperature in summer, especially in January. Cold winters and hot summers are characteristics of this location.

Figure 2 – Characteristics of cities



Latitude: 7° 6' S; Longitude: 34° 51' W, Alt: 40m
Solar noon in winter=59°26' and summer=73°40'
Photoperiod in winter=11:43 and in summer=12h32



Latitude: 27° 35' S; Longitude: 48° 32' W, Alt: 15m
Solar noon in winter=38°57' and summer=85°50'
Photoperiod in winter=10:26 and in summer=1:53

2.2. UV measurements and data collection

The UV data were collected with ultraviolet index (UVI) spectrally weighted action for erythema due to the lack of long-term measurements of this magnitude for a low latitude city (João Pessoa). The measurements were conducted from 6 am to 6 pm (Brasilia Time Zone: -3h BRT) during the period 1st January to 31st December 2013 in time series over 1h intervals. The instrument Davis Vantage Pro2 weather station was installed on the site with an unobstructed view on the Federal University of Paraíba. These data were estimated from the application of the statistical model developed for the city of Recife (8° 04' S, 34° 55' W, 4m) that estimates the UVI in broadband ultraviolet radiation (in Wm⁻²) with spectral range from 280 to 450nm, with R², standard errors MBE% and RMSE% equal to 0.90, 0.41, and 14.07, respectively (TIBA; LEAL, 2012; TIBA; SILVA LEAL, 2017), defined by Equation 1.

Equation 1 – Dimensionless model to conversion UV in UVI

$$UVI = 0,2321 * UV - 1,3411$$

where UVI = Ultraviolet Index (dimensionless), e UV = UVA+UVB (Wm⁻²)

For a mid-latitude location, the UV irradiation data were measured at the same time series in 2020. The monitoring station is deployed at Photovoltaic Lab, at the Federal University of Santa Catarina in Florianópolis/SC, Brazil (MANTELLI; MARTINS; RUTHER, 2020). Measurements have a peak of 400Wm⁻² ±0.58Wm⁻² and a spectral range of 280 to 400 nm (UVA and UVB). To evaluate the global irradiance, the annual hourly measurements available in the database of the National Institute of Meteorology were used and collected at automatic stations installed in both cities. Therefore, the same time series of ultraviolet radiation measurements were followed (INMET, 2013, 2020).

2.3. Statistical analysis

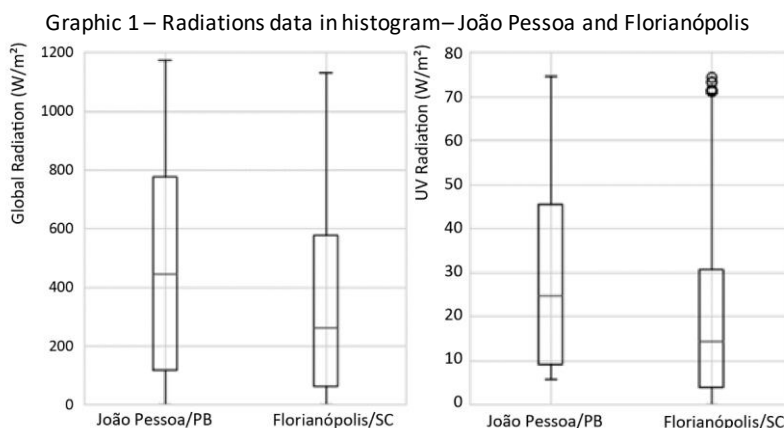
All statistical analyses were performed using RStudio Software v.1.3 (RSTUDIO TEAM, 2022). All the experiments were performed with a 95% interval confidence and a p-value < 0.05 as statistically significant. The application of the Lilliefors statistic test detected non-normality in data distribution (p-values < 2.2*10⁻¹⁶). So, the nonparametric Spearman correlation test was used to compare the relationship between global and ultraviolet radiance. The Wilcoxon test was applied to verify the equality (null hypothesis) or difference (alternative hypothesis) of the hourly and monthly UV (Wm⁻²) in João Pessoa and Florianópolis. In addition, boxplots and line graphs were used to represent the behavior of radiation as a function of temporal parameters and to verify the hourly and seasonal pattern (seasons of the year)

The minimum standard for seasonal vitamin D synthesis was evaluated according to the period in which each season of the year starts, as well as the solar elevation angles (SEA). SEA greater than 20° was adopted as a time reference (or solar zenith angle belows 70°), with the minimum limit representing the beginning of UVB incidence in the atmosphere, even at a lower intensity. For peak hours of UVB radiation, SEA between 70° and 90° (20° < SZA < 0°) was considered, corresponding to hours close to solar noon (MCKENZIE; LILEY; JOHNSTON, 2009).

The data were collected according to the legal time (standard time) converted into true solar time and in SEA using the Tropsolar software (CABÚS; RIBEIRO, 2015). In addition, the distributions of UV radiation as a function of SEA were analyzed.

3. RESULTS AND DISCUSSION

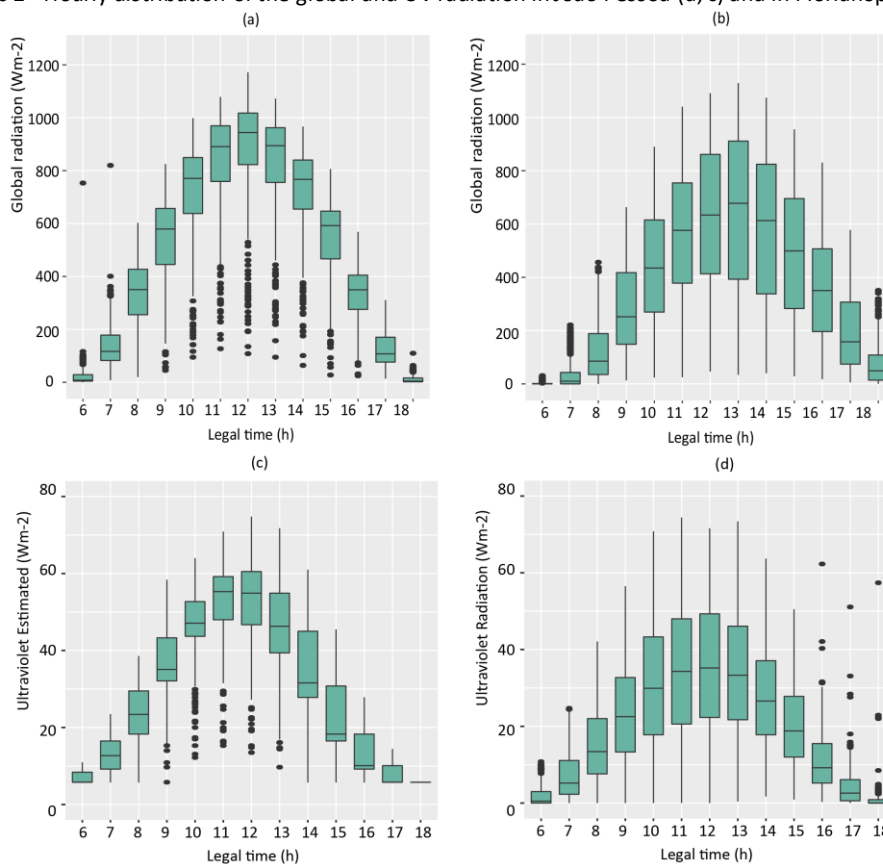
Within the scope of descriptive statistics, the dataset was parsed into dependent variables: Global Radiation and UV Radiation for both cities, while the temporal span (monthly and seasonal) served as independent variables. Examination of the boxplots depicted in Graphic 1 revealed a positively skewed distribution for the variables, with data clustering below the mean and a pronounced rightward curve. Notably, there is a prevalence of lower values in both variables, particularly evident in UV Radiation. Moreover, the data for João Pessoa demonstrates a wider distribution with relatively elevated medians compared to Florianópolis.



3.1 Comparing UV versus global solar radiation

Data related to hourly radiation records for the cities of João Pessoa/PB (Graphic 2a and 2c) and Florianópolis/SC (Graphic 2) presented non-normal distribution. The median data were used as a measure of analysis. The annual global irradiance in João Pessoa presented higher occurrences of outliers below the lower quartile, especially between 10 am and 3 pm and higher medians achieved values at 800 and 1000Wm⁻² (Graphic 2a). In Florianópolis, the hourly data showed greater variation in legal time noon (Graphic 2b).

Graphic 2 - Hourly distribution of the global and UV radiation in João Pessoa (a, c) and in Florianópolis (b, d)



The ultraviolet radiation data for João Pessoa was registered from the UV Index with the minimum value calculated was 6Wm⁻² when the UVI was null, from 6 am to 6 pm - legal time (Graphic 2c). In Florianópolis, results indicate an amount of hourly variation, and the occurrence of values close to zero at the beginning and at the end of the day (Graphic 2d). In João Pessoa UV medians recorded above 50Wm⁻² between 11 am and 1 pm – legal time. In contrast, Florianópolis/SC reached higher UV medians close to 30Wm⁻² at the same time range. Greater variability of the data was observed in a middle latitude (27°), decreased to zero, and maximums above 70Wm⁻², especially from 10 am to 1 pm (legal time). In low latitude (7°), higher and lower occurrences were reached above 70Wm⁻² and 20Wm⁻², respectively. At 6 am and 6 pm, the lowest UV irradiance was above 6Wm⁻² for João Pessoa and close to zero for Florianópolis.

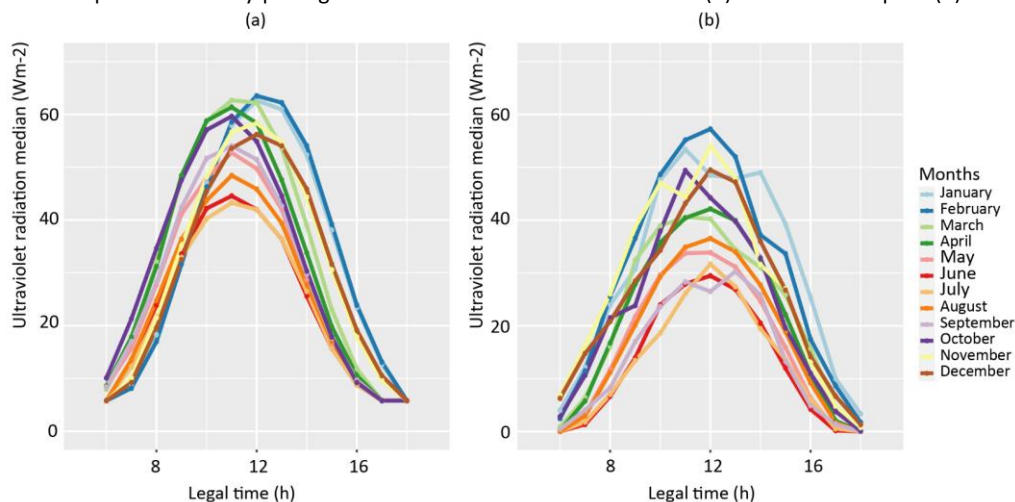
As data with non-normal distribution, the association of the variables was measured using Spearman's non-parametric correlation test, “ρ” (/rho), which determines the degree of dependence ranks and resulted in a high correlation ($\rho > +0.80$) between global and UV radiation, +0.89 for João Pessoa and +0.80 for Florianópolis.

3.2. Ultraviolet radiation: monthly and seasonal variation

The daily changes from the hourly medians of UV for the two cities are shown in Graphic 3. The results demonstrated that the highest UV radiation occurred at legal time noon.

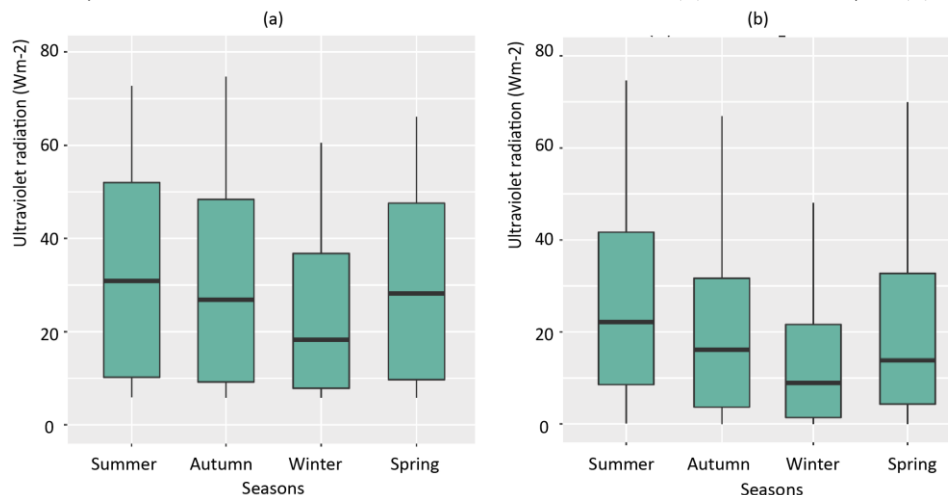
However, UV medians decreased especially in the winter months (June/July). For this season, the attenuation effects of UV radiation are caused by the increased rains and scattering cloudiness in João Pessoa/PB and the lower SEA, fully overcast skies, and the shorter photoperiod or day length in Florianópolis/SC. UV radiation reached values above 60Wm^{-2} in a range from 10 am and 1 pm from January to April (summer and autumn) in João Pessoa (Graphic 3a) and got the maximum medians above 50Wm^{-2} , not exceeding 60Wm^{-2} , in January, February, and November in Florianópolis (Graphic 3b). At the beginning and at the end of the day (6 am and 6 pm), the medians ranged from 0 to 10Wm^{-2} .

Graphic 3 – Monthly per legal time for UV medians in João Pessoa (a) and in Florianópolis (b)

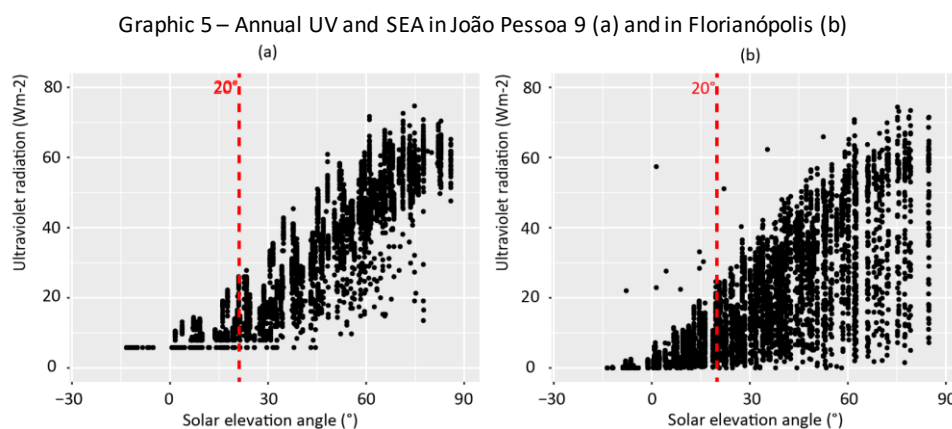


The seasonal distribution of UV is quite like the median hourly behavior with higher levels of UV radiation in João Pessoa (Graphic 4). Values were also slightly higher than in summer, with 50% of the data between 10Wm^{-2} and 50Wm^{-2} and a median close to 30Wm^{-2} . Results suggest similar performance in autumn and spring. In Florianópolis, there was greater variability between the third and upper quartile. The lowest occurred in winter with a median close to 10Wm^{-2} and variation between 5 and 20Wm^{-2} in the interquartile range.

Graphic 4 – Seasonal variations of UV radiation in João Pessoa 9 (a) and in Florianópolis (b)

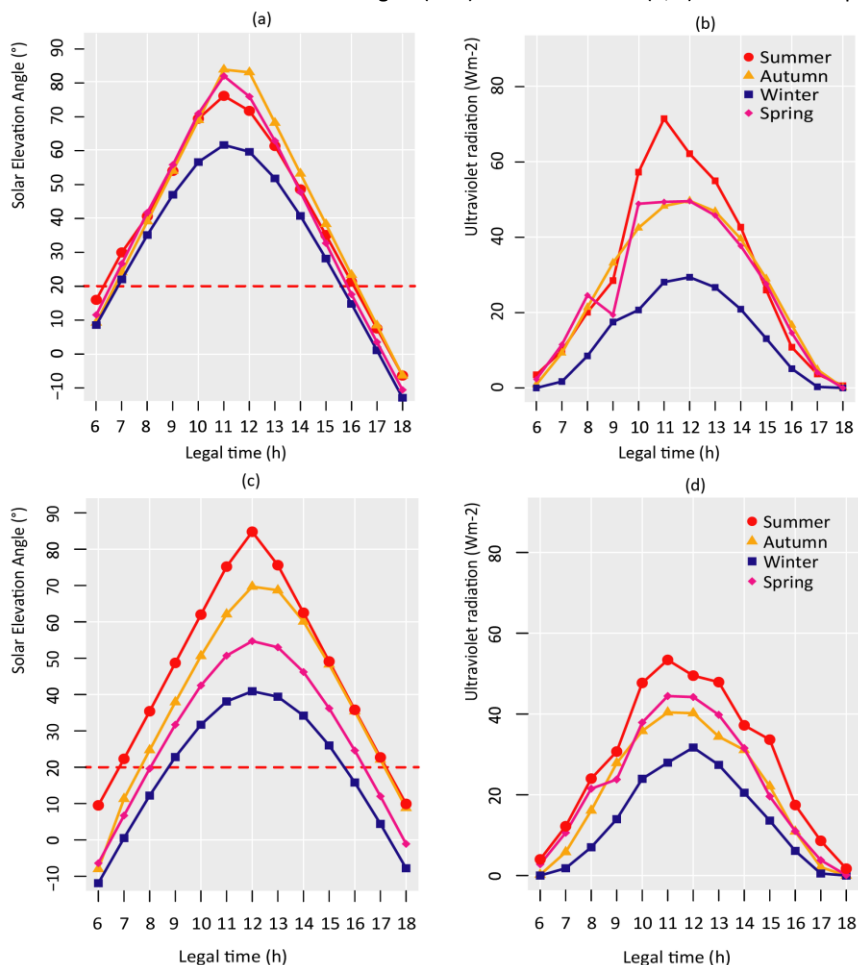


To evaluate the patterns of vitamin D synthesis, a SEA higher than 20° was adopted. There is a greater daily intensity of UVB radiation at SEA close to 90°, due to the reduction of relative air masses. The annual behavior of UV irradiation as a function of the SEA for the cities is shown in Graphic 5. The maximum UV values were reached when the sun reached higher positions in the sky, more precisely at solar noon (SEA~90°). In angles above 20°, João Pessoa achieved higher UV than Florianópolis. A rise in the dispersion of irradiance was obtained at a middle latitude, even at angles closer to the peak SEA, due to the possible variation in atmospheric conditions and the increase of clouds. For this latitude, an interference of the seasonal effect is also evident.



Using as a reference the day which begins each season, legal time and solar time were related, as well as UV irradiance in cities. For João Pessoa (Graphic 6), autumn and spring have a greater SEA close to solar noon (local time = 11:30 am), reaching approximately 80°. Considering SEA above 20° for reference of vitamin D synthesis, the daily margin of UVB radiation in the low-latitude city is from 7 am until 3:30 pm for the winter with a peak SEA of 60° at 11 am (legal time). The maximum values of UV radiation were 63Wm⁻², 60Wm⁻², 57Wm⁻², and 45Wm⁻² in the summer, autumn, spring, and winter, respectively.

Graphic 6 - UV radiation and solar elevation angles (SEA) in João Pessoa 9 (a, b) and in Florianópolis (c, d)



For the middle latitude in Florianópolis, the lowest SEA (from -10° to 40°) is reached in winter and, consequently, the lowest ultraviolet radiation. In summer, SEA reaches 10° and exceeds 80°. The midday solar irradiances registered 30Wm-2 in winter up to 55Wm-2 in summer. In autumn and spring, UV achieved values close to 40Wm-2. As for the possibility of vitamin D synthesis, the daily range to Florianópolis is from 8:30 am to 3 pm in winter and from 7 am to 5 pm in summer, with a peak close to legal noon.

3.3. Statistics difference between the cities

In the non-parametric Wilcoxon Rank test, the UV radiation in João Pessoa was higher than Florianópolis with a statistically significant difference ($V= 9501899$, $p < 0.001$) (Graphic 7). The difference in the estimated values tends to be 7.54 Wm-2 with a 95% confidence interval ranging between 7.18 and 7.91. Graphic 7 and Table 1 show, respectively, the distribution of UV radiation in cities by time ranges (with emphasis on the medians) and the result of the hypothesis test with the estimated differences at five specific times (from 8 am to 4 pm).

Graphic 7 – Distribution of ultraviolet radiation by time ranges in João Pessoa 9 (a) and Florianópolis (b)

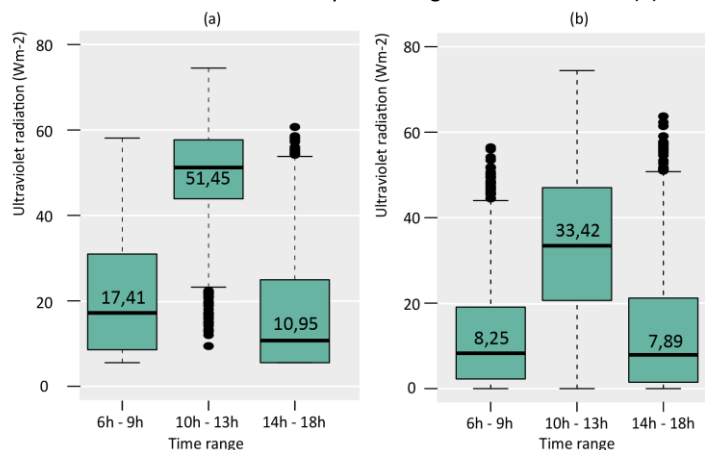


Table 1 – Wilcoxon test – UV radiation differences in cities

Legal Time	Confidence Interval	Estimated Difference (Wm-2)
Morning – 8 am	7.85 – 10.42	9.14
Morning – 10 am	15.21 – 19.13	17.19
Midday – 12 pm	14.69 – 19.47	17.07
Afternoon – 2 pm	5.67 – 9.47	7.48
Afternoon – 4 pm	1.90 – 3.57	2.75

Table 2 – Wilcoxon test result - monthly differences between cities

Season-Month	Confidence Interval	Estimated Difference (Wm-2)
Summer - January	1.55 – 3.72	2.57
Autumn – March	8.08 – 11.06	9.50
Winter - August	6.97 – 8.97	7.96
Spring - November	2.31 – 5.24	3.72

In the morning, the estimated difference in UV radiation between cities is 9.14 Wm-2 at 8 am and goes to 17.19 Wm-2 at 10 am, and this constance goes until noon (17.07 Wm-2). A gradual reduction was reached in the afternoon with 2.75 Wm-2 at 4 pm. According to the monthly medians, the estimates of UV irradiance in the most representative months of each season of the year were compared and presented in Table 2. The greatest effects of the differences are in autumn (March) with 9.50 Wm-2 and in winter (August) with 7.96 Wm-2. In contrast, January (summer) and November (spring) reduced to 2.57 Wm-2 and 3.72 Wm-2, respectively.

4. CONCLUSION

This study specified the relation between global and ultraviolet irradiance in Brazilian cities with low and mid-latitudes (7°S and 27°S). Annual values of UV radiation in a time series were collected at stations installed in the cities of João Pessoa/PB (INMET, 2013) and Florianópolis/SC (INMET, 2020). The hourly radiations reached greater variations when compared to the seasonal ones. The mid-latitude city showed a higher variability of the hourly data with a minimum tending to zero. Moreover, a strong relationship was observed between UV and global radiation, with a positive trend ($\rho \geq 0.80$). The peak values were observed at times

close to legal noon, due to the reduction of air masses and the clear sky conditions, being close to 11 am in João Pessoa and between 12 pm and 1 pm in Florianópolis.

Another potential factor that justifies high UV irradiance is the solar elevation angle, which is higher at midday. The SEA is a reference because it is the period that starts the incidence of UVB in the atmosphere with the possibility of vitamin D synthesis. The maximum UVB time is believed to be responsible for both sunburn and skin cancer, so it's equally important to determine these time frames in each city. In João Pessoa, the SEA > 20° is reached before 7 am, with minimal differences between seasons. Whereas, in Florianópolis, the sun reaches its minimum height at 7 am in summer and 9 am in winter. Considering the recommendation time by (MCKENZIE; LILEY; JOHNSTON, 2009), the vitamin D production in both cities begins before the criterion based on studies by (HOLICK, 2004). Knowledge of the optimum sun exposure times can be highly effective in preventing vitamin D deficiency and avoiding the harmful consequences of excess sunlight.

Being geographically located very close to the equator is the cause of high levels of radiation (global and UV) practically during the entire year in the State of Paraíba, particularly in the capital João Pessoa. Therefore, João Pessoa showed the highest estimated difference at legal noon (17.09 Wm⁻²) and the lowest at 4 pm (2.54 Wm⁻²) compared to Florianópolis. In addition to latitude, being at 45m above sea level may have interfered with these differences, as well as caused changes in the intensity of radiation. The summer reached a high incidence of ultraviolet radiation because it is a period with a low frequency of cloudiness for the cities. However, the autumn presented the highest estimated UV difference, with 9.50 Wm⁻² in João Pessoa. Despite the lower concentration of O₃ during the winter and rains, there is an increase in cloudiness and relative humidity, which are causes of the attenuation of UV radiation, reaching differences of 7.96 Wm⁻².

UV irradiances close to solar noon may pose a considerable health risk, even if they are sufficient to guarantee vitamin D synthesis. Thus, it is essential to verify the minimum hourly and the time range in which UV is achieved in the atmosphere. This kind of study clarifies and enables recommendations on periods of low and high intensity, considering the different ranges of ultraviolet A and B, as well as implications such as skin damage and stimulation of vitamin D. Even so, they contribute to a better understanding of the incidence of ultraviolet irradiance in locations with similar latitudes and climatic characteristics.

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