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Special Edition

UV index seasonal variability in an Amazonian city of Brazil based on satellite data

Variabilidade sazonal do Índice UV em uma cidade Amazônica do Brasil com base em dados de satélite

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ABSTRACT

The solar ultraviolet radiation - UV (280-400 nm) is a highly energetic component of the solar spectrum that needs to be monitored especially because of the effects on human health and on the ecosystems. The UV index (UVI) is a dimensionless indicator designed to report the intensity of UV incident on the Earth's surface. It has five exposure categories, ranging from low to extreme, with recommended sun protections at each level. The higher the value, the greater the health risk. With only few stations reporting long-term ground-based UV measurements in several countries, which significantly restricts its extrapolations to all populated areas, a way for continuous monitoring UV on a global scale is through satellites. In this work, the monthly and seasonal variability of the incident UVI in Santarém, Pará, was analyzed. For this, a 13-year time series of daily UVI data from the OMI satellite instrument was used, as well as the 13-year UVI time series from the GOME-2 satellite instrument. According to the results, the dry period (July to December) shows higher average UVI than the rainy period (January to June) for the GOME-2 time series. The rainy period, on the other hand, in both series presents greater amplitude in the variability of the UVI.

Keywords: Solar ultraviolet radiation; Temporal variability; Santarém-Brazil

RESUMO

A radiação solar ultravioleta - UV (280-400 nm) é um componente altamente energético do espectro solar que precisa ser monitorado especialmente devido aos efeitos sobre a saúde humana e sobre os ecossistemas. O índice UV (IUV) é um indicador sem dimensões projetado para relatar a intensidade do incidente UV na superfície terrestre. Ele tem cinco categorias de exposição, variando de baixa a extrema, com as proteções solares recomendadas em cada nível. Quanto maior o valor, maior é o risco à saúde. Com apenas poucas estações relatando medições UV de longo prazo no solo em vários países, o que restringe significativamente suas extrapolações para todas as áreas povoadas, uma forma de monitoramento contínuo da radiação UV em escala global é através de satélites. Neste trabalho, a variabilidade mensal e sazonal do IUV em Santarém, Pará, foi analisada. Para isto, foi utilizada uma série temporal de 16 anos de dados diários de IUV derivados do instrumento de satélite OMI, bem como a série temporal de IUV de 13 anos do instrumento de satélite GOME-2. De acordo com os resultados, o período seco (julho a dezembro) mostra uma média de IUV maior do que o período chuvoso (janeiro a junho) para a série temporal do GOME-2. O período chuvoso, por outro lado, em ambas as séries apresenta uma maior amplitude na variabilidade do IUV.

Palavras-chave: Radiação solar ultravioleta; Variabilidade temporal; Santarém-Brasil

1 INTRODUCTION

Solar Ultraviolet Radiation (UV) is an important environmental parameter, affecting living organisms, materials, and atmospheric chemical processes (Medhaug et al., 2009). UVR corresponds to electromagnetic waves with wavelengths of 100-400 nm, constituting approximately 5% of the energy emitted by the sun (Cadet et al., 2020). Beside this small percentage, UVR affects the biosphere having both benefits and detrimental effects, whose relative importance depends strongly on time of exposure, latitude, season and on various meteorological parameters like total ozone, clouds, aerosols, and surface albedo (Porfírio et al., 2012; Brogniez et al., 2016).

Diseases related to the accumulation of UVR exposure, like skin cancer and cataract, are largely preventable with proper sun protection (Who, 2002). In view of the need for this type of information, the World Health Organization – WHO released the Ultraviolet Index - UVI, a dimensionless indicator that inform the amount of UVR that reaches the Earth’s surface and has varying values on a scale from 0 to 11 or more (Who, 2002). Based on this scale, the Who defines five exposure categories, ranging from low to extreme, with recommended protections at each level.

UVR data measured by ground-based monitoring stations comprise an essential component of datasets of UVR, however, these measuring facilities are limited in number at only certain locations due to the cost of these facilities and the need for skilled maintenance personnel (Parisi et al., 2021). With only few stations reporting long-term UVR measurements in several countries (like Brazil), which significantly restricts its extrapolations to all populated areas (Gonzáles-Rodríguez et al., 2022), the only way for continuous monitoring UVR on a global scale is through satellites, although ground-based monitoring of UVR is more accurate than satellite retrievals (Kosmopoulos et al, 2021).

In Brazil, there are still few cities monitoring surface UVR, and fewer are those monitoring it continuously for more than 10 years (Teramoto et al., 2014). In the Brazilian Amazon region, the lack of ground-based UVR data is even greater (Reis et al., 2022) with only two published papers using ground-based UVR measurements in the region. One for the city of Humaitá in the state of Amazonas (Alves et al., 2022). The other one, for the city of Santarém, state of Pará, both published in 2022 and using only data referring to the years 2019 and 2020 (Reis et al., 2022).

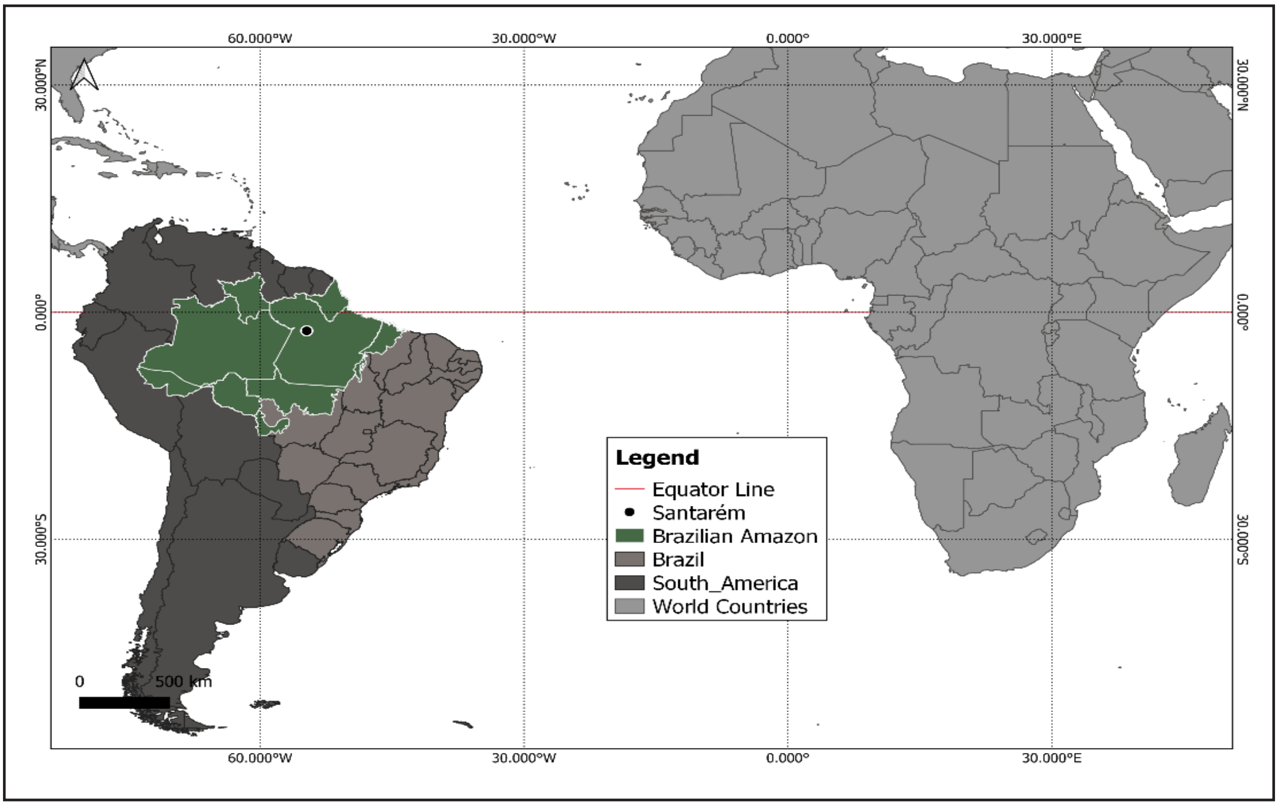
In addition, the Amazon region is under increasing threat from both climate change and human practices such as deforestation and biomass burning (Bevan et al., 2009). Thus, cities such as Santarém, the study area of this research, may become a common pattern, representing a new challenge to understanding the atmosphere-biosphere interactions. Furthermore, even with the importance of monitoring UVR, especially in a tropical region, at a low altitude, where there is a low photoperiod variation and higher UVR throughout the year (Reis et al., 2022), Santarém does not have a ground-based weather station monitoring UVR over a long period, and satellite data is needed for a better understanding of how UVR varies in this area.

Therefore, given the UVR importance and the lack of ground-based data the aim of this study is to characterize the monthly and seasonal variability at Santarém, Pará, using satellite data. This research represents an important scientific contribution regarding UV patterns in an Amazonian city. In addition, to serve as a basis for future research, for better understanding about UV variability and to be considered for the development of an excess UV exposure prevention strategy.

2 MATERIAL AND METHODS

Santarém (2°25'S, 54°44'W) is situated in the Western Pará, in North of Brazil at approximately 51 m above sea level (Figure 1).

Figure 1 – Map showing the location of Santarém in north Brazil



Source: Authors (2022)

The climate in Santarém is humid equatorial with a well-defined dry and wet seasons (Alvares et al., 2013). Precipitation in Santarém is dominated by convection with a summer rainy and a winter dry season (Bevan et al., 2009). The rainy season generally lasts from January to June. The dry season comprises the months between July and December (Jacinto et al., 2006). This area also presents small variability in relative humidity, air temperature, atmospheric pressure, wind speed and UVR, due its location at tropical latitude, close to the Equator (Andrade & Corrêa, 2014; Reis et al., 2022).

2.1 UV index derived from satellite-based instruments

The main objective of this study is to characterize the temporal variability of UVR in monthly and seasonal time scale. To this end, daily time series of UVI obtained from the OMI instrument (Ozone Monitoring Instrument) on board the AURA satellite and from GOME-2 instrument (Global Ozone Monitoring Experiment) on board the Metop-A/B/C satellites are used. All this data is available online and free for download through the websites listed on table 1.

Table 1 – Satellite sources of UV index data

Satellite	Instrument	Type of data	Time	Website
AURA	OMI	UVI	01/2008–12/2021	https://giovanni.gsfc.nasa.gov/giovanni/
Metop-A/B/C	Gome-2	UVI	01/2008–12/2021	https://safserver.fmi.fi/index.html

Source: Organized by the authors (2022)

The study period is from 2005 to 2021, varying according to each data source (Table 1 - Time). The UVI is a dimensionless indicator, usually divided into five risk categories: UVI < 2 (low); 2 ≤ UVI < 5 (medium); 5 ≤ UVI < 7 (high); 7 ≤ UVI < 11 (very high); and UVI ≥ 11 (extreme). This index is defined by the equation (1) (WHO, 2002).

$$UVI = K_{er} \int_{250nm}^{400nm} E_{\lambda} S_{er} d\lambda \quad (1)$$

where is a scaling factor originally equal to 40m2W-1,Eλ is the erythemal action spectrum, and is the spectral solar irradiance at the surface (Who, 2002; Parra et al., 2019).

2.2 OMI data

The OMI is a nadir viewing spectrometer that measures solar reflected and backscattered light in a selected range of ultraviolet and visible spectrum (Levelt et al., 2006, Ialongo et al., 2011). This instrument is onboard the NASA EOS Aura spacecraft, flying in a sun-synchronous polar orbit since July 2004 (Ialongo et al., 2011). The Aura satellite crosses the equator at 1:45 pm local time, providing global daily coverage of ozone columns and profiles, aerosols, clouds, spectral irradiance data at solar noon in the UVA waveband at 324 nm and 380 nm, as well as in the UVB waveband at 305 nm and 310 nm, solar noon daily erythemal irradiance, erythemal daily exposure and the solar noon UVI (used in this study) (Ialongo et al., 2011, Parisi et al., 2020). The OMI-based evaluation is of the order of 7% to 30% higher than ground measured data, due to absorbing aerosols in the boundary layer not being taken into account (Parisi et al., 2020). Also, additional errors sources are changes in the cloud cover between the satellite overpass time and solar noon, variations over the size of a pixel, diurnal variations in the cloud cover for the calculation of daily exposures and variations in albedo and aerosols (Tanskanen et al., 2006).

2.3 GOME-2 data

The GOME-2 instrumentation is an optical spectrometer on board the three Metop sun-synchronous polar orbiting satellites of Metop-A, Metop-B and Metop-C (Kujanpää & Kalakoski, 2015). The first Metop satellite was launched in 2006, with the other two following at five-year intervals (Krebs, 2022). The GOME-2 instrument provides UV data products as well information on atmospheric trace gases. Daily maximum UVA (315-400 nm) irradiance at solar noon, total daily UVA exposure, total daily erythemal irradiance, unweighted UVB, solar noon UVI and other products are provided by this instrument. Comparison with ground-based data has shown that the GOME-2 daily erythema UV exposures are generally higher by 10%-20% (Parisi et al.,2021).

2.3 Statistical Analysis

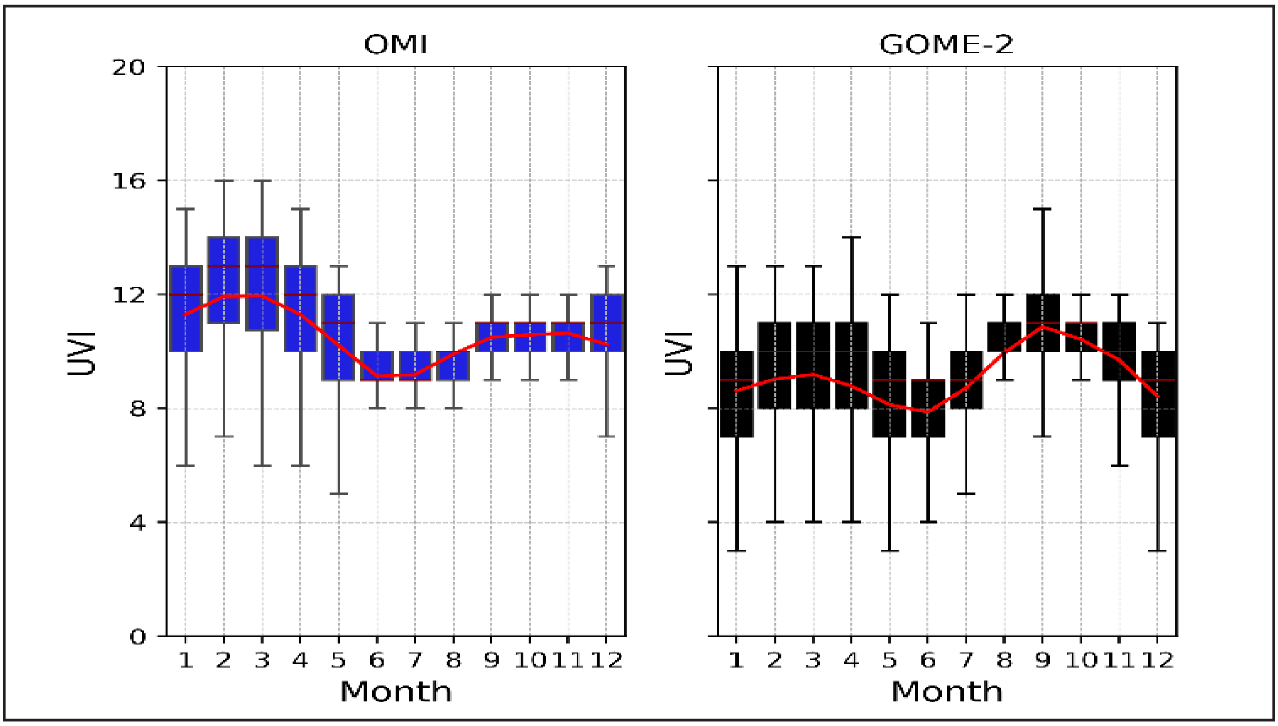
To provide information about data variability using statistical measures, boxplots were prepared. From the daily measurements, the monthly distribution was also performed, as well the discussion of the seasonal distribution of the year (rainy period and dry period).

3 RESULTS

In this section, the UVI time variability is presented to demonstrate how UVI varies in monthly and seasonal time scale, according to the 2 satellite-instruments data.

3.1 UV index monthly and seasonal variability

Figure 2 – Monthly variability for OMI and GOME-2 time series at Santarém (month average in red line) over 2008-2021 periods



Source: Authors (2022)

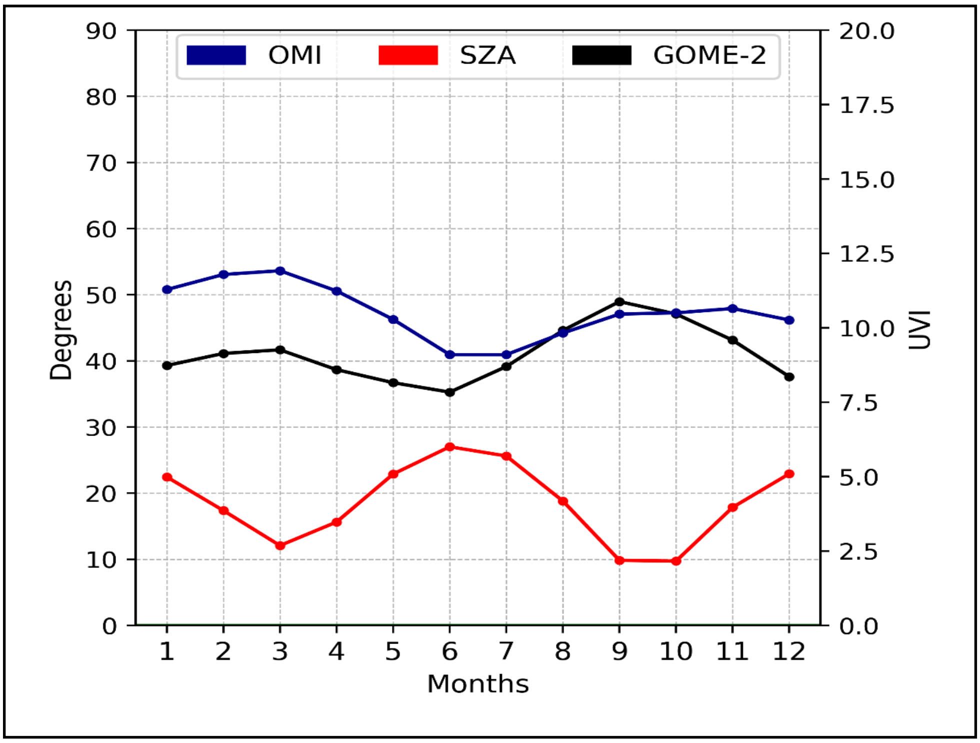
The Figure 2 presents the UVI monthly variability at Santarém according to OMI and GOME-2 time series. The seasonal characteristic is evident, with the lowest averages recorded in the early austral winter months, with the average increasing with the arrival of spring and summer.

Generally, one of the main factors affecting the intensity of UVI is the season of the year: in summer the sun is higher than in winter, resulting in more intense UVI in summer than in winter (Sacchetti *et al.*, 2022), even though, at Santarem's latitude (equatorial), one does not distinguish four seasons, but only two seasons, summer and winter, which correspond to the rainy and dry seasons, respectively (Reis et al., 2022). It is also possible to observe that the OMI series presented higher UVI than the GOME-2 series, as for example, with the UV index levels achieving 16 in the raining period. These higher levels were expected, since the literature describes that UVR data from OMI are more over estimated when compared to ground-based data, than GOME-2 data (Ialongo et al., 2011, Brogniez et al., 2016, ParisI et al., 2021).

As can be seen in Figure 2, the minimum records in both time series occurred in the rainy period months. However, the averages and maximums were higher in this period for the OMI series, while for the GOME-2 series, the dry period presented higher averages and maximum. Porfírio et al., (2012) found similar results in his study at Maceió-Northeastern Brazil, with global and UV maximum irradiances also occurring in the Spring/Summer months (dry period). Surface UVR had similar variation throughout the year in 2019-2020 at the Santarém, according to Reis et al., (2022). Another point to be highlighted is the amplitude, which is higher in in the rainy period in both series. During the rainy period, clouds are expected to play an important role in the variability of UVR (Reis et al., 2022), therefore UVI, mostly by attenuation, what can explain the minimums over this period, but sometimes by increasing the intensity reaching the ground (Corrêa et al., 2010).

Taking into account that there is no ground-based derived UV index for Santarém, in order to make a comparison and clarify which of the two satellite time series better represent the reality of the UVI variability in this area, the variation of the solar zenith angle (SZA) over the year for Santarém was plotted (Figure 3), so that it was possible to understand which series presents variability more in accordance with the variability of the SZA. The SZA is the angle measured from the surface between the Sun and a point directly above the observer (Du Preez, 2019; Cadet et al., 2020). Smaller SZAs results in greater solar flux reaching the Earth's surface, this happens more frequently around noon and during summer months (Wald, 2018). At larger SZAs (at dawn and dusk time), UVR is lower, as the path through the atmosphere is longer and results in more attenuation of UVR through the scattering and absorption by particles and gases in the atmosphere (Wald, 2018; Du Preez, 2019).

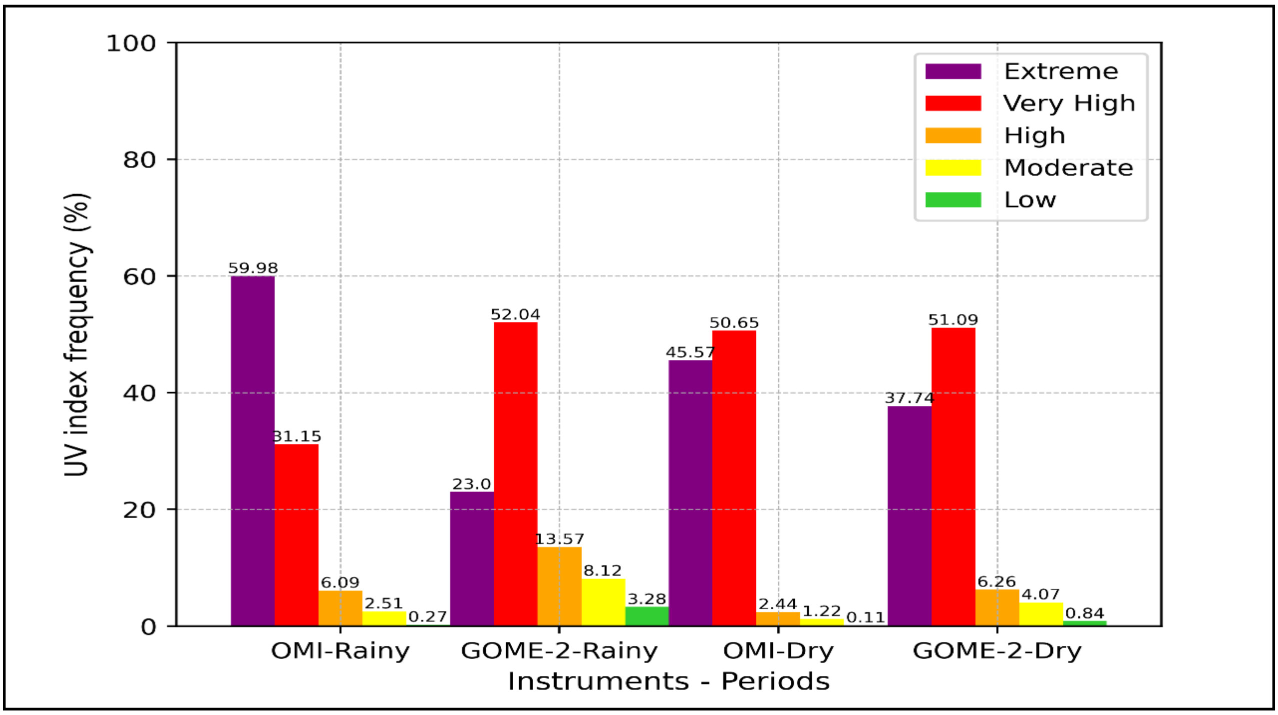
Figure 3 – Noontime UVI monthly average in all-sky conditions and the corresponding noontime solar zenith angles-monthly averaged (indicated with the red line and the right vertical axis) for Santarém



Source: Authors (2022)

At places within the Tropic of Capricorn the sun is at its peak twice a year and the stations register two annual maximums (Coariti, 2017). For Santarém, the noontime averaged UV index peaks occurred in the end of summer (around march), and in spring (around September) (Figure 3), in the GOME-2 series, in accordance with the SZA variability. The UVI OMI series varied in agreement to the SZA variation in the rainy period, but in the dry period it peaked in November, instead of around September and October. In comparison with research conducted in other places with a latitude close to the latitude of Santarém, two-year maximums were similarly reported by Kirchhoff et al. (2000) and Coariti (2017) for the city of Natal (5.84ºS, 35.21ºW), also by Lamyet al. (2021) for Mahé (4.67ºS, 55.53ºE).

Figure 4 – Noontime frequency of the UV index levels under all-sky conditions as function of the instrument (OMI, GOME-2) and period of the year (Rainy, Dry) for Santarém



Source: Authors (2022)

Figure 4 shows the frequency of the UV index levels as a function of the instrument (Omi, Gome-2) and of the period of the year (rainy or dry seasons). According to the U.S. Environmental Protection Agency (Epa) a low danger from the sun's UV rays only occurs when the UV index ranges from 0 to 2. Even so, it is recommended to wear sunglasses on clear days, protect yourself with clothing, and use broad spectrum SPF30+ sunscreen (Epa, 2017). Only 0.27% of the noontime UV index levels under all sky conditions were low during the rainy period, and 0.11% during the dry period, according with the OMI series. The GOME-2 series presented a bit higher percentage of Low levels, 3.38% and 0.84, rainy and dry period respectively.

When the level is at most moderate the recommendations are as follows: Stay in shade; if outdoors, wear protective clothing, a wide brimmed hat and UV-blocking sunglasses; generously apply broad spectrum SPF30+ sunscreen every 2 hours, even on cloudy days and after swimming or sweating; watch out for bright surfaces, like sand, water and snow, which reflect and increase UV (Epa, 2017). When UV index is high (6 to 7) or very high (8 to 10), the same recommendations as the ones cited before are necessary but is also recommended to reduce time in sun if there is a high or very high risk (Who, 2002).

Together, moderate, high, and very high UVI levels represent 39.75% of the UVI incident at noontime during the rainy period in Santarém and 54.31% during the dry period, for the OMI series. Even during the rainy period, when there are greater presence of cloud cover and precipitation (Reis *et al*., 2022), approximately 60% of the incident UV index at Santarém at noontime is extreme. For the GOME-2 series just 23% of the UVI levels were extreme during the rainy period and 37.74% in the dry period. If there is no use of sun protection, skin and eyes can have sunburn in minutes if the UV index is extreme (Who, 2002). It is recommended to avoid sun exposure when these levels are reached and take all the recommendations cited before (Who, 2002; Epa, 2017).

In summary, the dry period showed higher average UVI, according to the GOME-2 series, with 11 (extreme) being the average UVI in the dry period and 10 (very high) being the average UVI in the rainy period, at noontime. The average was also between very high and extreme in the OMI series, but with the rainy period being extreme. These characteristics of both time series reinforce that during the rainy as well the dry period the maximum protective measures need to be taken to avoid overexposure to UVR.

Santarém is in a tropical region, at a low latitude, close to the equator, therefore solar zenith angle (SZA) is lower throughout the year, which induces a higher UVR, smaller amplitude between the seasons, as well as a very low photoperiod variation (REIS et al., 2022). Predictably, the UVI is higher around solar noon when the SZA is minimum, therefore these higher UVI levels were expected. UVI in this range was expected for Santarém, given its location. The presence of seasonality but small amplitude of UVI between rainy and dry periods was also expected. As well as higher values of UVI in the OMI series than in the GOME-2 series.

The divergence between the higher means and medians found in the rainy months in the OMI series in contrast to those found in the dry months in the GOME-2 series is a characteristic to be further investigated, for example, with the insertion of a comparison of UVI data from the Tropomi instrument, from reanalysis, and in the future with ground-based data for a better understanding of the UVR variability in the Brazilian Amazon region.

4 CONCLUSIONS

Through this work it was possible to characterize the monthly variability of the UVI for the city of Santarém, as well as to analyze how UVI varies between the seasons of the year, using data from two different instruments on board satellites. The patterns found are in agreement with the literature, for example, with the highest average UVI recorded during the dry period, in the months corresponding to spring and summer, in the GOME-2 series. The results also reinforce that at solar noontime maximum protective measures need to be taken to avoid overexposure to UVR, both during rainy and dry periods. Comparison with ground-based data is needed for a more robust and complete work, as well as comparison with UVI obtained from other sources, such as from another satellite or reanalysis, to better understand the variability of UVR in this Amazonian city.

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