CEILING MONTHLY UV SOLAR RADIATION FOR THE STATE OF PERNAMBUCO

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Abstract: The Ultraviolet Solar Radiation UV (A+B) incident in the state of Pernambuco is considered high nearly almost all the year. This fact happens mainly due to its geographical localization nearing the Equator line. In 2008, aiming to collect the global radiation and UV (A+ B), two measurement stations were strategically set up, one in the municipality of Pesqueira, at 214 km of the capital of Recife, and the other, in the municipality of Araripina located at 690 km from the capital. The two municipalities are located in the countryside of the region, known as Agreste and Sertão, with two of the particular climates of the state of Pernambuco. The measurements enabled the creation of statistical models as to calculate the UV (A+ B) radiation in the neighboring regions, by means of the information of the global radiation. For the other localities, including the capital Recife, located in the region known as Zona da Mata, which represents the third particular climate in the state, the SPECTRAL2 computational parametric model was used from entry data as aerosol optical depth, pressure amongst others. The aerosol optical depth (AOD) was calculated by empirical equation relating this with Linke Turbidity Index, for air mass 2, TL_m , broadband water vapors optical depth and clean dry atmosphere. The method used for calculating TL_m was the following: from a very large given temporal series of daily solar irradiation (more than 5 years) for each month and year, the highest daily solar irradiation was chosen. For each local and each month, a clear sky model was processed for TL_m, varying from 2 to 8 until the clear sky irradiation corresponded to one of maximum values previously chosen. The process is then repeated for other maximum values and months and then 12 monthly mean values of TL_m are obtained for the Pernambuco state. Given all the facts, it was possible to generate solar UV monthly maps (maximum) for the state of Pernambuco. This map will be important as to alert the population regarding blindness and skin cancer prevention.

Key words: Solar radiation UV; erythema action spectrum; aerosol optical depht; linke turbidity index

1. INTRODUTION

The geographical location close to the Equator Line makes the UV solar radiation levels high in nearly all of the Pernambuco state. Knowing the levels of this radiation is of fundamental importance to alert the population about the possible harms, due to overexposure. Freckles, cataracts, erythema and skin cancer are biologic effects which result from this exposure. The effects of UV radiation in biological systems appear to be strongly dependent on wavelength. For the study of the biological effects, weighting factors are used, to which greater weight is attributed for wavelengths of greater biological interaction. The biological response to the different wavelengths is described by an action spectrum. The action spectrum is determined through medical experiments which signal the biological effects of different radiation wavelengths (Kircchoff et. al., 2000). Figure 1 represents the erythematic action spectrum for human skin.

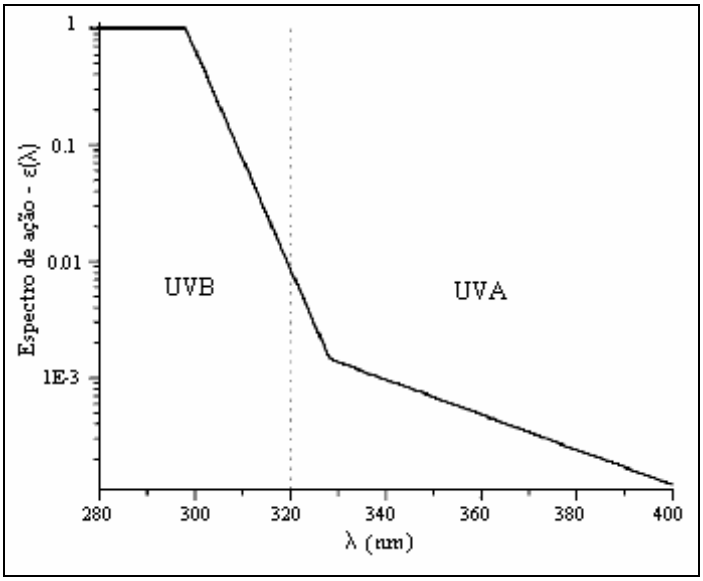

Fig 1: Erythema action spectrum (Diffey, 1991).

I_λ spectral radiation weighted by the ε_λ action spectrum results in S_λ spectral erythemic irradiance, in W / (m^2 nm). By integrating the S_λ spectral erythemic irradiance for the wavelengths interval referent to UV radiation, it is possible to obtain the biologically active irradiance S, which for human beings is also called erythemic irradiance.

$$S = \int_{280}^{400} I_\lambda \varepsilon_\lambda d\lambda \qquad \text{(eq.1)}$$

The erythemic irradiance unit is given in MED (minimal erythemic dose), which corresponds to approximately 210 J / m^2. The UV index (IUV), related to the UV irradiation levels, which cause the formation of erythemas on human skin, is determined from erythemic irradiation (WHO, 2002). Each IUV unit corresponds to 25 mW / m^2. Table 1 shows the classification of these indexes.

Tab 1: IUV Classifications and recommendations, according to the World Health Organization.

1	2	3	4	5	6	7	8	9	10	11	>11
BAIXO		**MODERADO**			**ALTO**		**MUITO ALTO**			**EXTREMO**	
You can safely out side		Avoid being outside during midday hours; shirt, sunscreen and hat are a must									

Besides erythemic irradiance, UV (A+B) radiation is also an important study parameter, not only for living creatures but also for materials of outdoor application, which suffer degradation according to their exposure level. Before such facts, information referent to UV radiation is yet rare, not only in Pernambuco state, but also in the rest of the country. With the goal of broadening the knowledge on UV radiation levels, in Pernambuco state, in 2008, three measurement stations were strategically installed, being one of them in the city of Pesqueira, 214 km away from the capital Recife, another in the city of Araripina, 690 km away, aiming to collect simultaneously global radiation and UV (A+B) radiation. In Recife, a station to measure the erythemic irradiation and thus determine the UV index for that site was installed. The cities of Pesqueira and Araripina are located respectivelly on the Agreste and Sertão regions, typical climates of the Pernambuco

state. The measurements enabled the creation of models for calculating UV (A+B) radiation in the surrounding areas, knowing the global radiation. However, due to the great climatic diversity of the state, the computational parametrical model SPECTRAL2 was used to calculate the maximal levels of UV (A+B) radiation, besides the IUV for other six places, including the capital, Recife, located in the Zona da Mata, which represents the third characteristic climate in the state. For calculating the UV (A+B) radiation and the IUV, the model required input data such as the optical depth of aerosols (AOD), ozone, and others. For calculating the aerosol optical depth, an empirical equation from the linke turbidity index for 2 air masses (TL_m), optical depth of water vapor and clean and dry atmosphere was used.

2. MATERIAL AND METODS

Table 2 shows the geographical coordinates and the measurement periods of the stations. The measurements done on these periods refer to global radiation.

Tab 2- Description of the stations and data used to calculate TL_m.

Station name	Latitude	Longitude	Elevation (m)	Period of measurement
Araripina	-7.46	-40.42	624	2000-2007
Arcoverde	-8.43	-37.05	716	2000-2007
Caruaru	-8.24	-35.91	488	1999-2007
Floresta	-8.60	-38.57	316	2002-2007
Ouricuri	-7.87	-40.09	451	2002-2007
Petrolina	-9.15	-40.37	366	1998-2002/2005-2007
Recife	-8.06	-34.92	10	1999-2005
S Talhada	-7.92	-38.29	430	2001-2004

The method used for calculating TL_m was the following: from a very large given temporal series of daily solar irradiation (more than 5 years) for each month and year, the highest daily solar irradiation was chosen. For each local and each month, a clear sky model was processed for TL_m, varying from 2 to 8 until the clear sky irradiation corresponded to one of maximum values previously chosen. The process is then repeated for other maximum values and months and then 12 monthly mean values of TL_m are obtained for the Pernambuco state (TIBA,and PIMENTEL, 2009).

Table 3 shows monthly calculated data, for the respective sites.

Tab 3- Linke turbidity index TL_m for stations.

Station	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Araripina	4.9	5.6	4.5	4.2	3.5	3.2	2.6	2.5	3.1	3.4	4.1	4.1	3.8
Arcoverde	3.6	4.5	3.8	3.4	3.3	3.7	2.9	2.7	3.0	3.0	3.1	3.9	3.4
Caruaru	4.2	5.2	4.1	4.1	4	4.6	4.1	4.3	4.5	4.4	3.9	4.7	4.3
Floresta	4.5	4.6	3.7	4.1	3.8	4.3	3.7	3.4	3.8	4.0	4.2	4.4	4.0
Ouricuri	4.8	5.0	4.6	4.6	4.5	4.4	3.5	3.4	3.6	4.0	4.3	4.5	4.3
Petrolina	4.4	4.5	4.5	4.3	4.0	3.7	3.5	3.2	3.9	3.9	3.9	4.3	4.0
Recife	4.6	4.0	4.0	4.6	4.4	4.6	4.2	3.9	4.2	4.1	3.9	4.8	4.3
S Talhada	4.7	4.4	4.1	4.2	3.8	4.0	3.5	3.6	3.7	3.9	4.0	4.1	4.0

For calculating the optical depth the following expression was used (Molineaux, 1989):

$$T_{L2}(\Delta_a, W) = (9.4 + 0.9 * M) * (\Delta_{cda} + \Delta_W + \Delta_a) \quad \text{(eq.2)}$$

where,

Δ_a is the aerosol optical depth.
Δ_{cda} is the panchromatic optical depth of a clean and dry atmosphere, being:

$$\Delta_{cda} = -0.101 + 0.235 * M^{-0.16} \quad \text{(eq.3)}$$

M is the air mass (M = 2)
Δ_W is the panchromatic water vapour optical depth.

$$\Delta_W = 0.12 * M^{-0.55} * W^{0.34} \quad \text{(eq.4)}$$

W is the precipitable water vapour content of the atmosphere (cm).

The optical depths calculated for the 8 places, from the linke turbidity indexes for 2 air masses (Table 3) along with other data such as latitude, longitude, ozone, atmospheric pressure, among others, served as input data for the computational parametrical SPECTRAL2 model, Figure 2. For calculating the maximal monthly UV (A+B) radiation and IUV, the average Julian days of each month were considered and according to these days the ozone indexes were determined through the TOM'S satellite data, considering the mean of the last three years.

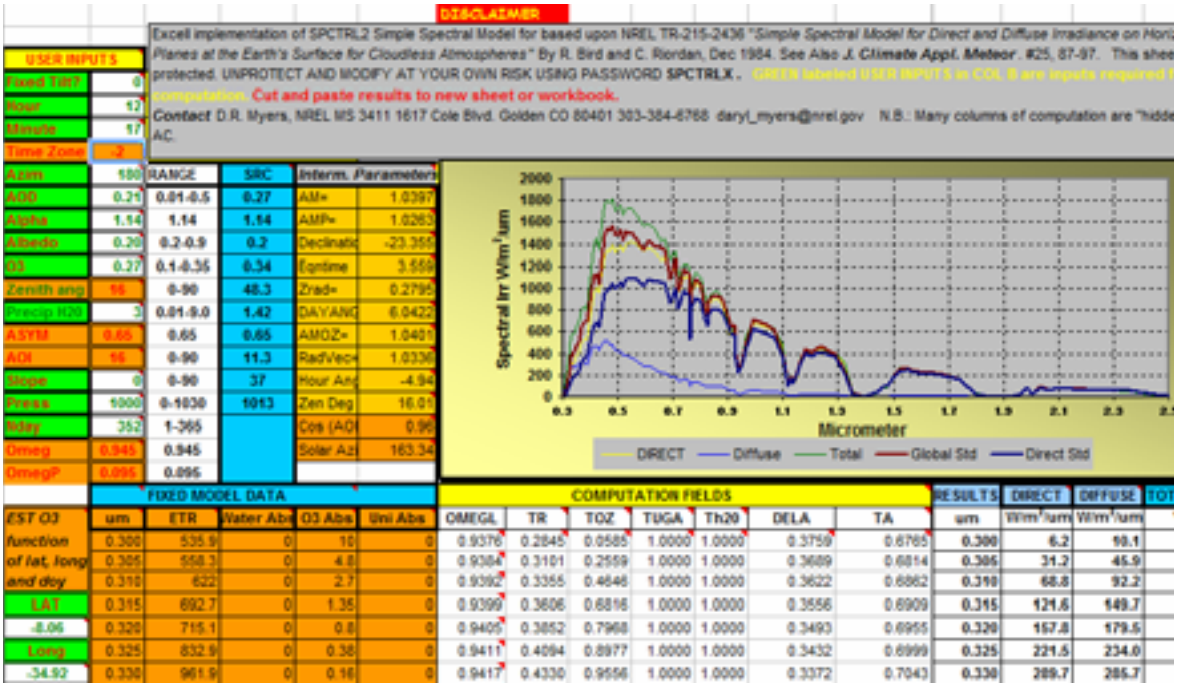

Fig 2: Workspace of SPECTRAL2

The maximal UV (A+B) radiations were calculated for both localities and for each month. The maximal IUV was determined according to the following expressions:

$$I_{UV} = K_{\lambda} \int_{280nm}^{400nm} I_{\lambda} S_{\lambda} d\lambda \quad \text{(eq.5)}$$

where,

K_{λ} is a constant equal to 40 m^2/W

S_{λ} is the action spectrum for erythema, given:

$$S_{\lambda}(\lambda) = 1 \rightarrow 250nm < \lambda < 298nm \quad \text{(eq.6)}$$

$$S_{\lambda}(\lambda) = 10^{0.094(298-\lambda)} \rightarrow 298nm < \lambda < 328nm \quad \text{(eq.7)}$$

$$S_{\lambda}(\lambda) = 10^{0.015(139-\lambda)} \rightarrow 328nm < \lambda < 400nm \text{ (eq.5)}$$

The UV (A+B) radiation results, obtained through the SPECTRA2 were compared with the available experimental data and with the model for estimating the UV (A+B) radiation, developed previously for the city of Pesqueira (Leal et. al., 2009). This model was generated from multiple regressions of the $< K_{TUV} >$ ultraviolet atmospheric transmittance index as a function of $< m_r >$ air masses and of the K_T atmospheric transmittance index.

$$K_{TUV} = A.K_T^B.m^{-C} \quad \text{(eq.8)}$$

where,

K_T and K_{TUV} are the daily global and UV radiation transmittance indexes, respectively:

$$K_T = \frac{H_G}{H_0} \quad \text{(eq.9)}$$

$$K_{TUV} = \frac{H_{UV}}{H_{UV0}} \quad \text{(eq.10)}$$

being,

H_G the daily global solar radiation on the Earth's surface

H_G is the daily global extraterrestrial solar radiation

K_{TUV} is the daily UV transmittance index ($K_{TUV} = H_{UV}/H_{UV0}$)

m is the air mass at solar midday

$$H_{0UV} = \frac{24}{\pi} I_{SC}(UV) E_0 \left[\cos\delta \cos\Phi \cos\omega_S + \frac{\pi}{180} \omega_S sen\delta sen\Phi \right] \quad \text{(eq.12)}$$

where, $I_{SC}(uv) = 80{,}83\ W\ m^{-2}$

E_0 is the relative Sun-Earth distance

ϕ is the local latitude

δ is the declination

ω_S is the sunrise or sunset angle

As a result of multiple regressions, using current data (2010), the following expression was obtained for the city of Pesqueira and surroundings:

$$< K_{TUV} >= 0.797 K_T^{0.801} m_r^{0.374} \quad \text{(eq.13)}$$

A comparison was also made between the IUV estimated by the SPECTRAL2 and the data measured by the station in Recife with the usage of a 501 UV-B model biometer from the Solar Light manufacturer. The statistical indicators were MBE% (mean bias error) and RMSE% (root mean square error):

$$\mathbf{MBE} = 100 \frac{\sum_n (\mathbf{H_{UV,calculated}} - \mathbf{H_{UV-measured}})}{\sum_n \mathbf{H_{UV,measured}}} \% \quad \text{(eq.14)}$$

$$\mathbf{RMSE} = 100 \frac{\sqrt{\frac{\sum_n (\mathbf{H_{UV,calculated}} - \mathbf{H_{UV,measured}})^2}{\mathbf{n}}}}{\sum_n \frac{\mathbf{H_{UV,measured}}}{\mathbf{n}}} \% \quad \text{(eq.15)}$$

3.RESULS AND DISCUSSION

Table 4 shows the maximal monthly UV (A+B) radiation values calculated by SPECTRAL2 for the Pernambuco state.

Tab 4 – Maximal monthly UV (A+B) radiation values

Station	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Araripina	28.9	28.5	29.3	27.3	25.2	23.9	25.5	28.3	30.1	31.2	30.1	29.8	28.2
Arcoverde	31.3	30.2	30.3	28.3	25.9	22.8	24.6	27.7	30.2	31.9	32.1	30.5	28.8
Caruaru	30.0	28.7	29.6	27.0	24.0	21.5	22.7	25.0	27.6	29.4	30.4	29.0	27.1
Floresta	29.5	29.6	30.0	26.8	24.1	21.7	23.0	26.1	28.5	29.9	29.8	29.3	27.3
Ouricuri	29.0	29.4	28.9	26.5	23.6	22.0	23.7	26.8	28.6	30.2	30.3	29.5	27.4
Petrolina	29.8	29.9	28.8	26.4	23.6	22.2	23.0	26.2	28.2	30.0	30.4	29.6	27.4
Recife	29.0	30.2	29.4	26.1	23.3	21.4	22.4	25.3	27.8	29.5	30.0	28.5	26.9
S Talhada	29.2	30.1	29.7	27.0	24.5	22.4	23.7	26.1	28.9	30.2	30.2	29.8	27.6

With the aim of comparing the estimated results by the SPECTRAL2 and confirming its good precision, the data measured by the station in Pesqueira, located 45km away from the city of Arcoverde, were compared with the UV (A+B) radiation values estimated by SPECTRAL2. The maximal UV (A+B) radiation values of each month of 2009 were selected. This data was gathered in the station in Pesqueira through a TUVR (Total Ultraviolet Radiometer) sensor. With the usage of the optical depth determined for the city of Arcoverde, considering the geographical coordinates of Pesqueira and using the SPECTRAL2, it was possible to estimate the maximal UV (A+B) radiation for Pesqueira. Figure 3 shows the resulting curves. The blue curve is the resultant of the model generated for Pesqueira.

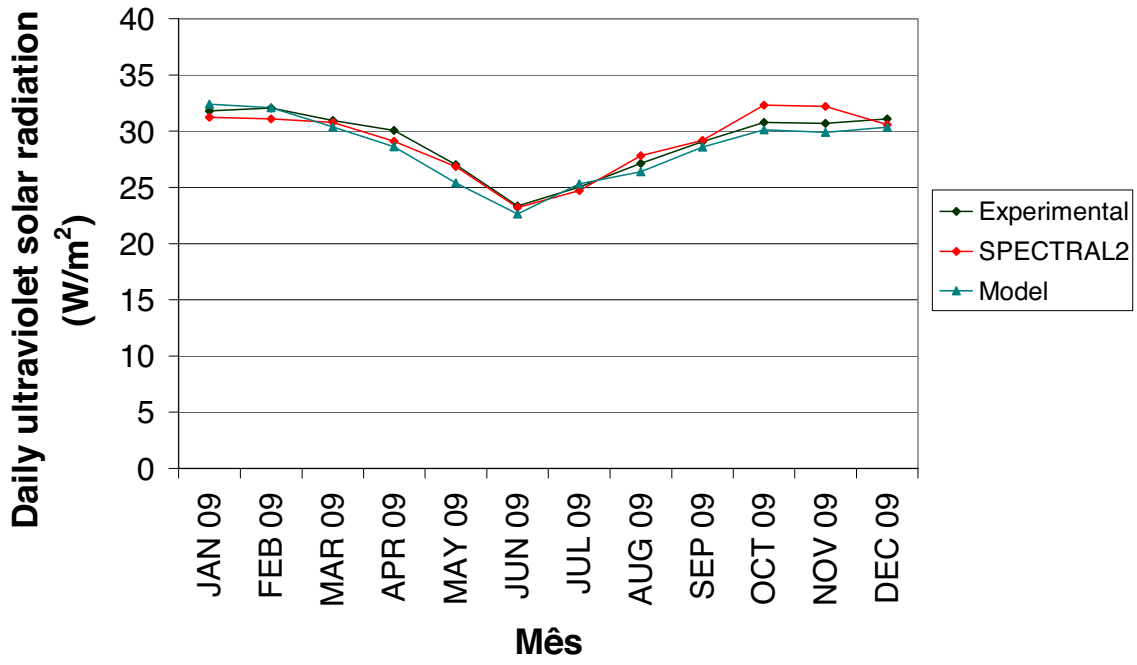

Fig 3 – Comparison between UV (A+B) radiation estimated by the SPECTRAL2 (red) and by experimental data (green) for the

city of Pesqueira.

From the graphic it is possible to observe that the maximal monthly UV (A+B) radiation levels took place in the Spring/Summer (September to February) and the minimal in Autumn/Winter (March to August), displaying the typical behavior for the Northeast of Brazil. However, the annual average UV (A+B) radiation was found high in all places and all year long. The values estimated by the SPECTRAL2 show a MBE% = -0.016% and a RMSE% = 2.7% and the model a MBE% = -1.98% and a RMSE% = 2.86%, confirming its good prediction capacity, when compared with experimental data.

Table 5 shows maximal UV indexes estimated by SPECTRAL2 for several locations.

Tab 5 – Maximal daily IUV estimated by spectral2.

Station	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Araripina	12	13	13	12	11	10	10	12	14	14	13	13	12
Arcoverde	13	14	13	12	11	9	10	12	14	15	14	12	12
Caruaru	13	12	13	12	10	8	9	10	12	13	13	12	11
Floresta	12	13	13	12	10	9	9	11	13	14	13	12	12
Ouricuri	12	13	13	12	10	9	10	12	13	14	13	12	12
Petrolina	12	13	13	12	10	9	9	11	13	13	13	12	12
Recife	12	14	14	12	10	9	9	11	13	14	13	12	12
S Talhada	12	14	13	12	10	9	9	11	13	13	13	12	12

A similar process was carried out for estimating the IUV (midday) for the months of maximal radiation UV (A+B) in 2010 in Recife, Figure 4.

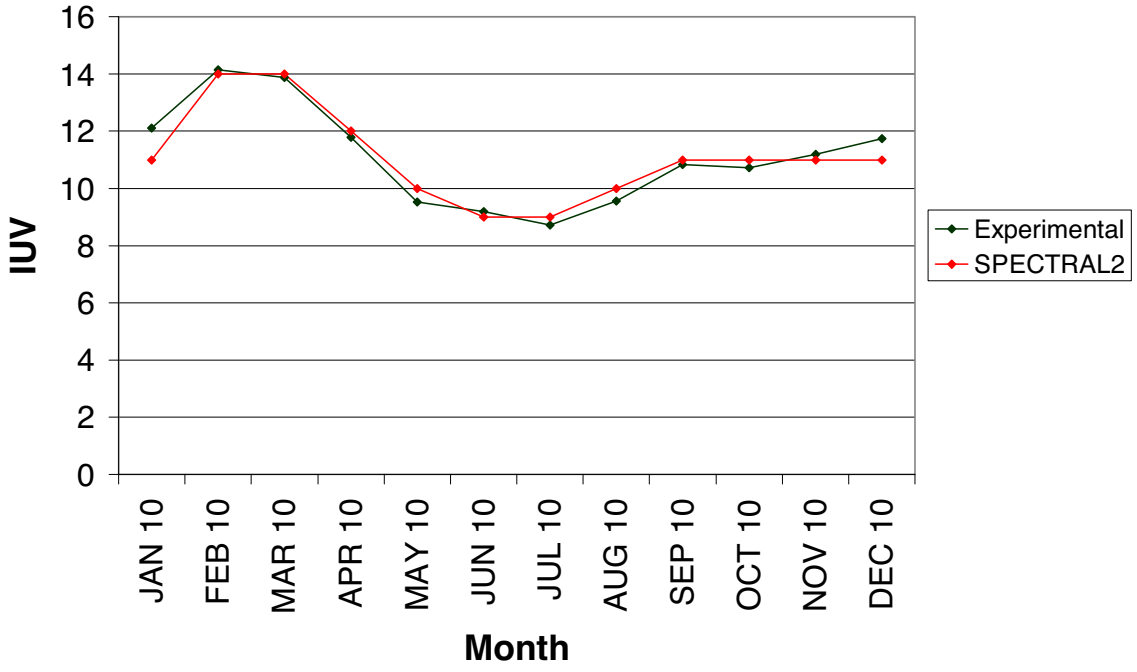

Fig 4 - Comparison between maximal monthly IUV estimated by the SPECTRAL2 and by experimental data for the city of Recife.

For the city of Recife the maximal monthly IUV values (midday) took place in the months of February to March, during which slightly reduced ozone and aerosol optical depth levels were observed. The mean annual values an extreme IUV for all localities. The estimated values and also compared with experimental data showed a MBE% = -2.95 %, RMSE% = 4.10 %.

4.CONCLUSIONS

The monthly maximum solar UV (A+B) radiation levels were found high for all years in the state of Pernambuco. Maximum values were observed during Spring/Summer and minimal in Autumn/Winter. Between the analyzed cities, Arcoverde showed the highest radiation levels, when compared to other places due to its higher altitude. The annual mean IUV (midday) was extreme for all localities.

SPECTRAL2 showed a good capacity for estimating IUV and UV (A+B) radiation. The estimated radiation for the city of Pesqueira showed a MBE% = -0.016% and a RMSE% = 2.7%, when compared with experimental data. For estimating the monthly IUV for Recife, a MBE% = -2.95 % and RMSE% = 4.10 % were obtained. These results transmit good reliability and, therefore, the estimated IUV and UV (A+B) radiation values can serve as reference for elaborating a maximal monthly UV irradiation map for the state of Pernambuco.

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