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Ozone and Aerosol influence on Ultraviolet Radiation on the east coast of the Brazilian Northeast

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Abstract

The purpose of this research is to determine the influence of the total ozone and aerosol on the variability of Ultraviolet Radiation **(**UV) based on a Ground-based Ultraviolet Radiometer (GUV) from the East Coast of the Northeastern region of Brazil. The methodology consisted of descriptive and cluster analyses using data from UV in channels UVB (305 nm) and UVA (320 nm, 340 nm, and 380 nm) and the UV index, Total Ozone, Aerosol, Global Solar Radiation, Cloudiness and speed (intensity) and wind direction. The results for Natal City indicated that an annual event occurs, which stabilizes the UV Index in September/October and that the total ozone levels reach their annual maximum at this time. This event could be influenced by marine aerosol that is found on the mainland at a higher concentration annually due to the greater intensity from the trade winds and their southeasterly direction in September. The cluster analysis using the variables above allowed us to detect three different study groups: the first group is formed by Natal, Recife and João Pessoa and determined that this event occurs in these three cities; the second group is formed by Maceió, Aracaju and Salvador and the third group includes only Fortaleza and had different results.

Keywords: Cluster analyses; Radiometer; Global Solar Radiation; Cloudiness; Annual Event of Spring from UV.

1. Introduction

The Ultraviolet Radiation (UV) has wavelengths (λ) between 100 and 400nm and can be classified according to the effects on human health and the environment in spectral ranges: UVA, 315 nm to 400 nm, UVB, at 280 nm to 315 nm and UVC, 100 to 280 nm [32]. The radiation in the UVC range corresponds to approximately 1% of solar emissions and does not reach the earth's surface due to the strong absorption in the atmosphere by ozone and molecular oxygen [15], [34].

The amount of solar UV radiation (200-400 nm) that reaches the Earth's surface is affected mainly by the atmosphere (absorption of ozone, cloudiness, aerosols and pollutants in the troposphere) and the reflectivity of the ground, which is composed in large part of UVA (90%) and to a lesser degree of UVB (10%) [14], [21].

The UV causes various effects on terrestrial and aquatic ecosystems and inorganic materials [16], [32]. Despite some beneficial effects [31], an unequivocal prolonged human exposure to UV can result in adverse effects, which may be both acute and chronic [16]. The negative effects are manifested predominantly on the skin by means of cancer, burns and erythema [4] and premature aging however they may affect the eyes [19] and immune system [3].

Skin cancer is characterized by different aspects of exposure: non-melanoma skin cancer or not malignant (NMSC) and melanoma skin cancer or malignant (MSC). There are estimates that NMSC (134.000 new cases) is the most frequent in the Brazilian population and corresponds to 25.7% of all tumors [9]. In comparison, MSC causes a high fatality rate but occurs less frequently. In the capitals of the Northeastern Region of Brazil (NEB), for men, NMSC is the second most frequent type of cancer (34.69/100 thousand) and the most frequent for women (31.17/100 thousand) [9].

The Ultraviolet Radiation index (UV index) is an important resource that increases public awareness to the risks of overexposure to the sun. Its function is to describe the level or intensity of UV on the surface of the planet, and is used as a warning to people to protect themselves from UV. This index is independent of genotypic factors, thus it is universally applicable to any individual of the population, without regard to their skin color [32].

UV in the atmosphere is attenuated by processes such as absorption or scattering by Total Ozone column (Total Ozone) and aerosol particles. The amount of ozone in the atmosphere is recovering as a result of the Montreal Protocol [34]. Despite the recovery of the Total Ozone, UV in high latitudes are predicted to increase in the near future [17], [30]. In the more populated regions, the highest increase of UV has been found in the Southern Hemisphere, such as in NEB, in latitudes from -20 to 0 [7].

The presence of aerosols in the atmosphere can be observed through a parameter called Aerosol Optical Depth (AOD). This variable is an extinction measurement (no dimension) of radiation and its interaction with aerosol particles in the atmosphere, mainly due to the processes of spreading and absorption [6], [23], [24].

This article seeks to understand and bring awareness to these issues and aims to conduct a descriptive and analytical study of the variability of UV and the UV index in relation to the overall Total Ozone and relevant variables for the state capitals of the east coast of Northeastern Brazil.

2. Material and Methods

2.1 Study Area

The study area covers the coastal region on the eastern and northern coasts of Northeastern Brazil (NEB) and the capital of the states of Ceará (Fortaleza), Rio Grande do Norte (Natal), Paraíba (João Pessoa), Pernambuco (Recife), Alagoas (Maceió), Sergipe (Aracaju) and Bahia (Salvador) (Figure 1).

The measurement of Ultraviolet Radiation (UV) was based on a Radiometer located in Natal (5°48'S, 35°12'W), which is thus regarded as the city of reference for this study from UV.

The city of Natal (5°48'S and 35°12'W) is located in the NEB on the eastern coast of South America, between the sea and the right bank of the River Potengi, where they reside 853.928 million inhabitants in an area of 17.298 km² [11]. Its proximity to the equator determines great luminosity and high levels of solar radiation. The trajectory of the Sun varies with solar zenith angle (sza) between 65-90° [25]. The average annual temperature is 26°C and relative humidity and 77.3% [10].

2.2 Data

The hourly and daily data (2001-2009) of UV in channel UVB (305 nm), channels UVA (320 nm, 340 nm, and 380 nm) and the UV index were measured on the surface by the Ground-based Ultraviolet Radiometer (GUV), Model 511-C. The irradiance is given in units of $\mu Wcm^{-2}nm^{-1}$ and was measured at four channels and integrated to convert the measurements of the UV index. The equipment is installed in Laboratory of Tropical Environmental Variables of National Institute of Spatial Research (LAVAT-INPE/CRN) in Natal city. The daily maximums of the UV and UV index were obtained from 11:00am to 1:00pm, independent of sky conditions.

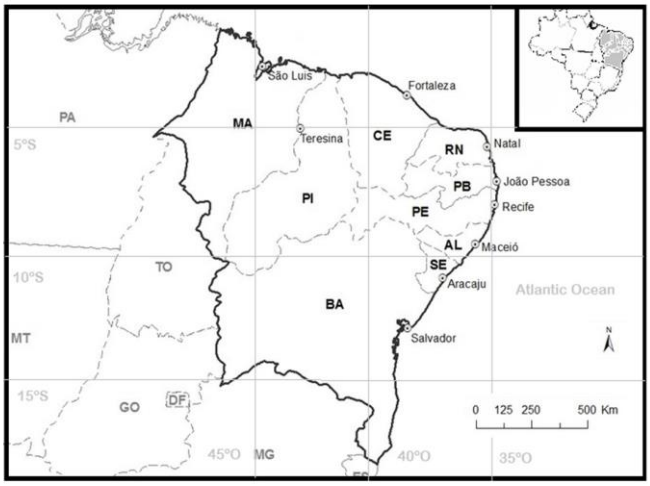

Figure 1- Location of Natal in Rio Grande do Norte and capitals of the states of Northeast Brazil.

A set of daily data (2001-2009) of Total Ozone in Dobson Units (DU) was obtained at the National Centers for Environmental Prediction/National Oceanic and Atmospheric Administration (NCEP/NOAA//USA), with grid resolution 2.5° x 2.5° [12], available at www.esrl.noaa.gov.

The daily data (from 2007 to 2009) of Global Solar Radiation (GSR) (W/m^2) was obtained from Radiometer from Solarimetric Station of LAVAT-INPE/CRN. The data represents the average value of GSR from 11:00-12:00pm.

The data of Cloudiness (range 0-10), direction (degrees) and Wind intensity or speeds ($m.s^{-2}$) were obtained from the database of meteorological data for Teaching and Research (BDMEP) and the Climate Standard of the National Institute of Meteorology of Brazil [10] available at www.inmet.gov.br.

The Aerosol Optical Depth (AOD), measured in 0.55 μm for Moderate Resolution Imaging Spectroradiometer (MODIS/AQUA) (from 2004 to 2009) was obtained in the division of environmental satellites of Center for Weather Forecasting and Climate Studies (CPTEC/INPE/Brazil) through the Environmental Information System (SISAM), available in http://sisam.cptec.inpe.br.

2.3 UV Index-Formulation

The UV index was formulated by the International Commission on Illumination (CIE) based on the reference spectrum of action erythema (ISO 17166:1999 / CIE S 007/E-1998) and describes the intensity of UV in relation to its photo biological effect [18]. The UV index is defined by Equation 1.0:

$$IUV = K_{er} \int_{250nm}^{400nm} E_{\lambda} S_{er}(\lambda) d\lambda, \ (1.0)$$

in which E_{λ} is the spectral irradiance expressed in $W.m^{-2}nm^{-1}$ to the wavelength λ and d_{λ} it is the wavelength range used in the integral calculus. Ser (λ) is the reference action spectrum erythema and K_{er} is a constant equal to 40 m^2/ W.

The UV index is the standardization of erythema irradiance (S_{er}) by means of a numerical scale, such that 1 UV index = 2.5 mW/m^2 [32] The UV index is divided into categories associated with the colors (Table 1), being proposed by the World Health Organization (WHO) and World Meteorological Organization (WMO) to facilitate the understanding of the population about the effects of UV on human beings.

Table 1. Relationship between UV index and category of risk to humans.

Category of Risk	Range of UV Index	Color
Low	0 to 2	Green
Moderate	3 to 5	Yellow
High	6 to 7	Orange
Very High	8 to 10	Red
Extreme	>11	Violet

Source: WHO, 2002.

The precautions to be taken by the individual, in accordance with this classification, are suggested by the WHO and refer to the use of hats, clothes, sunglasses, sunscreen, and umbrellas or even to stay inside the house. The UV index is an integer and dimensionless representing the maximum daily value in a horizontal surface.

2.3 Hierarchical Cluster Analysis.

Considering the limitations of UV data acquisition on the surface (these measurements were restricted to the city of Natal) and aiming to expand the analysis to the total area to be investigated, a cluster analysis of available variables was used to study the variability of the UV surface, highlighting the Total Ozone, AOD, intensity and Wind direction.

A cluster analysis is a multivariate form of analysis in which a technique for building clusters groups together similar measurements (metric) of distance and determines a connection between the clusters.

Central to the idea of the clustering of data points is the idea of distance. Clusters should be composed of points separated by small distances, relative to the distances between clusters. The most intuitive and commonly used distance measure in cluster analysis is the Euclidean distance in the K-dimensional space of the data vectors [33]. A more general alternative is the weighted Euclidean distance between two vectors x_i and $x_{j,}$

$$d_{i,j} = \left[\sum_{k=1}^{K} w_k \left(x_{i,k} - x_{j,k} \right)^2 \right]^{1/2} . (2.0)$$

For w_k = 1 for each k = 1,..., K, Equation 2.0 reduces to the ordinary Euclidean distance. A yet more general form of Equation 2.0 is the Minkowski metric,

$$d_{i,j} = \left[\sum_{k=1}^{K} w_k \left(x_{i,k} - x_{j,k} \right)^{\lambda} \right]^{1/\lambda}, \lambda \geq 1. \ (3.0)$$

The weights w_k can equalize the influence of variables with incommensurate units. For λ= 2, Equation 3.0 reduced to the weighted Euclidean distance in Equation 2.0. For λ= 1, Equation 3.0 is known as the city-block distance [33]. In this study was used the Minkowski metric.

They were used as linkage criterion in Ward's hierarchical method study. Ward's method suggested a general agglomerative hierarchical clustering procedure, in which the criterion for choosing the pair of clusters to merge at each step is based on the optimal value of an objective function [28].

3. Results and Discussions

3.1 UV Variability in Natal

The average irradiance of UV radiation in Natal for each wavelength is shown in Figure 2 and Table 2. After calculating the channel 305 nm (UVB), a 5.1% reduction was identified in the average irradiance for the second semester compared to the first (in UV index a reduction of 5.3%). During the second semester, there was a greater absorption of UVB / UVC due to a 3.8% increase in the average level of Total Ozone. Table 2 shows the values per semester.

Table 2. Variables in Natal, monthly variability.

Period	Wavelength (nm)				UV Index
	305	320	340	380	Nd
Jan	8.3	36.2	63.4	85.2	11.7
Feb	9.2	38.3	66.3	88.9	12.6
Mar	9.0	38	65.5	87.9	12.5
Apr	8.1	34.9	60.3	81.0	11.3
May	6.9	31.1	53.7	73.9	10.9
Jun	6.0	27.9	50.9	70.2	8.7
1st Sem	7.9	34.4	60	81.2	11,3
Jul	6.0	28.6	52	71.4	8.7
Aug	6.8	32.4	57.1	77.9	10.0
Set	7.3	34.5	59.7	82.3	10.4
Out	8.3	37.4	66	88.3	11.8
Nov	8.3	37.9	65.7	87.9	11.9
Dec	8.0	36.1	63.8	85.6	11.3
2nd Sem	7.5	34.5	60.7	82.2	10.7
Annual	7.7	34.4	60.4	81.7	11

Period	Total Ozone	AOD	Wind		Cloudiness	GSR
	DU	0.55μm	$m.s^{-2}$	Degrees	(0-10)	$W.m^{2-2}$
Jan	260.8	0.19	4.4	117	7.2	931.1
Feb	260.8	0.20	4.2	121	7.2	960.1
Mar	263.5	0.21	3.6	122	7.2	928.7
Apr	260.7	0.16	3.2	135	7.3	748.4
May	257.1	0.18	3.9	146	7.0	652.1
Jun	259.4	0.15	4.2	149	7.4	542.3
1st Sem	260.4	0.18	3,9	132	7.2	793,8
Jul	265.5	0.18	4.4	152	6.7	568.7
Aug	270.6	0.20	5.2	145	6.7	650.5
Set	**278.4**	0.22	5.3	136	6.6	785.5
Out	**276.2**	0.18	5.2	124	6.5	976.9
Nov	268.8	0.15	4.9	118	6.6	994.1
Dec	262.2	0.17	4.7	115	7.0	972.1
2nd Sem	270.3	0.18	5	132	6,7	824.6
Annual	265.3	0.18	4.4	132	7.0	809.2

Source: CRN-INPE/NCEP-NOAA/INMET/MODIS. Nd: no dimension

In Table 2 it can be observed that the UV index in Natal reached an “extreme” (>11) level for seven months of the year, predominantly between spring and summer. February and March presented the highest average monthly indices (between 12 and 13). June and July showed the lower indices around 9.0, a level which is still considered as "very high" (8-10). The first annual maximum of 12.6 occurred in February and the second annual maximum of 11.9, in November.

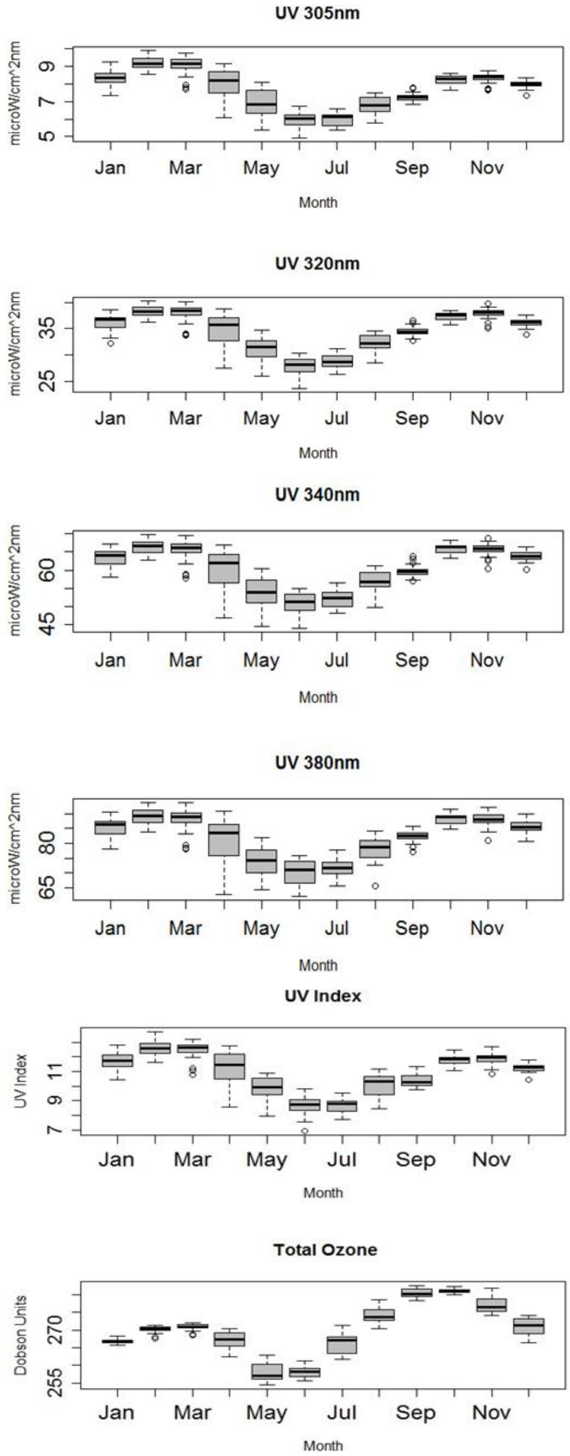

Figure 2. Irradiance for wavelength of UV radiation, UV Index and Total ozone column annual variability for Natal. Source: INPE/CRN.

This characteristic can be explained because the sun’s stations in the Tropic of Capricorn reach the angle solar zenith near 0^o (sza~0^o) twice a year and the stations of observations register two annual ceilings, one in the summer, in February, and the other in the spring, in October [20], in Natal occurred in November. The UV index annual average is 11 (Table 2).

In Figure 2, a stabilization of the UV index levels and wavelengths 305nm (UVB) was identified in September, however, this attenuation is slightly lower for 320, 340 and 380nm (nearest visible radiation) due to lower absorption by ozone in these UVA channels. In addition to the proposed objectives, this study sought to analyze the causes of this behavior identified in September, referred to as the Annual Event of Spring from UV (AES-UV).

The AES-UV takes place between September and October, since the Pearson correlation coefficient indicated an inverse relationship between Total Ozone and UV index corresponding to -0.5 or -50%. Figure 3 shows both the variability annual UV Index and Total Ozone (simultaneous). In this figure, one can observe the AES-UV in September/ October when the Total Ozone reaches a maximum annual.

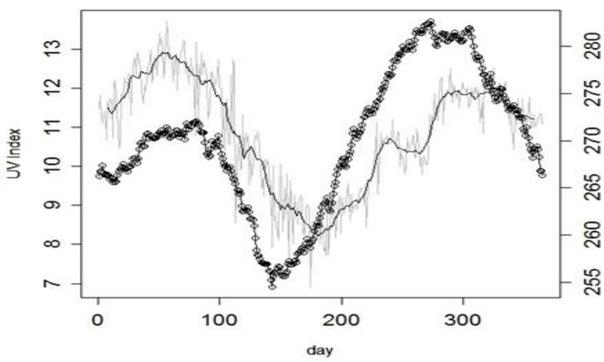

Figure 3- Simultaneous graph of variability annual UV Index (left scale) and filtering (moving average) and Total ozone (black points and right scale). Source: INPE/CRN and NCEP/NOAA

To explain AES-UV, the variability of GSR was first taken into consideration. The GSR (directly associated with the sun elevation or sza) determines the greatest influence on the UV index [32]. Figure 4 show the annual variability of the GSR to the city of Natal. It was identified that no occurs attenuation of GSR during UV-AES.

It was verified that the stabilization of the UV index observed in AES-UV couldn't be associated with Cloudiness, because at this time there are fewer clouds (Table 2). Excluding the GSR and Cloudiness, AES-UV can be explained by the highest Total Ozone in September/ October (highlighted values in Table 2).

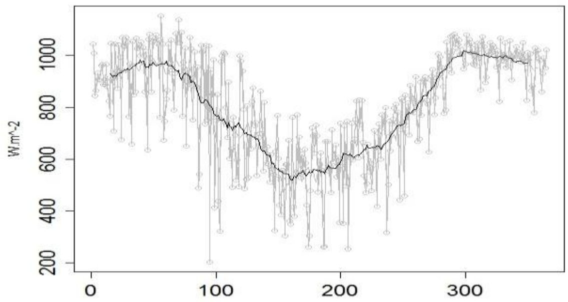

Figure 4- Variability annual Global Solar Radiation (GSR) (W/m^2) from 11:00-12:00pm and filtering (moving average). Source: INPE/CRN.

The annual variability of Total Ozone in the atmosphere varies periodically and conversely (approximately) to the increase in available solar radiation [8]. The temperature increase caused by absorption of GSR generates instabilities in the photochemical equilibrium in the stratosphere, which accounts for about 90% of the integrated Ozone. These high levels lead to the reduction of its production, so that the maximum content of Ozone is observed in spring with a decrease in summer and an increase again in the autumn [2], [8].

Despite the strong signal of GSR in areas near the equator, it has a lesser range and influence on the variability of UV index [1]. The city of Natal is located at a low latitude, so the influence of Total Ozone in variability of UV appears more clearly [22]. During the spring and autumn equinoxes (September and March respectively) in the Southern Hemisphere, when the elevation of the sun is almost the same, one can compare the oscillations of the UV index in relation to Ozone content in periods of very similar GSR intensity. The average difference of 14.9 DU (278.4 - 263.5 in Table 2) was observed between the two equinoxes. This resulted in UV index values of 12.5 and 10.4 respectively. This difference represents a change in the scale of "extreme" to "very high."

In December, if one only considered the reduction of Total Ozone, logically it would result in an increase in UV index, however the opposite occurred. This fact is associated with the reduction of GSR or sun elevation (Table 2). This behavior can be observed by measurements at various locations in the Southern Hemisphere [5], [26].

Besides the Total Ozone, UV is attenuated by other processes, such as the absorption of aerosol particles [23], [35]. The AOD in Natal reaches its highest value in the month of September (0.22 in Table 2). This may contribute to the reduction in the UV index during this period.

The AOD is related to the intensity of winds (trade winds) that have the highest average magnitude in September at 5.3 m/s (Table 2) and their predominant southeasterly direction [10]. The wind direction may explain the higher concentration of marine aerosol, since the city is located on the east coast of NEB. A physical-chemical study was not conducted and thus the type of aerosols cannot be confirmed. It is worth mentioning that the variations exercised by the aerosols are lower than those related to the variations of the Total Ozone and GSR [30]. Figure 5 shows the Wind and AOD in annual variability in Natal.

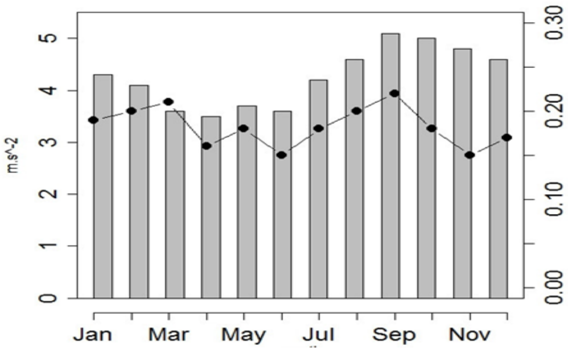

Figure 5- Barplot of Wind (graphical bars) and AOD (points and right scale) in Natal. Source: INMET and MODIS/AQUA

3.2 UV Variability Study of East Coast Capitals from the Northeast

The Cluster Analysis indicated three groups (Figure 6). The first group was defined by Natal, João Pessoa and Recife. The similarity in relation to Total Ozone, wind and AOD characteristics (Figure 7) shows that the AES-UV occurs identically in these cities.

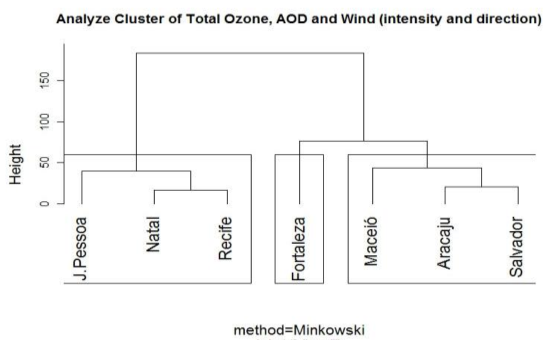

Figure 6- Dendrogram of clusters based on Total Ozone, AOD and Wind intensity and direction.

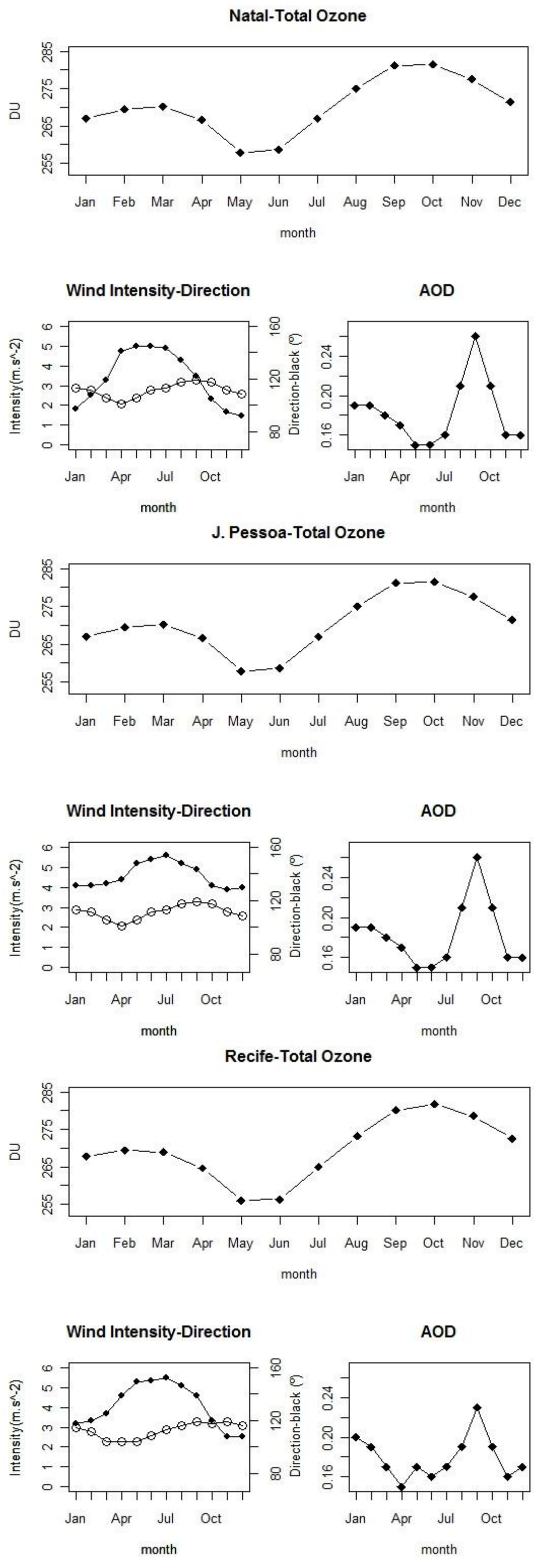

Figure 7- Total Ozone, intensity and Wind direction and AOD for Group 1.

The second group, formed by Maceió, Aracaju and Salvador, indicates that the wind characteristics and variability of Total Ozone are distinct to the first group, therefore, the stabilization of UV levels should not occur during this period and without proper measurement it is not possible to say if it occurs.

The last group was formed by a single city, Fortaleza, located in a distinct point on the northern coast of NEB. The data shows no similarity to that of the other cities and does not allow for a generalized conclusion about UV variability.

4. Final Considerations

The results indicated that the AES-UV takes place between September and October, since the Pearson correlation coefficient indicated an inverse relationship between Total Ozone and UV index corresponding to -0.5. Independent of sky conditions, the AES-UV happens when the Total Ozone reaches its absolute annual maximum. The event was not described in scientific literature and was identified by multispectral measuring Radiometer (GUV).

The AES-UV has a small influence of aerosols (marine type) due to a higher concentration in September, whose origin is the greatest strength of the wind and its direction (southeast).

The cluster analysis allowed us to confirm that this event occurs in a similar way in Recife and João Pessoa in terms of Total Ozone, AOD and wind intensity and direction.

Finally, the results are particularly relevant to the cities found on the northern coast of northeast Brazil, because they highlight the high levels of UV in practically all the seasons of the year. This may explain in part the higher number of cases of NMSC in Natal and alerts us to the need for preventive actions by the local population and the need to warn tourists of the imminent risk of MSC if they do not use proper protection, especially during the summer months.

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