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UV extreme events in Northeast of Brazil

Eventos extremos de UV no Nordeste do Brasil

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Abstract

The main objective of this paper is to analyze extremes UV episodes in Northeast of Brazil (NEB), generally associated to cloud cover and levels of total ozone column (total ozone). The methodology consisted of the calculation of the 95th percentile to define the extreme value in the seasons of UV in city of Natal-RN (reference city) and analysis of NEB obtained from Ozone Monitoring Instrument (OMI) to UV index, total ozone and cloud cover in dates of extreme events in reference city. The results of UV index for Natal city indicated 14.4 for the extreme event in summer and images selected of OMI showed that extreme event were associated mainly with absence of cloudiness and levels below average annual of total ozone. Analysis of extreme episodes of UV index in NEB indicated that the extreme event occurred in reference city does not happen in the entire region, because of the large spatial variability of cloud cover and total ozone.

Palavras-chave*: UV Index, ozone total column, cloud cover, Ozone Monitoring Instrument, 95th percentile.*

Resumo

O principal objetivo deste trabalho é analisar episódios extremos de UV na região Nordeste do Brasil (NEB), geralmente relacionados à nebulosidade e aos níveis da coluna total de ozônio (ozônio total). A metodologia consistiu no cálculo do percentil 95 para definir o valor extremo de UV nas estações do ano na cidade de Natal (cidade de referência) e análise de imagens do NEB obtidas do Instrumento de Monitoramento de Ozônio (OMI) do índice de UV, ozônio total e cobertura de nuvens em datas de eventos extremos. Os resultados na cidade de Natal indicaram 14,4 como evento extremo para o índice UV no verão e as imagens selecionadas do OMI mostraram que os episódios diários selecionados foram associados principalmente com ausência de nebulosidade e níveis abaixo da média anual de ozônio. Análise de episódios extremos de índice UV na NEB indicou que o evento extremo ocorrido na cidade de referência não acontece em toda a região, devido à grande variabilidade espacial da cobertura de nuvens e ozônio total.

Keywords*: UV index, ozônio total, cobertura de nuvens, instrumento de monitoramento de ozônio, percentil 95.*

1 Introdução

The Ultraviolet Radiation (UV) ranges from 100 nm and 400 nm wavelengths (λ) and are classified according to the effects on human health and the environment in spectral ranges, as UVA, 315 nm to 400 nm, UVB, at 280 nm to 315 nm and UVC, 100 to 280 nm [1]. 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 [2, 3]..

The amount of solar UV radiation (280-400 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 for UVA (90%) and to a lesser degree of UVB (10%) [4, 5].

The UV causes various effects on terrestrial and aquatic ecosystems and inorganic materials [1, 6]. Despite some beneficial effects [7], an inadequate and prolonged human exposure to UV can result in adverse effects, which may be both acute and chronic [6]. The negative effects are manifested predominantly on the skin by means of cancer, burns and erythema [8] and premature aging, as well as they may affect the eyes [9] and immune system [10].

Different aspects of exposure characterize skin cancer: 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% of all tumors [11]. In comparison, MSC causes a high fatality rate but occurs less frequently. In the capitals of the Northeastern Region of Brazil (NEB), NMSC is the second most frequent type of cancer (34.69/100 thousand) for men and the most frequent for women (31.17/100 thousand) [11].

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 it 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 [1]

UV in the atmosphere is attenuated by processes such as absorption or scattering by ozone total column (total ozone), aerosol particles and cloud cover [1, 5]. The amount of ozone in the atmosphere is recovering as a result of the Montreal Protocol [3]. Despite the recovery of the total ozone in high latitudes, there was an increase in the surface UV [12 -14]. In the more populated regions, the highest increase of UV has been found in the Southern Hemisphere, including the NEB, in latitudes from -20 to 0 [14].

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 [15-17].

An analysis of such defined extreme events reveals a significant decline in the number of low events, whereas the high events increased by about the same amount. However no significant trend is observed in the magnitude of extreme events. These measurements were used to investigate vertically trends in total ozone in the period 1994–2011 and for establishing an climatology [18].

Research on extreme events of UV index in Spain indicated that cloud cover usually attenuates the ultraviolet (UV) solar radiation but, under certain sky conditions, the clouds may produce an enhancement effect increasing the UV levels at surface. This phenomenon was characterized by a quick and intense increase of UV radiation in surface under broken cloud fields (5–7 oktas) in which the Sun was surrounded by cumulus clouds [19].

The main objective of this paper is to analyze extremes events UV episodes in Northeastern Brazil, generally associated with levels of total ozone and cloud cover.

2 Materials and methods

2.1 Study area

The study area covers the region of Northeastern Brazil (NEB).

Figure 1- Location of Brazil (colorful) in South America. Northeastern states are indicated in gray.

The measurement of UV in ground was based on radiometers located in capital do Rio Grande do Norte (Natal, latitude 5°48'S and longitude 35°12'W), is thus regarded as the city of reference for this study from UV.

2.2 Selection of days with extreme events and data

The selection of days with extreme events was based on measurement in soil and in defining the 95th percentile [20].

The daily data (2001–2012) of UV Index were measured in the surface by: (a) Radiometer GUV (Ground-based Ultraviolet Radiometer) installed in Laboratory of Tropical Environmental Variables of National Institute for Space Research/Center Regional of Northeast (INPE/CRN/LAVAT) and (b) Sensor Model UV-6490 of Meteorological Station Davis installed at the Laboratory of Hydraulic Machines and Solar Energy in Technology Center of Federal University of Rio Grande of Norte (UFRN/LMHES). The daily maximum of UV index was collected on interval of 11h - 13h, independent of sky conditions. The data have missing values due to lack of operation of the measuring instruments.

The data of Cloudiness (range 0–10), were obtained from the database of meteorological data for Teaching and Research (BDMEP) of the National Institute of Meteorology of Brazil [21].

A set of daily data (2001–2012) of ozone total column (DU units) was collected at TOMS (Total ozone Mapping Spectrometer) e OMI (Ozone Monitoring Instrument) [22].

The pictures or images of UV index, total ozone and cloud cover measurement were made in the NEB by instruments TOMS and OMI [22, 23].

2.3 TOMS and Satellite data-AURA/OMI

The Total ozone Mapping Spectrometer – TOMS is an atmospheric sensor that has been flying on different missions within NASA's Earth Probes Program. The objective of the mission is to extend the global ozone data set that began in 1978, with the flight of TOMS on NIMBUS-7. The end of the operation occurred in 2005, when it was on board of the Terra Probe platform [24]. The Ozone Monitoring Instrument – OMI is an instrument launched in July 2004 on board of EOS-Aura platform.

Aura is the atmospheric chemistry mission of NASA's platform Earth Observing System (EOS) launched on 15 July 2004. Ozone Monitoring Instrument (OMI) is a nadir viewing spectrometer designed to monitor ozone and other atmospheric species. OMI covers the wavelength range from 264 to 504 nm [25]. The OMI surface UV algorithm first estimates the clear-sky surface irradiance using the total column ozone measured by OMI, climatological surface albedo, altitude, solar zenith angle, and latitude-dependent climatological ozone and temperature profiles [26, 27]. Next, the clear-sky irradiance is multiplied by a factor that accounts for the attenuation of UV radiation by clouds and no absorbing aerosols. The current algorithm [29] does not account for absorbing aerosols or organic carbon, smoke, and dust and trace gases (NO2, SO2), which are known to lead to

systematic overestimation of the surface UV irradiance and neglects the cirrus effect on UV radiation [28]. The OMI derived surface UV irradiances are expected to show overestimation for regions that are affected by absorbing aerosols [27, 28].

Greatest overestimations are anticipated for regions affected by urban pollution and for major natural aerosol episodes. The UV irradiances are calculated once a day for local solar noon. Corrections are not made for possible changes in cloudiness or total column ozone between the local noon and satellite overpass time. The OMUVBd (version 3) data product selected are TOMS-like daily L3 gridded (lat-lon 1º×1º) data product [28]. The UVI are provided at the time of overpass and at solar noon for overpass conditions (labelled OMI) and for clear sky conditions (OMI-CS) [27, 28].

To validate the OMI data, comparisons were done with the UV radiation measured in 18 ground-based stations [29]. For flat, snow-free regions with modest loadings of absorbing aerosols or trace gases, the OMI derived daily erythemal doses have a median overestimation of 0 to 10 %, and some 60 to 80% of the doses are within ± 20% from the ground reference. For sites significantly affected by absorbing aerosols or trace gases one expects, and observes, bigger positive bias up to 50% is observed. For high-latitude sites the satellite-derived doses are occasionally underestimated by up to 50% because of unrealistically small climatological surface albedo [27, 28, 30].

OMI monitors the recovery of the ozone layer in response to the phase out of chemicals, such as chlorofluorocarbon (CFCs). Together with its companion instruments Microwave Limb Sounder (MLS) and High Resolution Dynamics Limb Sounder (HIRDLS) it will measure criteria pollutants such as O_3, NO_2, SO_2 and aerosols [28, 30].

2.4 UV Index-Formulation

The UV index was formulated by the International Commission on Illumination (CIE) based on the reference spectrum of action erythema and describes the intensity of UV in relation to its photo biological effect [31]. The UV index is defined by Equation 1.0:

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

in which E_λ is the spectral irradiance expressed in W.m-2nm-1 to the wavelength λ and $d\lambda$ is the wavelength range used in the integral calculus. $S_{er}(\lambda)$ is the reference action spectrum erythema and K_{er} is a constant equal to 40 m²/ 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 [1]. The index is an integer and dimensionless that representing the maximum daily value in a horizontal surface. The UV index is divided into categories associated with the colors (Table 1).

Table 1. Relationship between UV index and category of risk to humans.
Source: [1]

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

The UV index was 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. The precautions to be taken by the individual, in accordance with the Table 1, refer to the use of hats, clothes, sunglasses, sunscreen, and umbrellas or even to stay inside the house [1].

3 Results

3.1 Descriptive study

The averages in study period (2001-2012) to UV index and total ozone were respectively 11 ± 0.2 and 264.8 ± 1.8 DU.

The variability and monthly and annual average of UV index, total ozone and cloud cover are presented in Table 2, Table 3 in Figure 2. The colors in the graph of UV Index are associated with the categorization of risk of the WHO. The UV index reaches the value classified as 'extreme' (color violet) in seven months of the year, between spring and summer.

The annual variability of UV Index in city of Natal has a stabilization/reduction in September and October associated with a higher ozone concentration. The cloud cover does not change during these months [31, 32]. This feature was observed in this data series, as shown in Figure 2.

Table 2. Monthly average of UV index, total ozone and cloud cover (Natal-RN, 2001-12).

Month	UV index	Total ozone	Cloud cover
Jan	11.8	259.9	7.3
Feb	12.7	259.3	7.2
Mar	12.6	262.5	7.1
Apr	11.5	259.0	7.3
May	10.2	256.1	7.0
Jun	8.8	257.7	7.3
Jul	8.8	264.3	6.8
Aug	10.3	270.7	6.6
Sep	10.6	278.6	6.6
Oct	11.6	275.9	6.6
Nov	11.8	269.7	6.6
Dec	11.1	263.6	7.0

Source: INPE/CRN-LMHES/UFRN, TOMS-OMI/AURA and INMET.

Table 3. Annual average of UV index, total ozone and cloud cover (Natal-RN, 2001-12).

Year	UV index	Total ozone	Cloud Cover
2001	10.9	268.1	7.0
2002	10.9	275.2	7.0
2003	11.1	269.1	6.9
2004	10.7	274.2	7.1
2005	11.0	257.0	6.8
2006	10.9	264.4	6.8
2007	11.4	257.9	7.0
2008	10.6	266.9	7.1
2009	10.2	257.8	6.9
2010	11.3	263.4	6.7
2011	11.0	262.9	7.3
2012	10.9	260.5	6.9
2001-12	11.1	264,5	7.0

Source: INPE/CRN-LMHES/UFRN, TOMS-OMI/AURA and INMET.
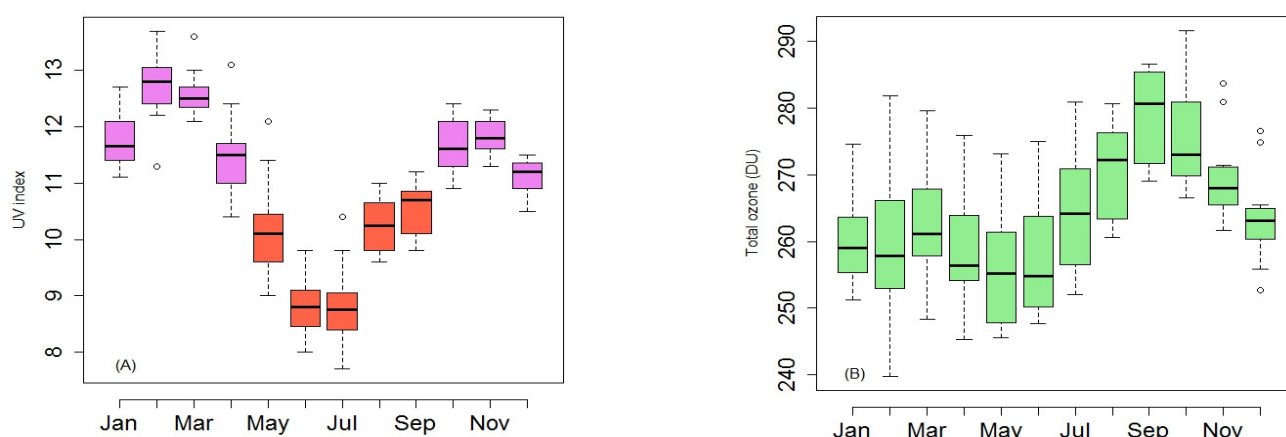
Figure 2– Boxplot of monthly variability to UV Index (A), total ozone (B) and cloud cover (C) to Natal-RN for period 2001-2012.
Source: INPE/CRN-LMHES/UFRN, TOMS-OMI/AURA and INMET.

3.2 Extreme events of UV index in Natal city and Northeast of Brazil

The extreme values to the UV index were calculated using the 95th percentile, encountering for each season values: summer, 14.4, autumn, 13.8, winter, 11.7, spring, 13.1

The extreme episodes of UV index were selected of summer in the data series using analysis of Figure 3 and 95th percentile. The reason for the choice of episodes in summer was due the higher extreme values of series occurred during this period of year. The Table 4 presented the extreme values found considering the criteria cited.

The extreme episodes for UV index are completely linked to values below or near the annual average of total ozone (≈ 265 DU) and partially associated with the extreme values of total ozone as the 5th percentile (245.6 DU) and 10th percentile (249.6 DU) or 20th percentile (252.9 DU).

The following Figures (4–7) obtained at OMI show four of events of Table 4 randomly selected. The images show the variables UV index, total ozone and cloud cover about the Northeast of Brazil.

Table 4- Extreme events of UV index and total ozone in Natal-RN (2001–2012).

Year	Month	Day	UV Index	Ozone
2005	2	16	15.2	251.0
2006	2	25	15.1	262.3
2007	2	10	15.4	246.4
2008	1	16	14.9	258.8
2009	1	30	14.4	248.3
2010	3	28	15.3	245.8
2011	2	21	14.4	267.3
2012	2	17	14.7	248.9

Source: INPE/CRN-LMHES/UFRN and TOMS-OMI/AURA

The Figure 4 shows that the extreme value of the UV index (13-14) in Natal (cityreference) is associated with low levels (10th percentile) of total ozone (248-250 DU) that occurring
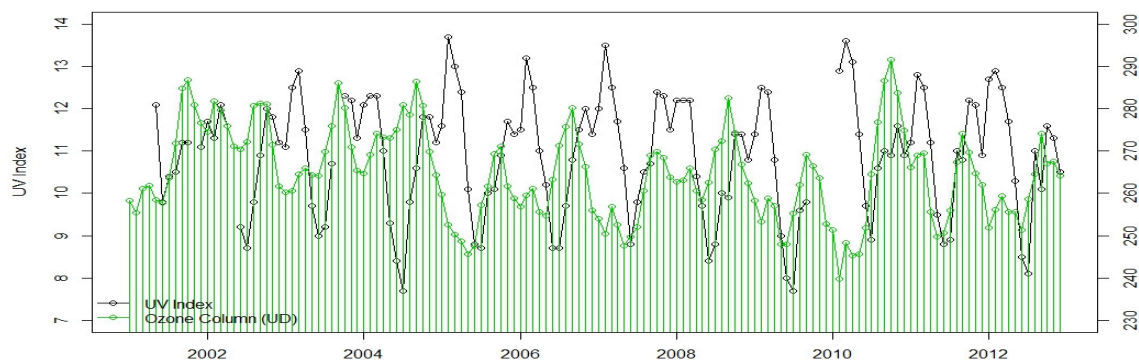
Figure 3 – Time series of UV Index X Ozone total (scale on the right side) for period 2001-2012 in Natal-RN.
Source: INPE/CRN-LMHES/UFRN and TOMS-OMI/AURA
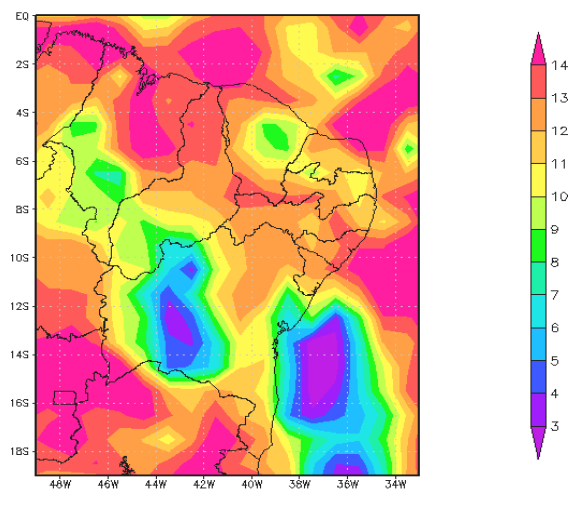
(a) UV index
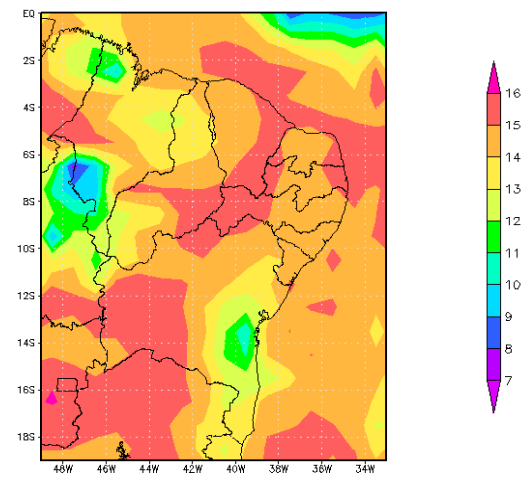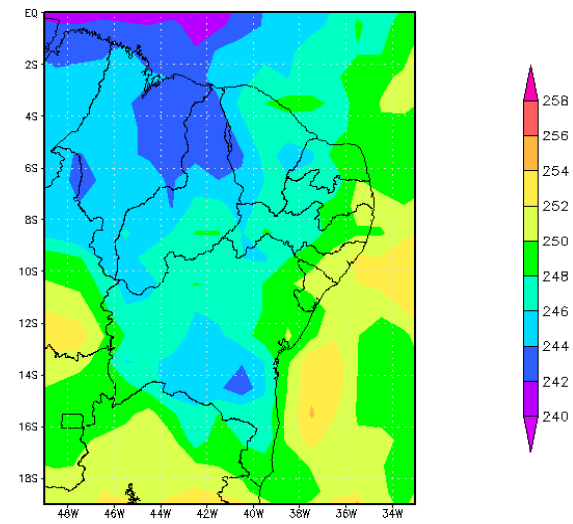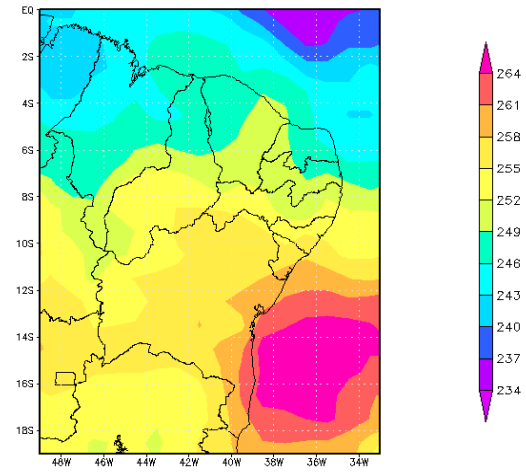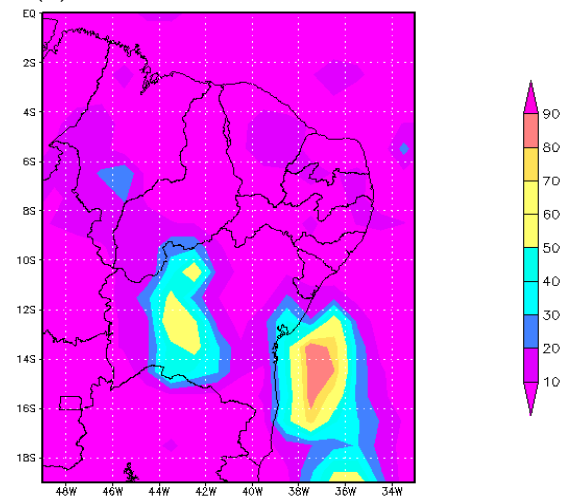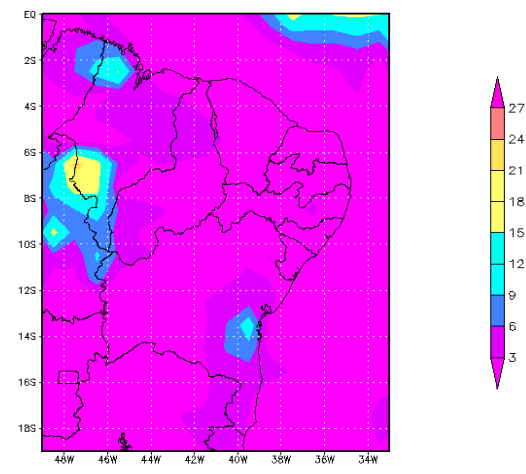
(b) Total Ozone
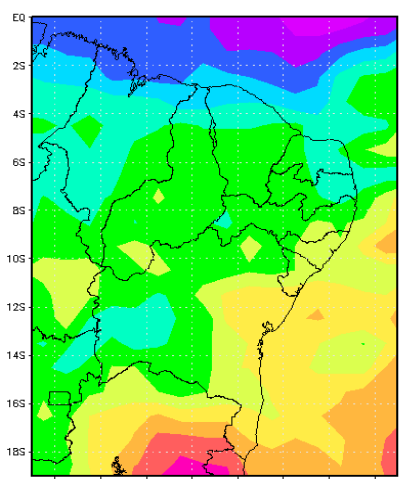

(c) Cloud Cover

Figure 4- Images the UV index, total ozone and cloud cover for February 16, 2005.

(a) UV index

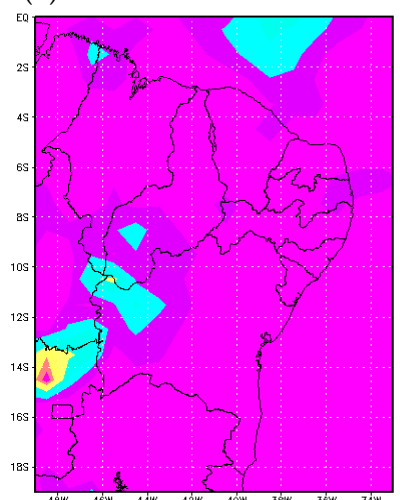(b) Total Ozone

(c) Cloud Cover

Figure 5- Images the UV index, total ozone and cloud cover for February 10, 2007.
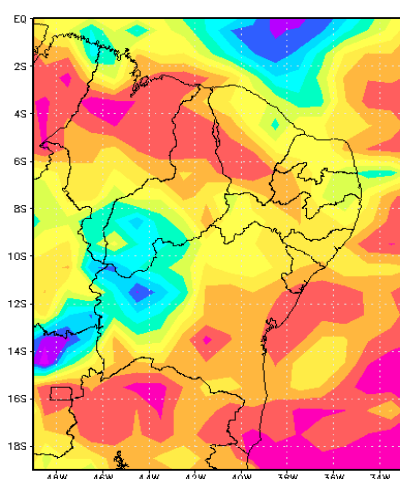
(a) UV index

(b) Total Ozone
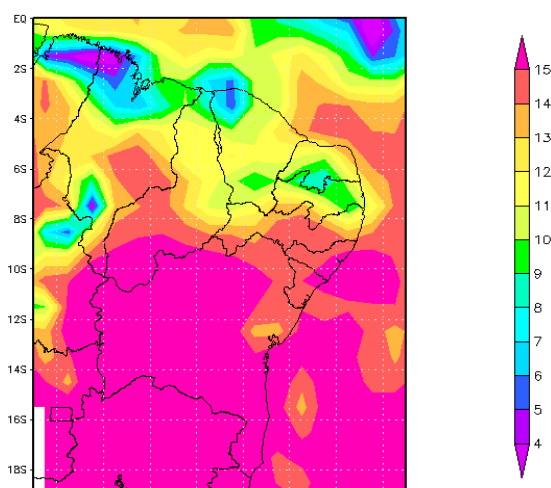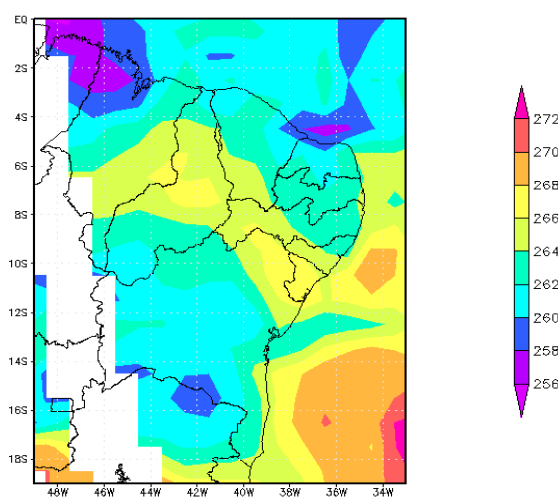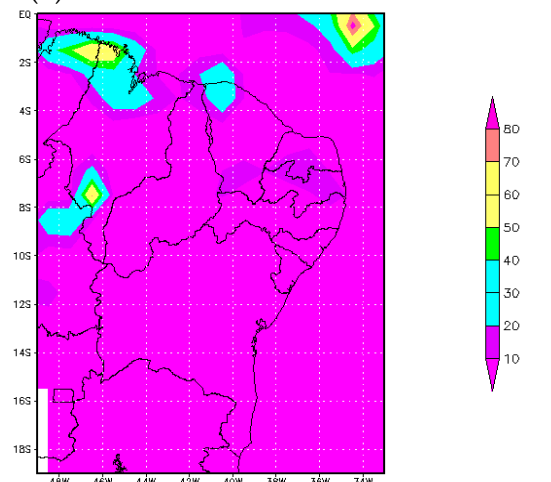
(c) Cloud Cover

Figure 6- Images the UV index, total ozone and cloud cover for January 16, 2008.

(a) UV index

(b) Total Ozone

(c) Cloud Cover

Figure 7- Images the UV index, total ozone and cloud cover for February 21, 2011

during the summer and absence of clouds. The presence of clouds on the coast and interior in state of Bahia (BA) greatly reduce the UV index.

The Figure 5 show that the extreme value of the UV index (15-16) in reference city is associated with low levels (5th percentile) of total ozone (243-246 DU) and lack of clouds. The extreme event of UV index also occurs in western of states of Rio Grande do Norte (RN), Paraiba (PB), Pernambuco (PE), inner of BA and coast of Ceará (CE) associated with low levels (20th percentile) of total ozone (249-252) DU.

In Figure 6 is not confirming an extreme value of the UV index (11-12) in the city of reference. The total ozone (255-258 DU) is in the 25th percentile (255 DU) and there is a slight cloudiness. There are episodes of extreme UV index in coast of BA, center of CE and in northern of states of Piauí (PI) and Maranhão (MA) due to lower levels of total ozone (252-255 DU).

The Figure 7 shows high values for UV index (13-14) very near the extreme value (14.4) for the city of reference. The total ozone (262-264 DU) presents below and close to the annual average. There is not cloudy in Natal-RN. Extreme values of UV were confirmands in coast and inner of BA and in coast to states of Sergipe (SE) and Alagoas (AL). At the center of PI, northeast of BA and west PE the UV index is attenuated by the increase of total ozone.

Generally, the images show that the extreme values of the UV index are associated with absence of clouds and levels below the annual average of total ozone.

The extreme event in the reference city did not happen in the whole region of the study, in function of the spatial variability of total ozone and cloud cover in the region.

4 Final considerations

In the summer happens the greatest extremes of annual series, so the extreme episodes of UV index in Natal-RN (reference city) were analyzed considering the by 95th percentile (14.4).

The analysis of images of the OMI indicated that the extreme events selected of measurements made at the surface by radiometer GUV were associated mainly with absence of cloudiness and levels below average annual of total ozone. The analysis indicated that the extreme event occurred in reference city does not happen in the entire region of study, because of the large spatial variability of cloud cover and total ozone.

Acknowledgements

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