Variations of water vapor and aerosol at the Brazilian northeast based on MODIS data

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Abstract

The MODIS (Moderate Resolution Imaging Spectroradiometer) is the main instrument on board of the Terra satellite; project EOS (Earth Observing System)of the NASA, which was launched in December 1999. The present study analyzes the variations of aerosol and water vapor at the Northeast (NE) of Brazil (semiarid region), based on the data of the Terra platform between years 2000 and 2008. The monthly and annual averages of aerosol optical depth (AOD) and water vapor are presented above the seasonal variations (rainy and dry seasons) in urban and rural areas. It is used daily data of MODIS based on Terra platform, product MDOD08, obtained in GIOVANNI site. In the case of AOD, the monthly averages are obtained considering a preset sample of 5 days in every month, despising the pixels with negative values or without information, what differs from the monthly average presented by the Terra platform. In the case of the water vapor the same averages of the Terra platform are used. The rainy seasons in the area is diversified prevailing from February to May. The AOD in the region, is not homogeneous, it presents values in some pixels 30 or 40 times larger than in others and the standard deviation is very high. In the dry seasons medium AOD is three times larger than in the rainy seasons and systematically it presents extreme values, larger than one, in several pixels. The urban areas present larger AOD than the rural ones indicating anthropogenic emission.

Introduction

The aerosol, which scatters and absorbs solar radiation, exercises strong influence on the composition of the atmospheric air, on the radiative balance of the atmosphere and on the surface. The aerosol alters the chemistry of the atmosphere modifying representative concentrations that affect the climate, for example, the gases of the greenhouse effect. The particles of aerosols existing in the atmosphere have high space and temporary variation. They constitute a group of uncertainties for forecast models of climatic changes.

The composition of the atmosphere can be modified by the mankind actions with the gas emission and aerosols resulting alterations in the environment and in the emission of radiation. Information of the atmospheric components, mainly water vapor and aerosols, are fundamental for the execution of models that involve the physics of the atmosphere, studies about the quality of the air, radiative process in the atmosphere and studies of climatic changes and atmospheric circulation.

The IPCC (Intergovernmental Panel on Climate Change) has presented studies showing that the mankind actions, emitting gases and aerosol for atmosphere, has provoked impacts in the environment and in the climate besides of variations in the emission of radiation. The Northeast (NE) of Brazil, semiarid region, had a great economical growth in the last ten years that might have contributed to increase the AOD in the atmosphere due to anthropogenic emissions.

Information of remote sensing, with great space covering, are fundamental in studies of great scale involving the system earth-atmosphere. In particular, the satellite images have been used in the estimation of atmospheric components, among them, concentration of aerosols, ozone and water vapor. Those components are essential data to the codes of radiative transfer. In that sense, many works have been developed (Holben et al., 1998; Kokhanovsky et al., 2004; Vermote et al., 2007). For the NE of Brazil, as for the entire continent, information on the aerosol and water vapor can be obtained from information of the Terra platform and Aqua platform, MODIS sensor, products MOD08 (Terra) and MYD08 (Aqua). Those platforms, maintained by NASA (National Aeronautics and Space Administration), supplies daily information on the aerosols and water vapor on the continent since 2000. In this work, based on data MOD08 (space resolution of 1° x 1°), it is accomplished a study of the seasonal variations of AOD and of water vapor along the period from 2000 to 2008.

The estimative the AOD in the atmosphere through signals of satellites is based in the radiance measured by these satellites in different channels taking into account the properties of reflectance of the surface, once the radiation reflected by the surface interferes in the radiance measured by the satellite. The optical depth of the aerosol (indicative of the amount and efficiency of extinction of solar radiation for the matter optically activate in a given wavelength) is very smaller in the near infrared (among 0.7 to 4 µm) than in the visible (0.4 to 0.7 µm), meaning that the effect of the aerosol in the spectral infrared region is small. Kaufman and Tanré (1998) show that the reflectance in 0.49 µm is approximately 4 times the reflectance in 2.2 µm and twice in 0.66 µm.

The atmospheric profile of the NE is a tropical standard atmosphere (MacClatchey et al., 1971). The amount of water precipitable in every column of that atmosphere is

4.2 g.cm^{-2}. In principle, the natural AOD in the NE has rural characteristic with AOD less than 0,2 and it should vary as the area in study (rural or urban) and the season (winter or summer) (Shettle & Fenn, 1979). Considering that in normal conditions the AOD urban is composed by 80% of rural aerosol and 20% due to anthropogenic emissions, it is expected that the AOD in the urban areas is larger than in rural areas. However, in the rural area, agricultural activities, mainly burning, can influence the AOD significantly, what makes the rural AOD be dozens of times larger than the urban AOD. Studies on aerosols, in burning areas at Amazonia show AODs in that area much larger than the industrialized area of São Paulo (Pauliquevis et al., 2007).

The causes of changes in the global energy balance are denominated “forcing” and are measured in watts by square meter (W/m^2). The forcing radiative of the aerosols depends on several parameters, and the existing uncertainties in the determination of those forcing, inclusive of their signals, lead many times to the omission of the important role of aerosols in the climatic models (Artaxo al., 2006).

Method

The data regarding the AOD can be obtained through images the Terra satellite products, MOD04 (resolution of 10 x 10 km) and MOD08 (resolution of 1° x 1°), or the Aqua satellite, MYD04 and MYD08. The data of water vapor can be obtained through images regarding the products MOD05 and MOD08 (Terra satellite) or MYD05 and MYD07 (Aqua satellite). Those data, daily and monthly, are available in files type HDF since March of 2000 and are available in the site: <http://ladsweb. nascom.nasa.gov/data/search.html>. However, in an effort of researchers of NASA in 2007, those same data, with resolution of 1° x 1° (products MOD08 and MYD08) can be obtained through a denominated application GIOVANNI, acronym for GES-DISC (Goddard Earth Sciences Dates and Information Services Center). GIOVANNI, with support in the internet, supplies a simple and intuitive way to visualize, analyze and access a vast amount of data of remote sensing regarding the system Earth-atmosphere (Acker and Leptoukh, 2007). In this work available GIOVANNI's data are used in the format ASCII in the site: <http://gdata1.sci.gsfc.nasa.gov/>, accessed in 27/02/2009.

The area regarding NE is inserted in a rectangle in which the latitude ranges from -3° to -15°S and the longitude from -48° to -34°W. The pixels that are out of the border of NE are eliminated, resulting in 120 pixels with, 15 urban and 105 rural areas.

With base in product MOD08, the analyzed data are:

- Positive AOD at the wavelength 0.55 µm.
- Water vapor in days of clear sky.

To observe the variation of data in areas with influence of urban centers it was taken by reference the 15 larger urban centers of the region, that is, cities with more than 100.000 habitants. Although that choice is not so precise due to great area of each pixel (space resolution of 1° x 1°), it is enough to supply indications about the contribution of AOD due to anthropogenic emissions.

The monthly averages, regarding AOD, presented by the Terra platform (product MOD08), on the continents, include negative values caused by the sensibility of MODIS sensor in evaluating near values ±0.05 (http://modis-mos.gsfc.nasa.gov/MOD04_L2/format.html). In this work, to reduce the great volume of data to be processed, the seasonal variations are obtained through monthly averages established just with the observation of five days, prefix in every month, 2-9-16-23 and 30.

The monthly averages, regarding the water vapor, are obtained directly from GIOVANNI site.

The monthly averages of the data are put in temporary series observing the season (winter or summer) with identification of the areas, urban or rural, identified using Google Earth and IBGE (Brazilian institute of Geography and Statistics) information.

For analysis of the obtained data it is observed the characteristics of each area (rural or urban), the climatic conditions of the period (winter or summer) and the variation of the parameters analyzed in each situation.

The region of NE with area of 1.558.196 Km^2 presents high climatic variation with prevalence of semiarid tropical climate. In 2000, when the Terra platform began to publish data, the population was 47.693.253 habitants and in 2007; 51.534.406 habitants. The Figure 1 display the distribution of the demographic density according to demographic census of 2007 (Source IBGE). The capitals: Salvador (12°58'19" S; 38°30'49" W) with are 706.795 Km^2 and 4.529.806 habitants, Fortaleza (3°43'04" S; 38°32'41" W) with are 313.140 Km^2 and 2.473.614 habitants, Recife (8°03'21" S; 34°52'53" W) with area 217.494 km^2 and 1.549.980 habitants are the largest urban centers of the region (IBGE 2008).

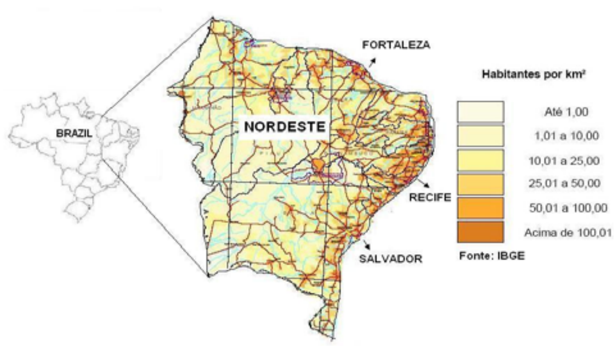
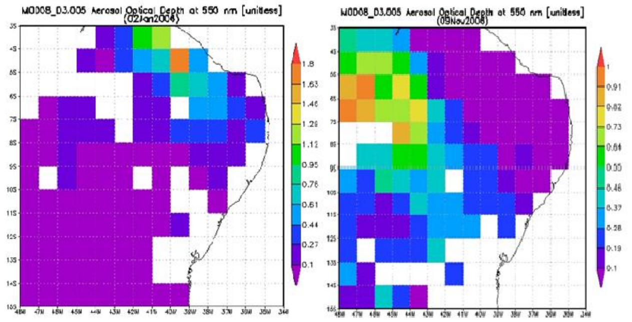


Figure 1. Demographic density of the NE of Brazil region. The capitals: Salvador, Fortaleza and Recife are the largest urban centers of the region (Source IBGE).

Results

The Figure 2 is a sample of the aerosols data for February Sixth and November Thirtieth of 2006. In GIOVANNI’s site <http://gdata1.sci.gsfc.nasa.gov /> the squared colors indicate aerosol measures and the whites, absence, possibly due to the presence of clouds in the moment the satellite was passing. For Figure 2a, AOD varies from values smaller than 0.1 to 1.8 and in the Figure 2b the variation is from values smaller than 0.1 to 1.0.



a) AOD between (0.1; 1.8], b) AOD between (0.1; 1,0]

Figure 2. Variation of AOD for January and November of 2006. (source: GIOVANNI site). The registered values of AOD are smaller or same to 1.8 in Figure 2a and smaller or same to 1.0 in Figure 2b.

In Figure 3, it is shown results regarding AOD in the period 2000-2008 in the NE region. Between January and February begins the rainy season in most of the region and it extends until May or June. The months of July and August are months of transition among rainy and dry seasons (September to January). In the rainy season, global average AOD (A-G) decreases tends to a minimum in July (month in which the predominant vegetation is still green), A-G = 0.06 ± 0.01. In the dry season, AOD increases reaching a maximum in

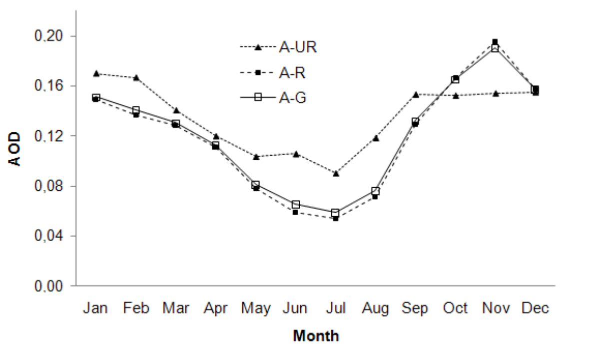
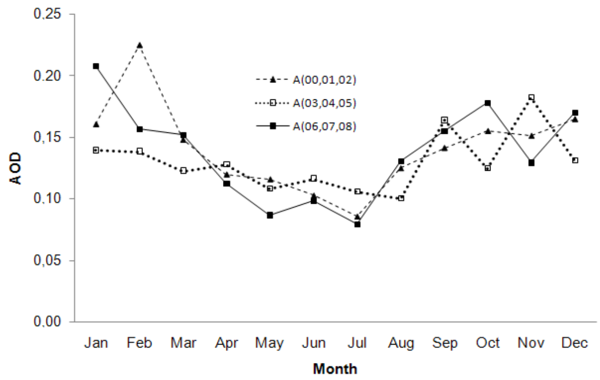


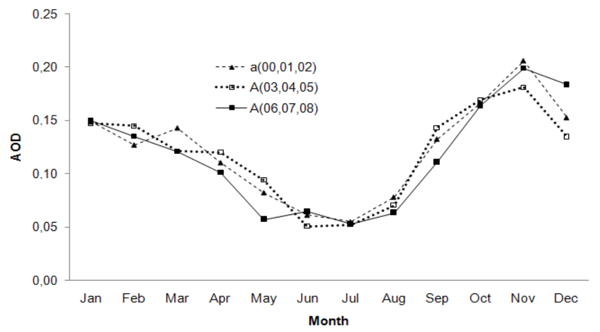
Figure 3. Variation of global medium AOD A-G, urban A-UR and rural A-R in the period 2000-2008 in the region of NE.

November A-G = 0.19 ± 0.03. The average variation in urban (A-UR) and rural (A-R) areas are: in July: A-UR = 0.09 ± 0.01 and A-R = 0.05 ± 0.01; in November: A-UR = 0.15 ± 0.03 and A-R = 0.20 ± 0.04. In the three observed situations, the global average, rural and urban, has a similar behavior. The AOD in the urban area is larger than in the rural area and it is almost constant in the dry season. It decreases to minimum values in the rainy season, possibly due to anthropogenic emissions. The difference between urban AOD and rural is larger among the end of the rainy season (June) and beginning of the dry season (September), period in which the concentration of water vapor in the atmosphere is smaller. When it is in dry season, the rural AOD increases in 3 or more times. The main reason is probably due to emission of burn existing in the region. In some pixels it is observed extreme values of AOD superior to 1.1 with Angstrom coefficient larger than 1, similar to value registered by AERONETE (Aerosol Robotic Network) in times of burning at Amazonia. When the rainy season begins the AOD in the rural area decreases reaching minimum value in the transition period among the rainy and dry season.

In Figure 4, it is shown results of the seasonal averages of AOD; a) in urban area and b) in rural area. The averages correspond to the averages of the three-year periods (2000-2002), (2003-2005) and (2005-2008). It is observed that the monthly average of AOD along the period 2000-2008 are systematic, it does not exist a clear tendency on the growth or decrease of them along the analyzed period. In the dry season, October to February, it is observed strong oscillations of AOD in the urban area. Those oscillations are due to the fact that some pixels contain urban and rural area with possible occurrence of burning. In the rural area it is observed a larger regularity than in the urban area, indicating that their activity and practices with the soil of the region are the same over the period 2000-2008.



a)



b)

Figure 4. Seasonal variations of AOD: a) urban area and b) rural area.

In Figure 5, it is shown the averages of AOD in urban areas involving the 15 urban centers of NE (A-U-NE) and the three larger urban center of the region; Recife (A-U-RE), Fortaleza (A-U-FOR) and Salvador (A-U-SAL). It is observed that the Fortaleza region, excepting the year of 2002, presents an annual average, 0.18 ± 0.06, larger than the region of Salvador that has a larger population. However the region polarized by Fortaleza has a demographic density 973 hab/km^2 while the area polarized by Salvador has a demographic density 363 hab/km^2.

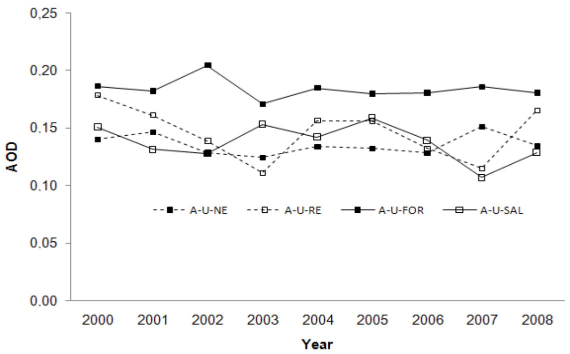


Figure 5. Averages of AOD in urban areas of NE.

Along the observed period 2000-2008 in the rainy season, it was recorded the maximum of water vapor (g.cm^{-2}) in the atmosphere and in the dry season it was recorded the minimum (Figure 6). The results in Figure 6, show that the largest amount of water vapor in the atmosphere happens in March (rainy month) where: A-G = 4.3 ± 0.25 g.cm^{-2}, A-UR = 4.4 ± 0.16 g.cm^{-2} and A-R = 4.3 ± 0.27 g.cm^{-2}, while the minimum values happen in August where: A-G = 2.95 ± 0.15 g.cm-2, A-UR = 3.17± 0.11 g.cm^{-2} and A-R = 2.93 ± 0.16 g.cm^{-2}. It is observed that between April and September the concentration of water vapor in the atmosphere in urban areas is larger than in the rural areas with an inversion between the months of October and March. This is due to the fact that among the 15 considered urban centers, 8 are capital located in the coast where the concentration of water vapor is very large.

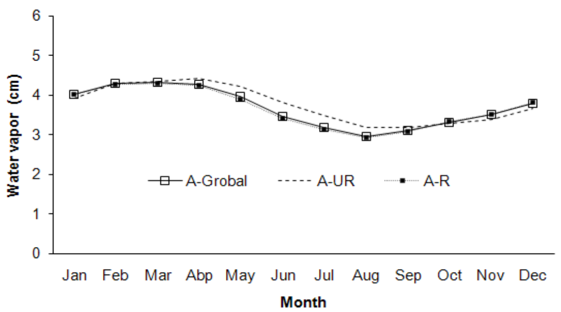


Figure 6. Monthly average of the water vapor along the period 2000-2008.

Conclusions

The observations show that NE is not an atmosphere as clear as it is commonly imagined. The smallest AOD, 0.06 ±0.01, was registered in the months of June to August. In the dry season, the AOD increases reaching a maximum in November A-G = 0.19 ± 0.03. It is possible to find AOD of up to 1.7, as high as in the area of burning at Amazonia. In principle, it is noticed a significant contribution of anthropogenic aerosols in the NE region, mainly in the area polarized by Fortaleza. The growth of the urban centers in the last decade, doesn't contribute significantly to the increase of anthropogenic emissions, at least in great scale, indicating a stable tendency of the AOD for next years. However, it is possible that satellite information with a better space resolution may show with more precision the influence of the urban growth in the study of the AOD. As well as for AOD, the results also indicate a stable tendency of the amount of water vapor in the atmosphere.

Acknowledgments

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