Air Pollution Dispersion Mapping by Remote Sensing: Case Study from the Federal District

Erick Frederico Kill Aguiar, Henrique Llacer Roig
Institute of Geosciences, University of Brasília - UnB
Brasília, Brazil
E-mails: {erickkill@aluno.unb.br, roig@unb.br}

***Abstract* - The city densification and, consequently, the potential polluting activities have increased significantly in the last decades, compromising the air quality. Thus, it is necessary to know this scenery to model the pollution behavior and its respective pattern in each region of the Federal District. So, the main goal of this study was to analyze the Aerosol product available by National Aeronautics and Space Administration (NASA) at the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor (TERRA). With these preexisting data, it was possible to analyze the aerosol (AOD) distribution from 2010 and the optical depth. These data were integrated to the processed values of Total Particles in Suspension (PTS) of the eight air quality monitoring stations variably distributed in the Federal District, with two of them (714 south and HUB) kept and managed by the Interdisciplinary Center of Transport Studies (Centro Interdisciplinar de Estudos em Transportes - Ceftru/UnB), correlating the month of October 2010. The study showed that the region of Brasília downtown and the surroundings of the Fercal region, overall, were the ones that kept most of the Aerosol Optical Depth (AOD) and the highest values of the Angström Exponent (AE), which can be attributed to the types of activities performed in these regions.**

Keywords: Aerosol. Optical Depth. Air pollution.

I. INTRODUCTION

The atmospheric pollution has become one of the most frequent topics on big discussions, showing that the resulting environmental impact is the biggest cause of the damages reflected on human health, ecosystems and materials.

The large urban centers progressively densify the population, supporting the intensification of anthropic activities. The emergence of industrial activities, the growth of vehicle fleets, fire, green areas devastation and deforestation, increasingly, damage the air quality.

The Federal District has, nowadays, a fleet of 1.321.552 motor vehicles [1]. The industries, represented by asphalt, cement, furniture, beverage, roasting and tire retread factories, also contribute with the emissions, but in smaller scale.

The Air Quality in the Federal District monitored by the Brasília Environmental Institute [3], which monitors 6 stations (Taguatinga, Rodoviária, Fercal I and II, CIPLAN and Queima Lençol), and the Interdisciplinary Center of Transport Studies (Centro Interdisciplinar de Estudos em Transportes - Ceftru/UnB) is in charge of 2 stations (714 south and HUB). The stations are fixed and only 3 parameters are quantified - out of 7 established by law [2]: Sulfur dioxide (SO_2), Total Particles in Suspension (PTS) and Smoke.

The monitored locations are considered critical sites, due to the intense motor vehicle traffic or to the existence of large cement factories. Both sources contribute to the high emission of elevated concentration of gaseous and particulate pollutants, which can be measured quantitatively at monitoring stations [3].

On previous studies about aerosol [4], it was shown that satellite data have been used to give information about air quality. The AOD can be analyzed by utilizing data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, which is an effective way to monitor and study the aerosol distribution and its effects along time, considering that the passing period is 1-2 days.

Therefore, this study's purpose is to analyze the data to set up a multitemporal prospect of the aerosol behavior in the Federal District, from preexisting data of the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor name TERRA.

II. OBJECTIVES

The general objective of this study is to analyze the aerosol distribution in the Federal District between 2004 and 2013 using remote sensing techniques and geoprocessing. Therefore, the specific objectives are:

• To correlate the data obtained from the Air Monitoring Stations of the Federal District with the Aerosol product from Moderate Resolution Imaging Spectroradiometer MODIS sensor (TERRA) in the specific date collected from the stations;

• Multitemporal analysis (2004 to 2013) of the AE, which is the spectral dependency measure of the AOD.

 ISBN: 978-1-61208-326-1

III. MATERIALS AND METHODS

The aerosol measurement in the Federal District does not exist (Figure 1). It is often limited to in situ analysis of Total Particles in Suspension (PTS) at the 8 air quality monitoring stations, and the information from the data are restricted to certain places.

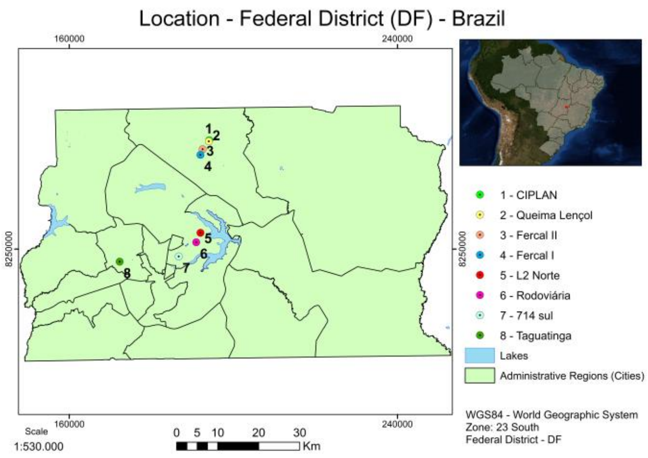

Figure 1. Location of the study area and the stations monitoring air quality.

The operating algorithm of the NASA (National Aeronautics and Space Administration) corresponds to the collection of aerosols group 5.1 (AQUA/TERRA Forward and Reprocessing) and provides for each pass daily files with values of the aerosol optical depth with spatial resolution of 10 km x 10 km over the ocean and the land [5].

Because of this limitation, to acquire the aerosol scenario in large scale encompassing the entire Federal District region, data from the MODIS's AERONET (Aerosol Robotic Network) [6] program is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire), ollaboration provides globally distributed observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water in diverse aerosol regimes. Aerosol optical depth data are computed for three data quality levels: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (cloud-screened and quality-assured). Inversions, precipitable water, and other AOD-dependent products are derived from these levels and may implement additional quality checks. Were selected (2003 to 2011), as it contains 36 bands, and the bands 1-2, 3-7 and 8-36 have special resolution of 250m, 500m and 1 km, respectively.

The data about aerosols were obtained from MODIS level 2, in type .hdf at NASA portal, at level 1 and atmospheric products data section, and are already processed and corrected. The date of the datum, the location, the period it was collected (day, night or both) and to which library it belongs (in this case, the choice was "Collection 5.1", which had all the data for the chosen time interval) are selected.

For this study, from 2010, daytime data was chosen, because the possible vectors with polluting potential have regular activity in this period. There were attempts to acquire products fortnightly, but it was concluded that there was not product available in the region in every pre-established date, so the acquisition was made in variable dates close to the interval pre-established.

In order to standardise the comparison of ground-based [7] observations with instant satellite-observed data at a given moment, the apparent reflectance and surface reflectance within an area of 10 km by 10 km centered at the Federal District observation station were averaged. Similarly, the ground-based data recorded within half an hour of the satellite overpass on cloud-free days were also averaged to derive AOD at the 550 nm wavelength using the Angström formula for validating satellite-based results [11].

AOD values from the high-resolution product land the standard Collection 5 AOD algorithm were compared to observed Aerosol Optical Thickness (AOT) values at three coastal Aerosol Robotic Network (AERONET).

These data has the nomenclature with the Julian data, specified as follow:

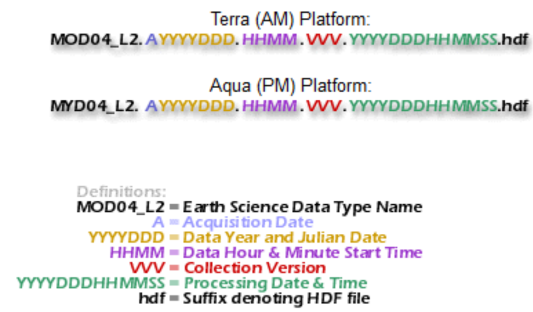

Figure 2. Nomenclature model of the .hdf archives from MODIS.

At the processing of level 2 final data, the following softwares were used: ENVI (Plugin MODIS Conversion Toolkit (MCTK)), which is a module and does the conversion of sinusoidal projection to UTM and the ArcMap for the construction of the database for the maps of AOD, Corrected Optical Depth, Cloud Fraction, Mass Concentration and AE, which present the following parameters in the .hdf file:

- Corrected Optical Depth

(Corrected_Optical_Depth_Land)
Description: Optical Thickness corrected by 0.47, 0.55 and 0.66 µm
Valid interval: -0.05 to 5.0;

- AOD (Optical_Depth_Small_Land)

Description: Optical Thickness corrected for 0.47, 0.55, 0.66 and 2.13 µm
Valid interval: -0.05 to 5.0;

- Concentration Mass

(Mass_Concentration_Land)
Description: Concentration of mass on Earth.
Valid range: 0 to 1000 1.0e-6g/cm x ^ 2;

- AE

(Angström_Exponent_Land)

Description: AE from 0.47 to 0.67 μm
Valid interval: -1.0 to 5.0;

- Cloud Fraction

(Cloud_Fraction_Land)
Description: Cloud fraction from the aerosol cloud mask recovered and cloudy pixels, not including cirrus cloud mask.
Valid interval: 0.0 to 1.0.

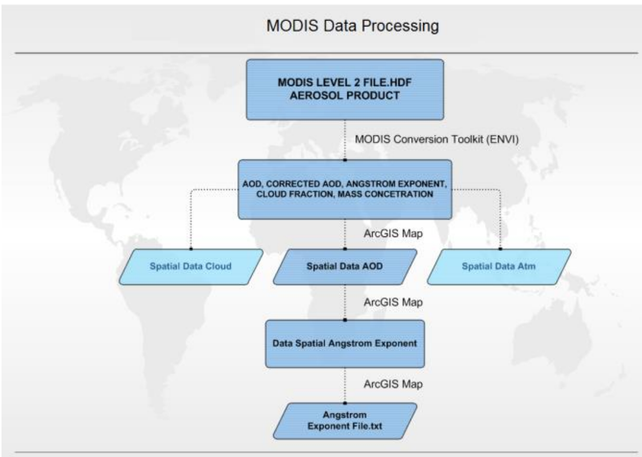

Figure 3. Stage of the data processing from Level 2 MODIS extraction to the final analysis phase using environment ArcGIS.

The first 19 bands are positioned in the region of the spectrum eletroradiometric situated between 405 nm and 2155 nm, so that the bands are 1-7 targeted for terrestrial applications; bands 8-16 for ocean observations and bands 17-19 for atmospheric measurements [12].

The sampled pixel has a 10 km spatial resolution, because data with smaller spatial resolution (ex: 250 m) were not available for the region. The histogram was assembled on ArcMap and the graphic maps of the above described items were made available.

The Interdisciplinary Center of Transport Studies (Centro Interdisciplinar de Estudos em Transportes - Ceftru/UnB) provided the spread sheets with the data of the Air Quality Monitoring Stations from the 8 stations located in the Federal District.

The *shapefiles* of the Census Sector 2010 [9] were used to verify the influence of the urban areas on the distribution of aerosol at the regions of the Federal District, Hydrography and Road System, from Real Estate Company of Brasília (Terracap) origin (2010) for region localization reference.

All provided and generated data can be found in UTM SIRGAS 2000 (Geocentric Reference System for the Americas), zone 23 south.

IV. RESULTS AND DISCUSSION

From 2003 to 2009, there was not daily accurate information that could be correlated with the data from the MODIS aerosol product. However, the Ceftru collected significative data for the year 2010, from the 8 stations, from which two close dates were selected, when there were data about aerosol in the Federal District area (10/04/2010 and 10/14/2010), during rainy season; there were not data production during the dry season (Tables I and II).

TABLE I – TOTAL PARTICLES IN SUSPENSION ON 04/10/2010.

04/10/2010		
ID	Station	PTS (μg/m³)
1	CIPLAN	1.250,06
2	Queima Lençol	-
3	Fercal II	-
4	Fecal I	218,05
5	L2 Norte (HUB)	96,92
6	Rodoviária (central bus station)	148,01
7	714 Sul	66,45
8	Taguatinga	240,98

On the data shown for these days, the average standard of AOD is below 0,5 μm. Figures 11 and 16 show the level of particle size variability that is affected by the sum of the types of activities in the Federal District. There are many activities that can influence a region, where a pollution with different particle sizes will arise. The result of the AE points the difference between the values of AE for the dry and rainy seasons. Previous studies [6] mention that the tendency is that during the rainy season, the value can be up to 1 μm, in the case of the analyzed dates, varying from 1,35 μm to 1,92 μm, which means that the type of aerosol is compound of thin particle. Usually, on a rainy day, the aerosol goes down to the ground surface, due to the entrainment by the water drop.

On 10/04/2010, the data from the air quality monitoring stations show a substantial particle concentration at the CIPLAN station (1.250,06 μg/m³), where the AE is 1,92 μm (Table I and Figure 6). It is known that the higher its value, the bigger the spectral dependency, which means bigger optical depth variation with the wavelength; in other words, the AE is related to the medium size of the aerosol particles on the atmospheric column, since smaller particles has bigger spectral dependency that larger ones.

Some studies [4] in the dry season also showed that soil dust from agricultural land un-vegetated being great source of aerosols in regions with arid characteristics. AOD is closely related to the topography [10], suggesting that a significant inverse correlation exists between them. AOD is significantly lower in high-altitude areas. Conversely. anthropogenic activities produce large amounts of fine aerosol particles in densely populated urban areas. However, airborne dust originating from traffic and construction activities in urban areas, in addition to larger particle sizes of soot aerosols produced by industrial and civil coal fuel combustion cause coarse-mode aerosols.

 ISBN: 978-1-61208-326-1

The particles originated in this region activities are usually from mechanical and chemical processes. The latter are, generally, smaller, unlike the ones made during the production of dust by the cement factories. So, the AE is also often used as an indicative of regions where aerosols of different types are predominant, originated from several processes.

The same situation happens at the Taguatinga station, where there is a large urban center that produces aerosols resulting from chemical processes like engine combustion. The AE value is 1,35 µm (Figures 6 and 10), and reduces to 0,52 µm on 10/14/2010, which presents in the zone of aerosol made by thin particles, with less spectral dependency.

This tendency to smaller values can be linked to a station where there is a “renovation” of the air column because of rain and wind, decreasing the values for regions with an expected polluting potential. Both dates show similar scenarios, without a very significative variation of the data of optical depth and AE. Only the spatial distribution of the datum varied.

Similar fact happened to the mass concentration parameter, which is the aerosol column on the atmosphere. It varied up to 1,35 µm on 10/14/2010, and also the spatial distribution in the region varied.

The figures (Figures 4, 6, 8 and 10) below show the AOD and AE for the dates of 04/10/2010 and 14/10/2010, which could be directly correlated with the existing data in fixed stations stations.

TABLE II – TOTAL PARTICLES IN SUSPENSION ON 14/10/2010.

14/10/2010		
ID	Station	PTS (µg/m³)
1	CIPLAN	971,71
2	Queima Lençol	-
3	Fercal II	-
4	Fercal I	246,07
5	L2 North (HUB)	72,73
6	Rodoviária (central bus station)	114,76
7	714 South (714 sul)	66,45
8	Taguatinga	208,64

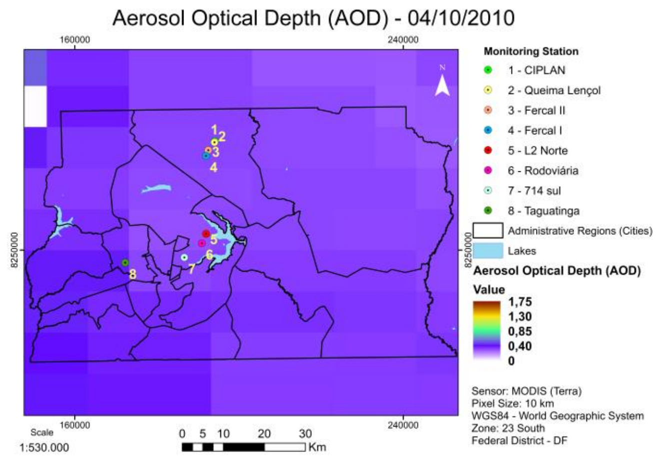

Figure 4. AOD for the day 04/10/2010, indicating the location of the monitoring stations and the population distribution region.

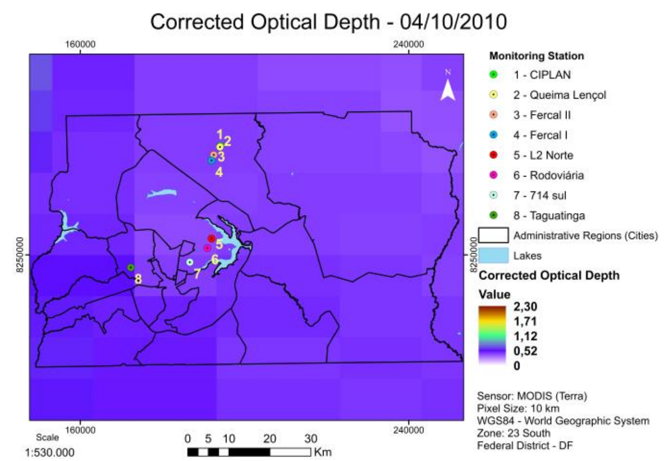

Figure 5. Corrected Optical Depth for the day 04/10/2010, indicating the location of the monitoring stations and the population distribution region.

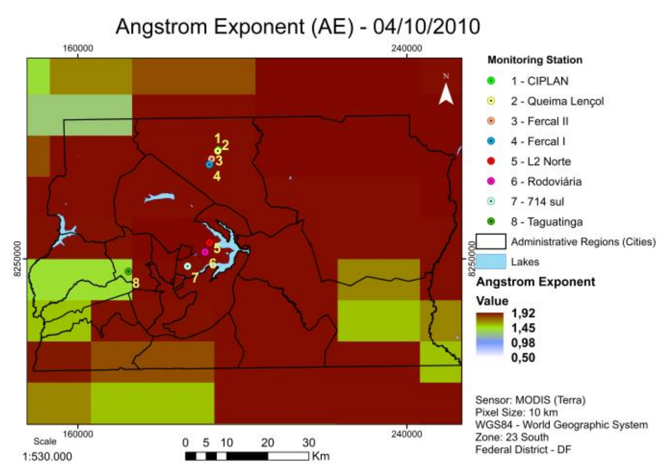

Figure 6. AE for the day 04/10/2010, indicating the location of the monitoring stations and the population distribution region

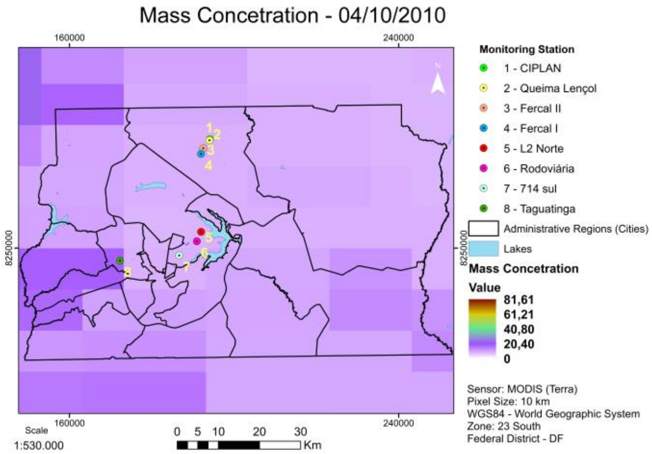

Figure 7. Mass concentration for the day 04/10/2010, indicating the location of the monitoring stations and the population distribution region

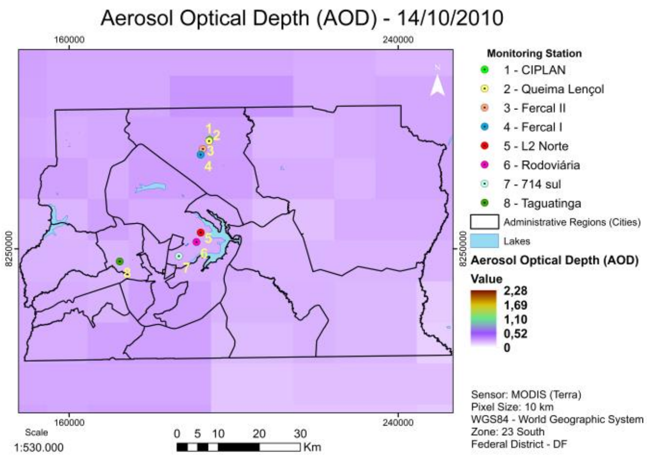

Figure 8. AOD for the day 14/10/2010, indicating the location of the monitoring stations and the population distribution region.

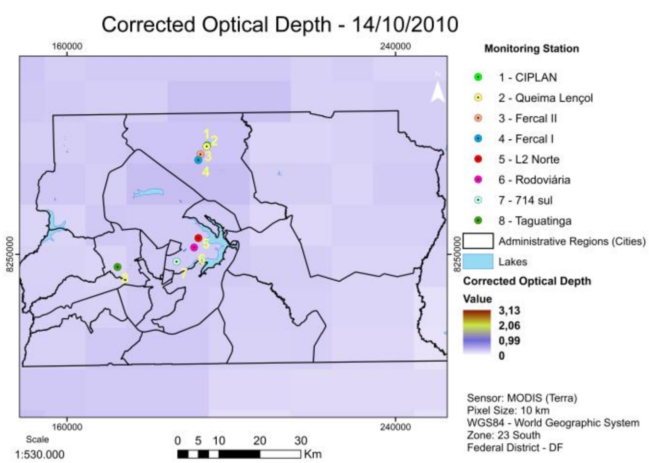

Figure 9. Corrected Optical Depth for the day 14/10/2010, indicating the location of the monitoring stations and the population distribution region.

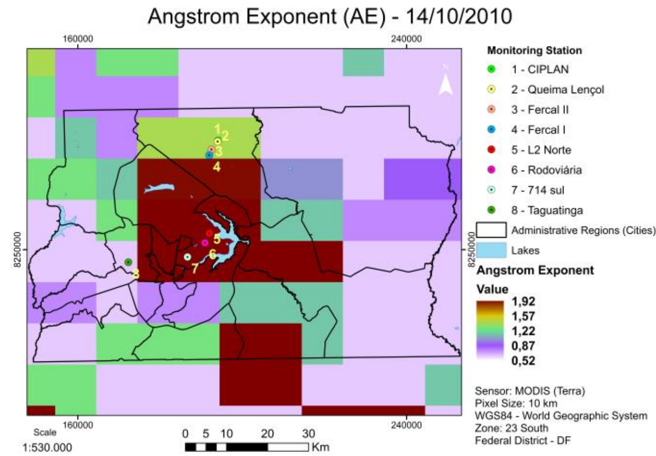

Figure 10. AE for the day 14/10/2010, indicating the location of the monitoring stations and the population distribution region.

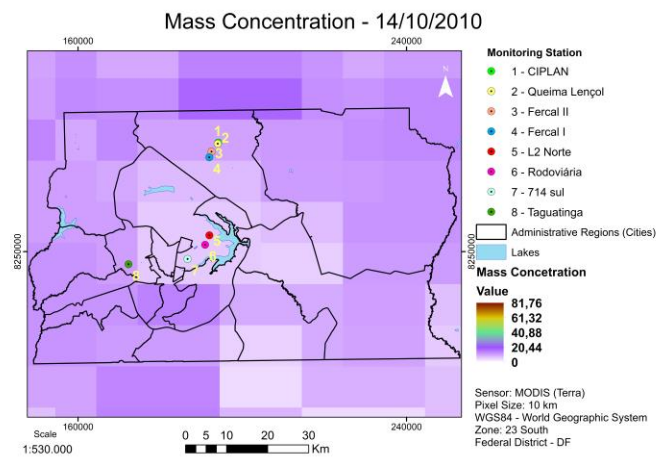

Figure 11. Mass concentration for the day 14/10/2010, indicating the location of the monitoring stations and the population distribution region.

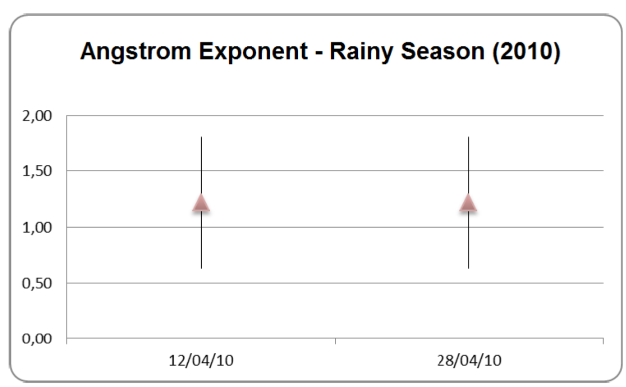

Figure 12. AE - Rainy Season – (only data MODIS) (2010).

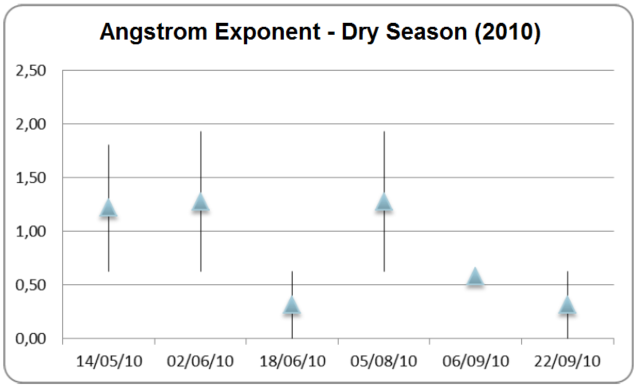

Figure 13. AE – Dry Season (only data MODIS) (2010).

Overall, during the dry season, the large particles stayed on the atmosphere longer than during the rainy season, because during the drought there is no process of "rinsing" the air, proving in most parts of the analysis that, by the distribution of the value of the AE in the region, the pixel average value was ≤ 0,5, which is equivalent to larger particle sizes.

The downtown area of Brasília and the surrounding of the Fercal area, in general, were the ones in the scenario that maintained most part of the concentration of AOD and the highest values of the AE, along the years. It can be attributed to the types of activities existing in these regions. Taguatinga showed a smaller variation of the AE and bigger AOD variations in some dry season situations.

The lack of more recent data (from year 2011) prevented subsequent correlation to aerosol data from MODIS with ground stations (the stations are government and have no more maintenance).

V. CONCLUSION AND FUTURE WORK

The range of the AE analyzed indicates the level of the particle variability that can be correlated with the types of activities of a specific region.

The particle sizes in urban areas tend to be larger compared to the ones found in natural environments, also during drought, when the distribution of the particle sizes tends to be more varied. Sand and dust were the main sources of AOD in Federal District.

AOD was affected mainly by human activities and showed a slight increasing trend. Anthropogenic activities caused the increase of fine mode AOD in most areas. In addition, variation in fine mode aerosols dominated the yearly fluctuation of AOD, and the main aerosol type shifted gradually to the urban industrial type.

During the rainy season (Figure 12), the particles tend to be smaller, with the average AE between 0,5 to 2, while the particle size during the dry season (Figure 13) tend to be more varied, as mentioned in previous studies [4][5].

Overall, the areas with industrial activities are the main source of pollution, as well as big urban centers.

It is noteworthy that more accurate field validations, with a larger number of parameters at the existing air monitoring stations would make it closer to the reality of the information monitored by the MODIS satellite, leading to a safer correlation with the final result of an analysis of this kind.

Lesson learned and indication to future studies with radiometers and spectrometers will help understand the particles, specifying the pollution type existing in each region, thus, enabling to compare which types of sources cooperate with the dispersion of aerosol in the Federal District.

In future work we intend to use low-cost sensors in mobile devices for increased accuracy in generating data on ground level for correlation with data from MODIS.

REFERENCES

[1] Denatram. Car fleet – 2011 [Online]. Available online: http://www.denatran.gov.br/frota.htm (acessed on 2014.02.15).

[2] Ibram. Monitoring Report of Environmental Quality Air Quality in Federal District - Brasilia Environmental Institute, Brasilia, 2008.

[3] Conama - National Council for the Environment, Conama Resolution 03. Establishes standards for air quality. Brasilia, 1990.

[4] Rosida. Variability of AOD Over Java Continent by Using MODIS Data. Applications of Climatology And Environment Division, National Institute Of Aeronautics And Space, 2007.

[5] Lorraine Remer, Yoram Kaufman, and Didier Tanré.. Algorithm for remote sensing of tropospheric aerosol from MODIS: Collection 005 (Product ID: MOD04/MYD04). NASA, 2006.

[6] ZiPeng Dong, Xing Yu, XingMin Li, and Jin Dai. Analysis of variation trends and causes of aerosol optical depth in Shaanxi Province using MODIS data. Meteorological Institute of Shaanxi Province - China, 2013.

[7] Aerosol Robotic Network (AERONET). Available online: http://aeronet.gsfc.nasa.gov/ (accessed on 2014.02.10).

[8] Junliang He, Yong Zha, Jiahua Zhang , and Jay Gao. Aerosol Indices Derived from MODIS Data for Indicating Aerosol-Induced Air Pollution. Laboratory of Virtual Geographic Environment, Ministry of Education, College of Geographic Science, Nanjing Normal University, Nanjing, China, 2014.

[9] Ibge - Brazilian Institute of Geography and Statistics. 2010 Census. Brazil, 2010.

[10] Anup Prasad, Ramesh Singh, and Ashbindu Singh. Variability of Aerosol Optical Depth Over Indian Subcontinent Using MODIS Data. Journal of Indian Society of Remote Sensing vol. 32, no. 4. December, 2004.

[11] Ångström, A. The parameters of atmospheric turbidity. Tellus 1964, 16, 64–75.

[12] John Barker, Paul Anuta, and Joann Harnden. MODIS spectral sensivity study: requirements and characterization. Washington: Nasa, Oct, 1992, 84p.

ATTACHMENTS

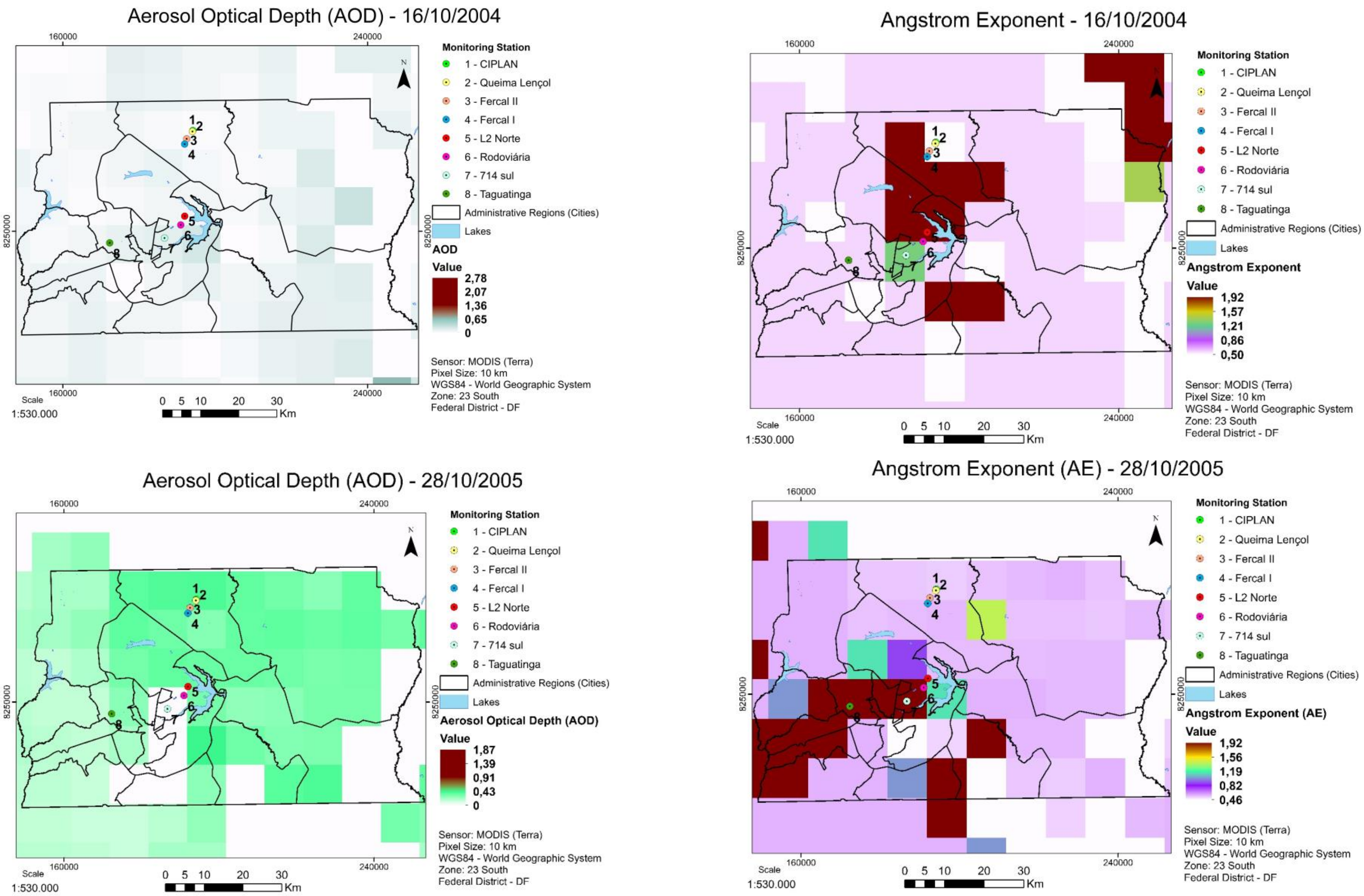

Figure 14. AOD and AE for the days 16/10/2004 and 28/10/2005.

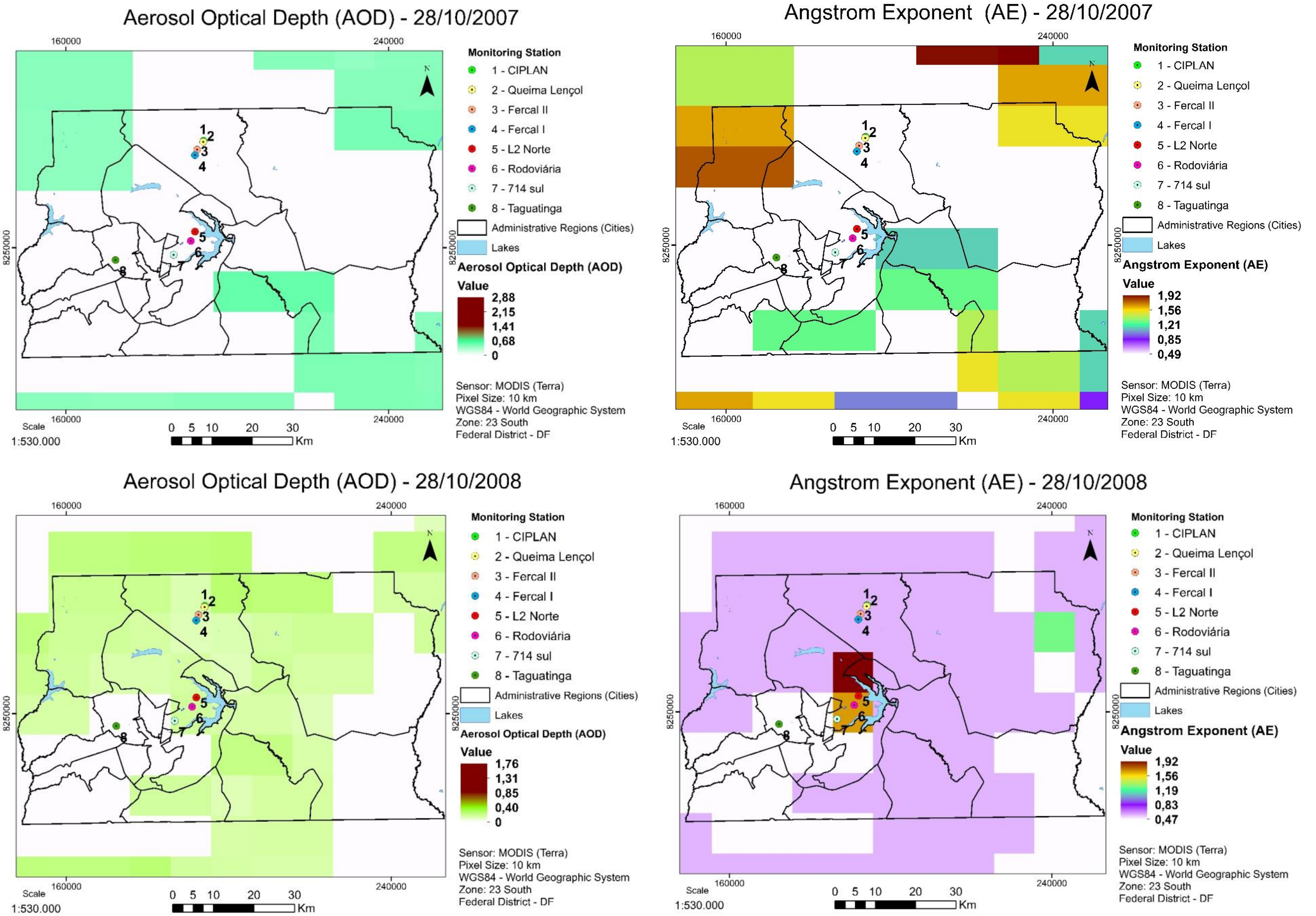

Figure 15. AOD and AE for the days 28/10/2007 and 28/10/2008.

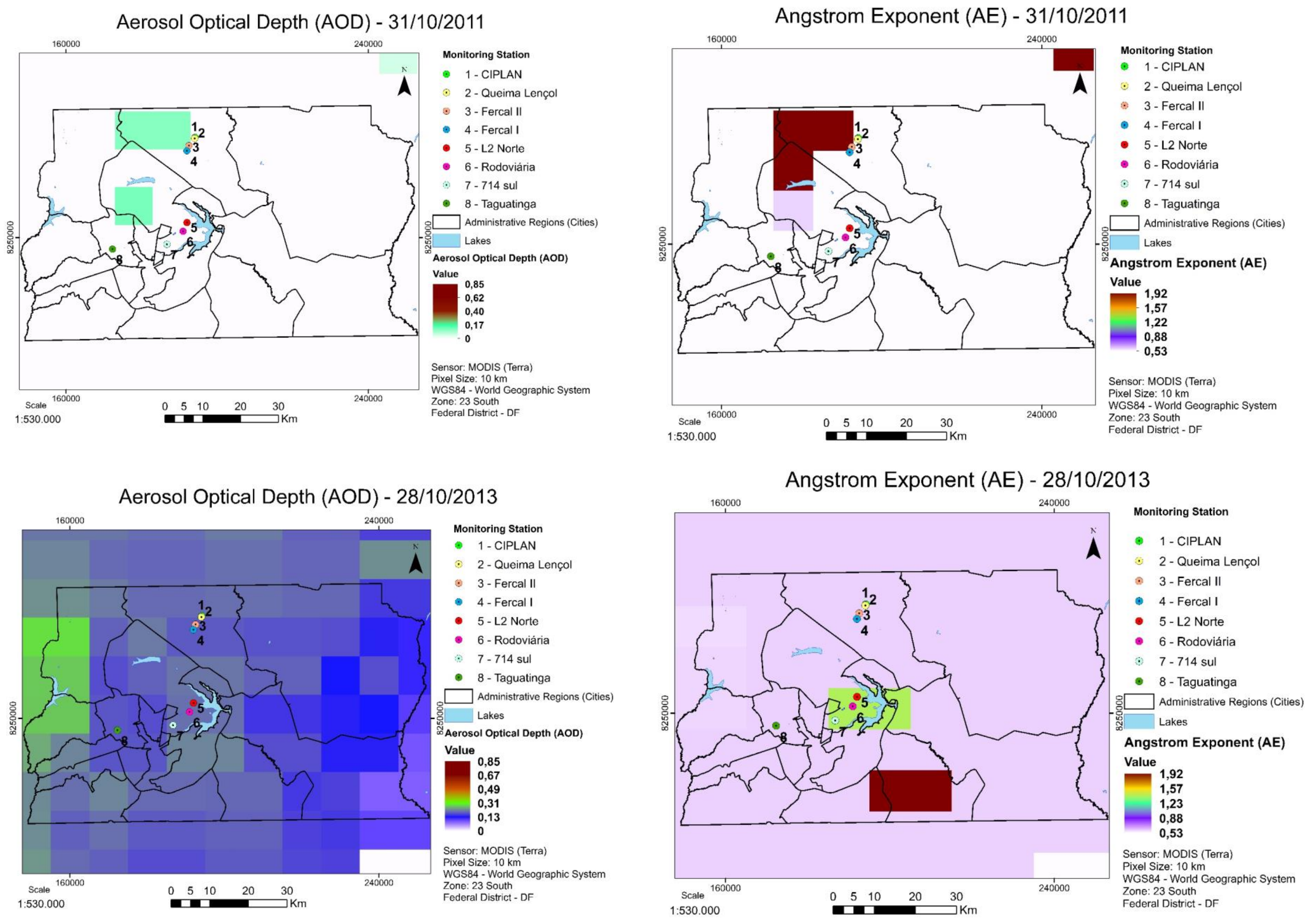

Figure 16. AOD and AE for the days 31/10/2011 and 28/10/2013.