Atmospheric Pollution Research 6 (2015) 484‑494

Atmospheric Pollution Research

www.atmospolres.com

Implications of MODIS impression of aerosol loading over urban and rural settlements in Nigeria: Possible links to energy consumption patterns in the country

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ABSTRACT

A study of aerosol loading patterns in some selected cities in Nigeria was carried out using MODIS, TOMS/OMI AND AIRS satellite imageries for a period of 10 years. The results showed that an aerosol optical depth (AOD) loading obtained ranged from 0.02–0.9, UV aerosol index (AI) and carbon monoxide (CO) results ranged from 1.32– 2.43 and 2.22–2.6 molecule/cm^2, respectively. The CO data was used to infer the presence of carbonecous aerosols from biomass, fossil combustion and industrial activities. This result indicates that areas with higher AOD and AI do not correspond in high CO loading. From the HYSPLIT and HAT analysis conducted it showed that advection plays important role in the dispersion of aerosols. This implies that aerosols can reside in a place remote from where they are generated. Also, the high concentration of CO aerosol in the southern cities suggests a high rate of industrial pollution as a result of fossil fuel burning, vehicular emissions, high population density and gas flaring. Therefore, emphasis should be on the need to switch to renewable energy options as an alternative to fossil fuel. Furthermore, plans for mitigations should not be limited to industrialized cities only but extended to other cities which might be bearing the real brunt of industrial emissions as shown in this work.

Keywords: *MODIS, aerosols, anthropogenic, energy, emissions*

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Article History:
Received: 23 July 2014
Revised: 01 December 2014
Accepted: 02 December 2014

doi: 10.5094/APR.2015.054

1. Introduction

The study of atmospheric aerosols is a very important element in understanding of the earth's solar radiation budget, water cycle balance, and climate change dynamics. This is because aerosol particles in the atmosphere scatter and/or absorb earth–bound solar radiation as well as emit and reflect radiation from the earth, to different degrees, depending on their chemical and physical properties. The magnitude of these effects, however, is poorly constrained, because we have a limited knowledge of the processes that control the distributions as well as the physical, chemical, and optical properties of aerosols which still remain an uncertainty in climate change studies (IPCC, 2007; IPCC, 2013). McMurry (2000) attributed this partly due to the instrumental limitations associated with the current aerosol measurement techniques. The low level of understanding associated with atmospheric aerosols also arises from modeling limitations, such as uncertainties in particle emissions (initial particle size, shape, mixing state), particle uptake in clouds and precipitation, and model's meteorology (transport, clouds, precipitation) (Huang, 2010). Therefore, aerosol is defined as a suspension in air of liquid or solid particles. They are ubiquitous and include dust particles from deserts, sea salt, smoke, as well as soot, sulfates, and other particles produced by people burning fossil fuels. Natural and human–caused fires are also significant sources of aerosols. Aerosol particles of natural origin (such as windblown dust) tend to have a larger radius than anthropogenic aerosols such as particle pollution, which absorb light in the visible and UV range.

Other aerosols, such as small droplets containing sulfate or particulate organic compounds do not absorb visible light. Of these organic aerosols most of which are created by condensation of volatile organic compounds, which can be emitted directly (primary organic aerosols), or can be a product of chemical reactions in the atmosphere [secondary organic aerosols (SOA)]. However, there is the need to separate between the natural and human–induced aerosols. This informed the use of the near UV technique to separate absorbing and non–absorbing aerosols. But because the UV cannot distinguish between absorbing aerosol types of carbonaceous and mineral dust the use of CO to trace out the carbonaceous aerosols of biomass burning and combustion came handy. Carbon monoxide (CO), is the second most abundant trace gas produced by biomass burning (Andreae and Merlet, 2001; Sinha et al., 2003; Torres et al., 2013), and has a multiday–long lifetime that makes it a suitable tracer of long range transport carbonaceous aerosols. Edwards et al. (2006), using multiple data from MODIS (AOD) and MOPPIT (CO) arrived at a case of agriculture–related biomass burning and wildfires which gave rise to high CO values. Torres et al. (2013), suggested that the CO–based aerosol type separation technique is particularly useful to pick up the presence of drifting layers of carbonaceous aerosols over arid areas. The spatial distributions and magnitudes of tropospheric CO amounts and atmospheric load of carbonaceous aerosols are naturally correlated as both species are generated by biomass burning.

Consequently, various techniques were used to study and measure aerosols in Nigeria. Nwofor (2010) used AERONET data to determine the influence of aerosols on the persistent aridity over Ilorin the capital of Kwara State. Chiemeka (2008) used signal analyzer to indirectly determine the aerosol number concentration using intensity scattered by particles. Anuforom (2007) applied data from synoptic stations observed in Nigeria to determine that particle size decreases from north to south during Hamattan. Chineke and Chiemeka (2009) used a three year in–situ data collected using the Whatman filter to quantify the concentration of some PM in Uturu the university town of Abia State. Obiajunwa et al. (2002) determined the elemental concentrations of aerosol samples in a factory environment using EDXRF. On the other hand Oyem and Igbafe (2010) investigated the atmospheric aerosol loading over Nigeria using meteorological data and HYSPLIT model. On a global scale, satellite remote sensing instruments such as the Moderate Resolution Imaging Spectro–Radiometer (MODIS) on aboard both polar orbiting TERRA and AQUA satellites etc. continue to produce global AOD maps retrieved from back-scattered solar radiation through the atmosphere (King et al., 1992; Kaufman et al., 2003; Levy et al., 2003; Hutchison et al., 2005; Tang et al., 2005; He et al., 2012; Oluleye et al., 2012). Hence Satellite–retrieved AOD is a useful parameter for the estimation of optical and physical characteristics of aerosols on global and regional scales.

2. Materials and Methods

2.1. Data collection

The MODIS, remote sensing satellite can be effectively used for the purpose of spatio–temporal analysis of AOD. The derivation of aerosol parameters from the Moderate Resolution Imaging Spectro–Radiometer (MODIS) sensors on–board the Earth Observing System (EOS) TERRA and Aqua polar orbiting satellites led in a new era in aerosol remote sensing from space. TERRA and Aqua were launched on December 18, 1999 and May 4, 2002, respectively, with daytime equator crossing times of approximately 10:30 am and 1:30 pm, respectively. MODIS acquires data globally at 36 spectral bands, which range from the visible to the thermal infrared wavelengths. The data for each band are acquired in one of three spatial resolutions (250, 500 and 1 000 m). MODIS aerosol algorithm employs separate approaches to retrieve parameters over land (Kaufman et al., 1997) and ocean surfaces (Tanre et al., 1997), because of the inherent differences in the solar spectral radiance interaction with these surfaces. The aerosol retrieval makes use of seven of these channels (470–2 130 nm) to retrieve aerosol characteristics (Remer et al., 2005) and uses additional wavelengths in other parts of the spectrum to identify and mask out clouds and suspended river sediments (Ackerman et al., 1998; Gao et al., 2002; Martins et al., 2002; Remer et al., 2008).

In this study we used MODIS Collection 5.1 aerosol product at 550 nm wavelength, which provided a consistent record of the Earth's aerosol system. This wavelength is used for the comparison of MODIS with AERONET, because this is close to the peak of the solar spectrum and is therefore associated with major radiative effects (Papadimas et al., 2009; Alam et al., 2010). Also, it is consistent with the primary wavelength used by many climate and chemistry transport models (Kinne et al., 2003; Anderson et al., 2013) as well as previous MODIS validation studies (Ichoku et al., 2005; Remer et al., 2005; Levy et al., 2007; Levy et al., 2010). When compared with ground–based AERONET observations of aerosol optical depth (AOD), Remer et al. (2008) found out that Collection 5 MODIS aerosol products estimate AOD to within expected accuracy, more than 60% of the time over ocean and more than 72% of the time over land. This authenticates the usability of the data for research analysis. Therefore, MODIS TERRA level 3 monthly averaged remote sensed images from Goddard Earth Sciences Data and Information Services Center Interactive Online Visualization ANd ANalysis Infrastructure., (GIOVANNI) from 2002–2012. This is a NASA web–based data analysis and visualization system that provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data, without having to download the data (Acker and Leptoukh, 2007; Berrick et al., 2009; NASA, 2013). This online platform allows researchers to rapidly explore data, so that spatial–temporal variability, anomalous conditions, and patterns of interest can be directly analyzed online before optional downloading of data. It utilizes a variety of software packages (such as IDL, GrADS, and Python) and analytical functions authored by the GES DISC software development and engineering staff.

On data quality considerations, GIOVANNI is a useful tool for data exploration and research that uses remote–sensing data. It has several instances, but for the purpose of this research we focused our attention on the MODIS Visualization and Analysis System (MOVAS), AeroStat and Hurricane Analysis Tool (HAT). MOVAS Giovanni instance displays atmospheric parameters from the MODIS instruments on both the TERRA and Aqua satellites. The adventage of using GIOVANNI is that it allows users explore various atmospheric phenomena without learning remote sensing data formats and downloading voluminous data (Leptoukh et al., 2010). The data acquired from GIOVANNI was sub–setted to cover the entire Nigeria. The GIOVANNI Level 3 data was used since averaging reduces random noise and number of days with missing data normally encountered in level 2 data in line with Suman et al. (2014). Subsequently, NASA Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) sensor launched in July 1996 and July 2004 data were acquired and information on UV aerosol index were extracted from them (NASA, 2013). Furthermore information on CO loading was acquired from the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU), and the Humidity Sounder for Brazil (HSB) (AIRS/AMSU/HSB) suite of instruments which flew on board of Aqua satellite, and deployed on 4 May 2002.

The NOAA HYSPLIT model was used to determine the origins of the prevailing air masses (Draxler and Hess, 1997; Draxler et al., 2009; Draxler and Rolph, 2014), while NASA Hurricane Analysis tools (HAT) was used to determine wind speed and direction, to assess the influence that long–distance transport from various regions had on the aerosol loading which will determine if pollutants will be localized where it was generated or transported elsewhere (William and Barbara, 2001).

2.2. Prevailing wind pattern

The analysis on the prevailing wind pattern that was responsible for the advection of aerosol from one part of the country to the other was done using two sets of data, the NOAA HYSPLIT model (Draxler and Hess, 1997; Draxler et al., 2009) and NASA Hurricane analysis tool (HAT) (NASA, 2014). The NOAA HYSPLIT model was run online at (NOAA, 2013), six locations were selected for this particular operation which covered the different landscapes of the country based on the following criteria; location, aerosol measurement facility and type of socio economic activity. The places are Borno, Sokoto, Kwara, Abuja, Lagos and Rivers. HAT is a NASA online analysis tool which allows users to overlay various data products relevant to the study of hurricanes in an area plot, time plot or animation using an interactive tool. The data used in this model were derived from National Centre for Environmental Protection (NCEP) at 4 km global and TRMM's 3B42. The NCEP data was delivered as a vector showing the wind speed and direction at 850 hPa in m/s, while the TRMM is 3B42V6 in mm/h. The set back with this tool is that the temporal scale was between January 2004–July 2008, which did not cover the entire study period. But this data gives a comprehensive overview of the wind pattern of the entire country. The temporal scale for the HAT in this study is seasonal while the HYSPLIT is weekly. In Nigeria, where there has not been any incidence of hurricane the data delivered depicts the wind speed and direction only.

2.3. Study area

Nigeria is located in West Africa on the Gulf of Guinea and has a total area of 923 768 km^2 (Figure 1). It lies between latitudes 4° and 14°N, and longitudes 2° and 15°E. The far south is defined by its tropical rainforest climate, where annual rainfall is 1 524 to 2 032 mm a year. In the southeast stands the Obudu Plateau Coastal, plains are found in both the southwest and the southeast. This forest zone's most southerly portion is defined as salt water swamp, also known as a mangrove swamp because of the large amount of mangroves in the area. Everything in between the far south and the far north is savannah and rainfall is between 508 and 1 524 mm per year. Also, the amount of rainfall decreases as one move northwards. It is also made up saline water towards the coastal region and fresh water at the hinterlands. The southern region of Nigeria experiences a double rainfall maxima characterized by two high rainfall peaks, with a short dry season and a longer dry season falling between and after each peak. The first rainy season begins around March and last to the end of July with a peak in June. This rainy season is followed by a short dry break in August known as the August break which is a short dry season lasting for two to three weeks in August. This break is broken by the short rainy season starting around early September and lasting to Mid–October with a peak period at the end of September. The ending of the short rainy season in October is followed by long dry season. This period starts from late October and lasts till early March with peak dry conditions between early December and late February. Nigeria has a population of 160 million people according to the 2006 census (NPC, 2009) (Figure 2).

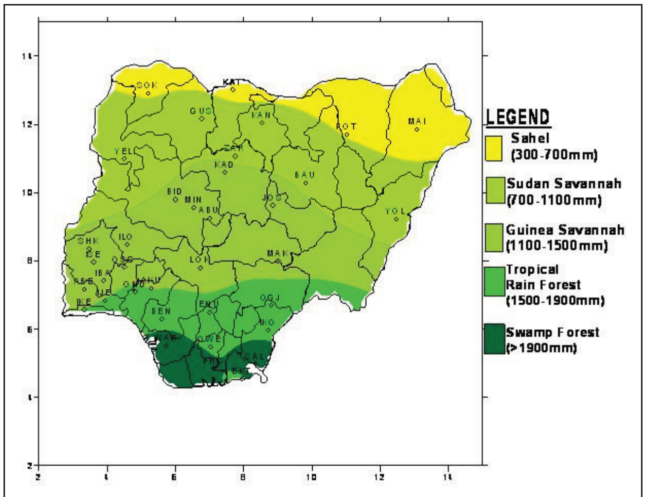

Figure 1. *Study area map.*

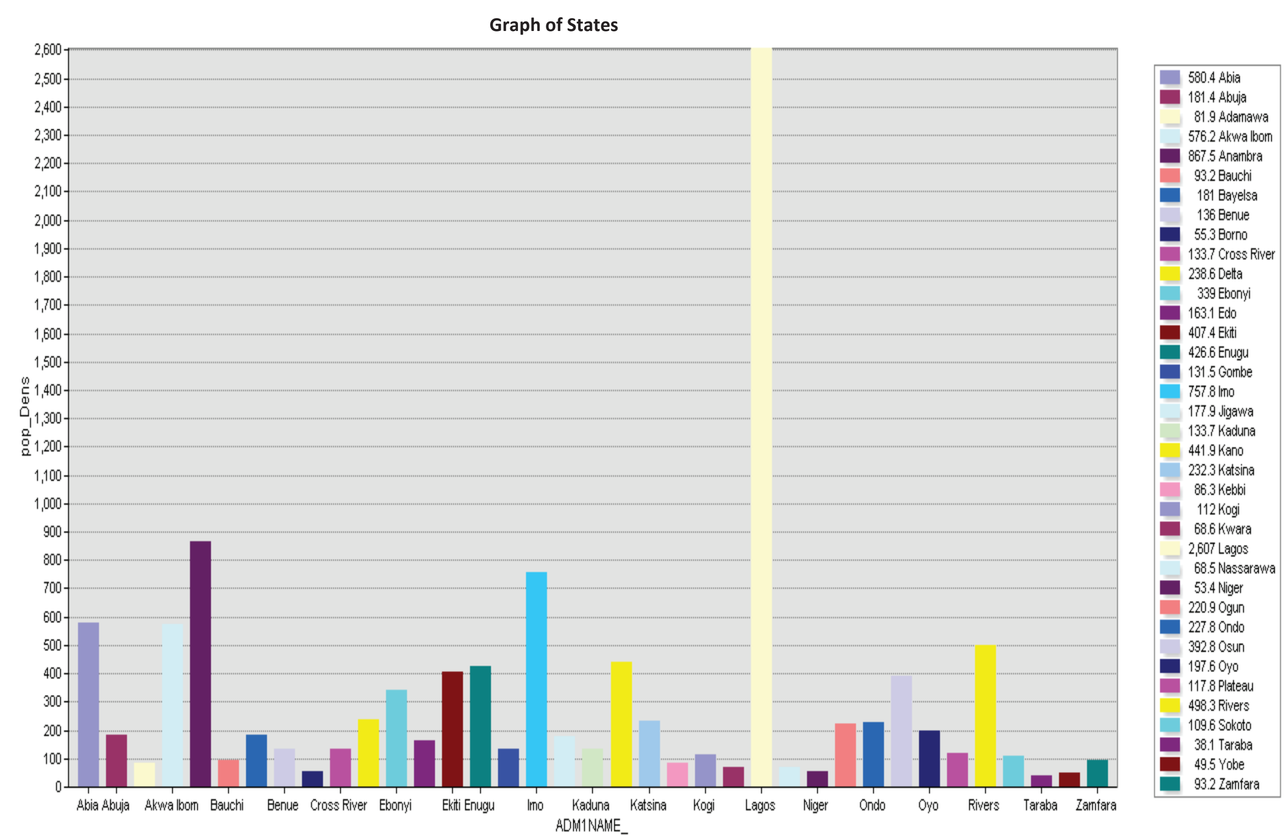

Figure 2. *Population densities of the various states in Nigeria.*

3. Results and Discussions

3.1. Seasonal and annual variation of AOD

The seasonal and annual variations of AOD were analyzed for six selected locations. The mean AOD and standard deviation at 550 nm were calculated for the period of 2003–2012 as shown in Table 1. During the dry season very high mean AOD values were recorded in the southern states (from latitude 4–8.5°N), with the least AOD value of 0.75. This was followed by the states that lie in the middle belt part of the country (latitude 8.5–10°N). The northern states were characterized by pristine atmosphere. Generally, the AOD values increased from south to north (see Figure 3). It also followed the line of population density in Figure 2 which shows that high population dense states of Lagos and Rivers have a corresponding high AOD loading from the sample locations as follows: Lagos mean AOD during dry season 0.85 (SD±0.103), rainy season 0.4 (SD±0.082), annual 0.64 (SD±0.067). Rivers mean AOD dry season 0.62 (SD±0.094), rainy season 0.35 (SD±0.088), annual 0.65 (SD±0.051). Lagos and Rivers are large urban and industrial hotspots in Nigeria. They are at the same time coastal states with sea ports coupled with several gas flaring stations.

Table 1. *AOD of some selected locations in the country*

Locations	Jan–Dec (Annual)	Nov–Mar (Dry Season)	Apr–Oct (Rainy Season)
Lagos (lat 6.4°N long 3.3°E)	0.64±0.0673	0.85±0.1038	0.40±0.0825
Rivers (lat 5°N long 7°E)	0.65±0.0515	0.82±0.0946	0.35±0.0678
Kwara (lat 8.5°N long 4.1°E)	0.46±0.0569	0.67±0.1275	0.32±0.807
Abuja (lat 9°N long 7°E)	0.49±0.0503	0.63±0.1084	0.39±0.0887
Sokoto (lat 13°N long 5°E)	0.45±0.0648	0.39±0.1320	0.52±0.0423
Borno (lat 12°N long 13°E)	0.36±0.0947	0.24±0.0537	0.45±0.0126

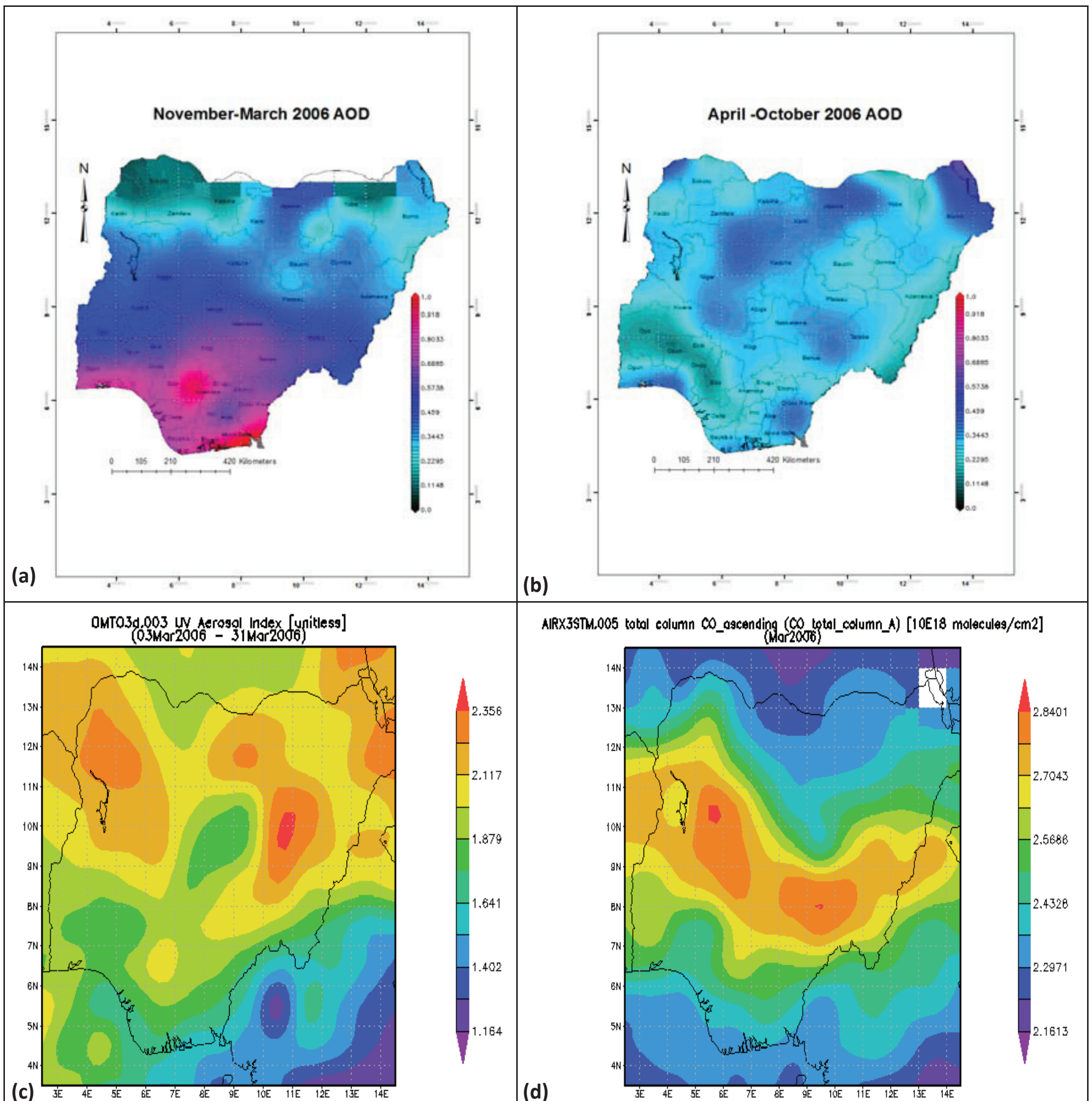

Figure 3. *Some of the sampled satellite data.* ***(a)*** *MODIS AOD for the dry season 2006,* ***(b)*** *MODIS AOD for the rainy season 2006,* ***(c)*** *OMI AI for March 2006,* ***(d)*** *AIRS CO for March 2006.*

The other study locations have a relative low AOD loading. Kwara has a mean AOD value of 0.67 (SD±0.127) for the dry season, 0.32 (SD±0.807) and an annual mean value of 0.46 (SD±0.056). Furthermore, it was observed that Borno and Sokoto have higher AOD values during the rainy season than dry season contrary to the trend observed in other locations (Borno: dry season=0.39±0.1320, rainy season=0.52±0.0423), (Sokoto: dry season=0.24±0.0537, rainy season 0.45±0.0126). The high aerosol values recorded during the rainy season is attributed to the dust advection from the surrounding deserts, which as a result of the counteraction of the north east trade wind by the South west trade wind at latitude 11°N as shown in Figure 6, are then restricted to this region. This implies that the aerosols are not transported beyond Sokoto and Borno. These later locations are majorly agrarian states with the exception of Abuja which is the capital of Nigeria. The implication of this is that most of the aerosols in this area are coarse dust and agro–based particles like pollens have low travel speed and little residence time in the atmosphere. An examination of the time series plot on Figure 4 shows that the peak of the AOD loading for the country occurs between March and February each year, which is in line with the results obtained by (Oyem and Igbafe, 2010; Oluleye et al., 2012). This period is the peak of the dry season with aerosol transport from the Sahara and Bodele depression as shown in Figure 5. The least AOD was found to occur between August and October each year, as a result of washout and wet deposition of aerosols and the inter tropical discontinuity which is created by a convergence of trade winds (Adimula et al., 2008) as shown in Figure 6.

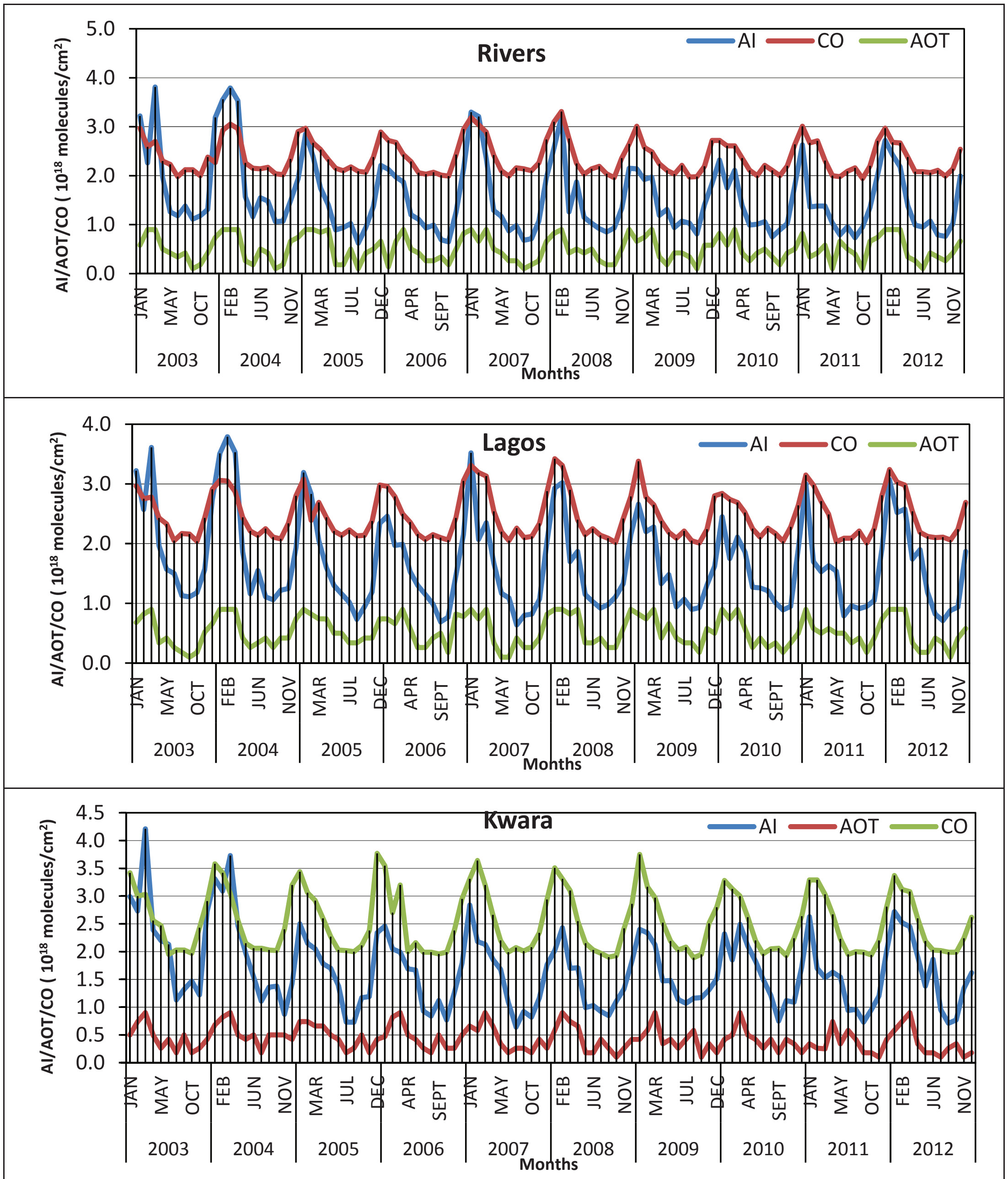

Figure 4. *Aerosol time series based on MODIS, TOMS, OMI and AIRs retrievals from 2003–2012.*

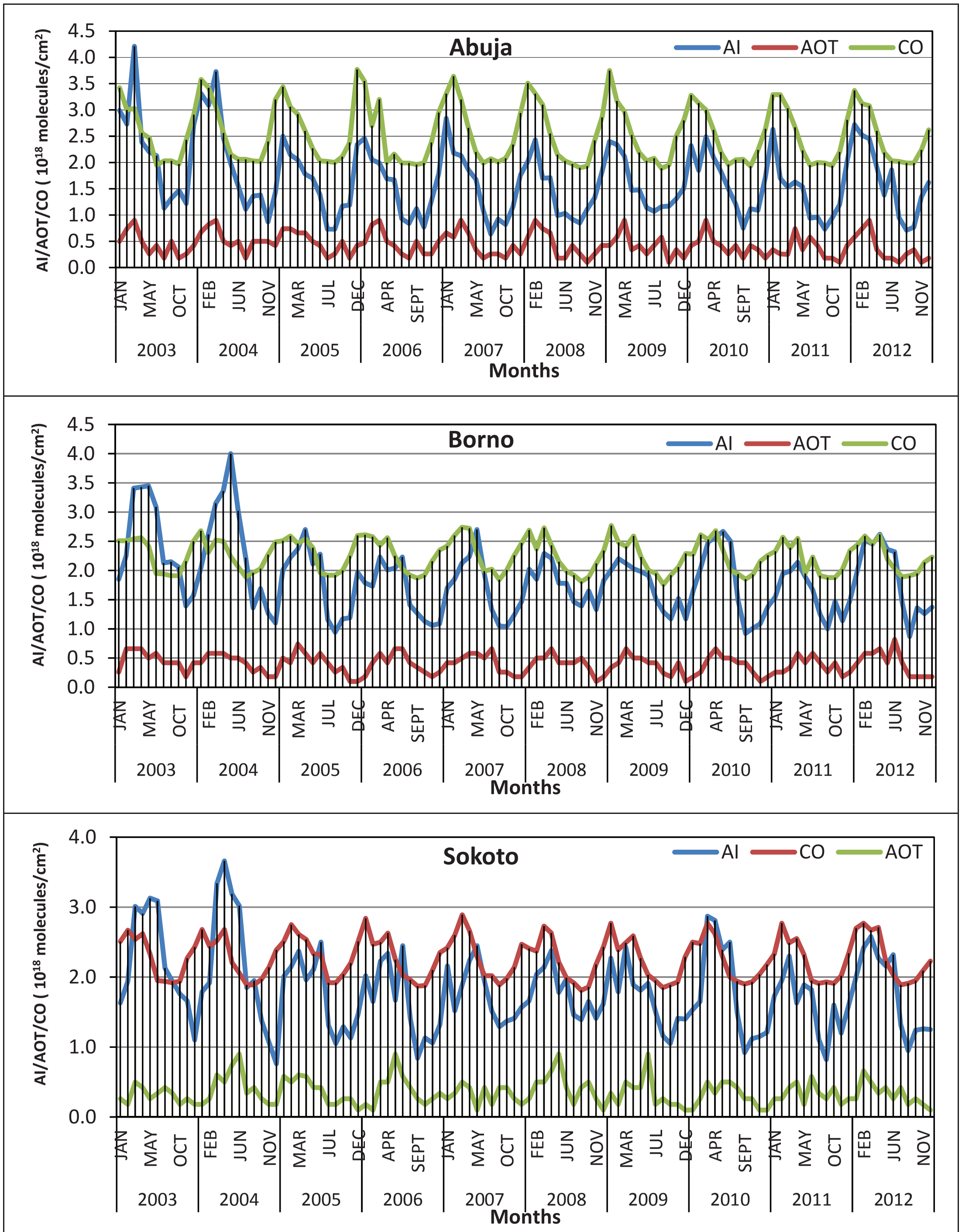

Figure 4. *Continued.*

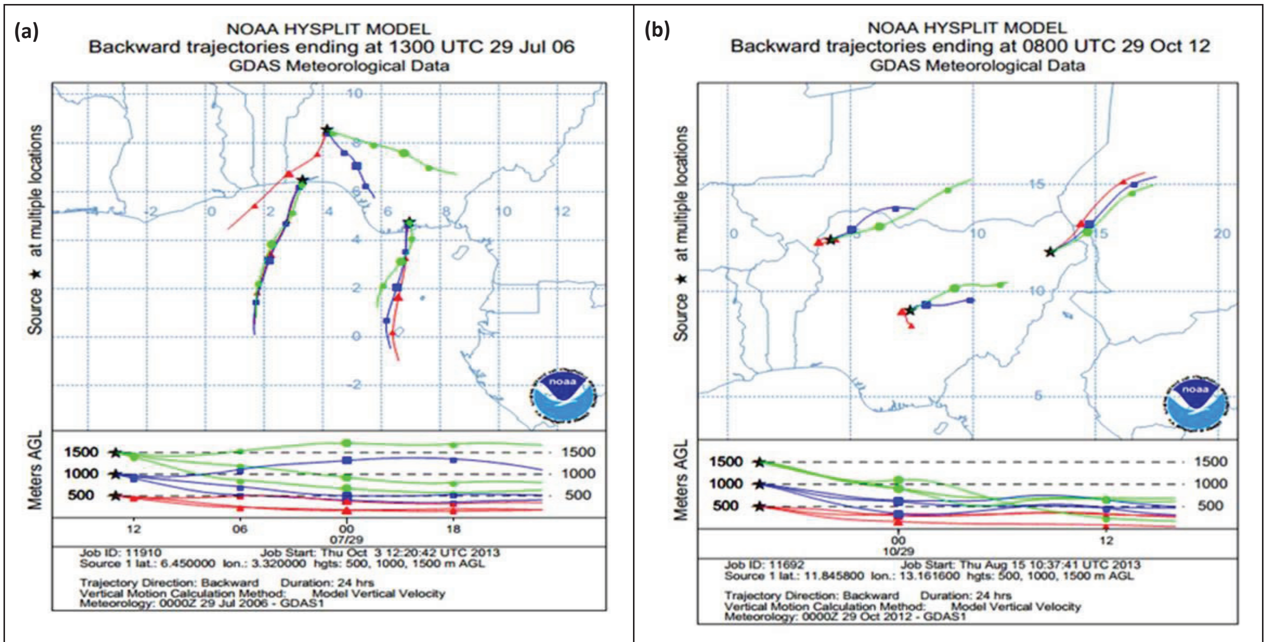

Figure 5. *Seven day back trajectory for some selected location for the rainy and dry seasons.* ***(a)*** *July and* ***(b)*** *October back trajectories.*

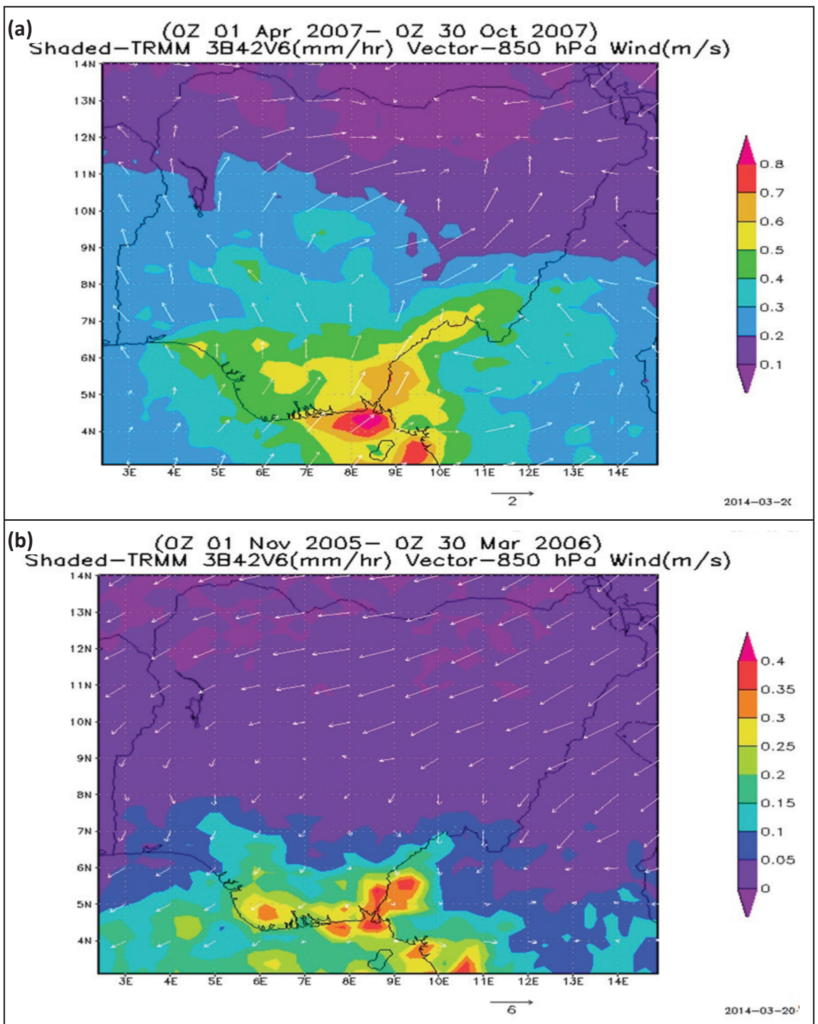

Figure 6. *Result from the HAT,* ***(a)*** *is for the rainy season and* ***(b)*** *is for the dry season.*

3.2. Seasonal and annual variation of AI and CO

The result from the AI/CO aerosol analysis as shown in Table 2a and 2b, indicates that both parameters increase at the same period when AOD increases in all locations studied with the exception of Borno and Sokoto.

Table 2a and 2b shows the annual variations and cumulative seasonal of CO and AI. It could be observed that the northern states of Borno and Sokoto that lie within the Sahel Region consistently recorded the highest AI values and the least CO values annually (see Table 2a). Meanwhile from Table 2b it could be observed that these two locations recorded the lowest values of AI during the dry season and high values during the rainy season. This implies that the high AI values are dust dominated; interviews conducted with some residents of Borno confirmed this. The respondents informed us that during the rainy season there is heavy dust influx from the surrounding deserts into the area, which drastically reduces visibility and the general air quality. Furthermore, these particles are not transported beyond the Sahel Region at this period of the year because of wind counteraction at latitude 11°N (see Figure 6). As a result, Borno recorded the highest cumulative annual total of AI value of 1.87 and the lowest value of 2.24×10^{18} molecules/cm^2 for the CO followed by Sokoto with an AI of 1.82 and CO of 2.26×10^{18} molecules/cm^2 implying the predominance of dust particles.

The central part (Abuja and Kwara) of Nigeria, otherwise known as the middle belt recorded the highest values for both AI and CO (Abuja AI=1.66, CO=2.52×10^{18} molecules/cm^2; Kwara AI=1.73, CO=2.47×10^{18} molecules/cm^2), cumulatively for the entire study period (see Table 2b). Also from the above result it could be observed that Abuja has a lower AI value with a corresponding higher CO value than Kwara. This shows that several anthropogenic activities which encourage the emission of CO related gases go on in Abuja, and this was also the case during the dry and rainy seasons. Again from Table 2a the result showed that both locations in the middle belt had AI value ranging from 1.46–2.26 and CO ranging from $(2.36–2.6)\times10^{18}$ molecules/cm^2 which is the highest recorded in any locations studied in the regions. Previously, Nwofor et al. (2007) and Nwofor (2010) attributed the high aerosol values over Ilorin to be as a result of dust and biomass burning, because of their strategic locations and the prevailing economic activities in those locations. The high values in Abuja could further be attributed to the multifaceted activities going on around there, such as large construction activities, vehicular emissions and biomass advection from the neighboring agrarian states of Kogi, Niger, Kaduna and Kwara as could be observed from Hysplit on Figure 5 and HAT analysis on Figure 6.

Furthermore, the south part of Nigeria (Lagos and Rivers) recorded the least AI values and moderate CO values for the entire study period as shown in Table 2b (Lagos AI=1.65, CO=2.46×10^{18} molecules/cm^2; Rivers AI=1.56, CO=2.37×10^{18} molecules/cm^2). Seasonally, southern locations recorded the highest cumulative dry season AI values and the least rainy season AI values, while CO values varied between the two seasons hence the dry season cumulative average values are higher than the rainy season cumulative average values. It should be noted at this point that these two cities are unique in their economic activities. Lagos is the industrial/commercial hub of Nigeria; it is characterized by large industries mostly powered by diesel generators, high population density (see Figure 2), sea ports, heavy vehicular movements and influx of biomass from neighboring states of Oyo and Ogun (see Figures 5 and 6). It should be noted that as at 2013 the number of vehicles registered in Lagos is 1 017 459 motor cars while motor cycles amounted to 31 349 (LBS, 2013). It could be inferred that CO and dust are very much available in Lagos, with CO dominating the aerosol types. On the other hand, major oil and gas exploration and exploitation companies in Nigeria are located around Rivers state. These companies are still engaged in gas flaring which contributes to CO loading. Other economic activities that contribute to CO loading in Rivers are biomass burning and vehicular emissions.

Table 2a. *Annual variation of aerosol parameters*

		Lagos	Rivers	Kwara	Abuja	Sokoto	Borno
Latitude/Longitude		6.4°N/3.3°E	5°N/7°E	8.5°N/4.1°E	9°N/7°E	13°N/5°E	12°N/13°E
2003	AI	2.01	1.98	2.26	2.22	2.2	2.43
	CO (10^{18} molecules/cm^2)	2.45	2.33	2.5	2.52	2.28	2.26
2004	AI	1.99	2.01	2.23	2.02	2.17	2.34
	CO (10^{18} molecules/cm^2)	2.48	2.45	2.52	2.59	2.26	2.26
2005	AI	1.6	1.48	1.62	1.61	1.75	1.82
	CO (10^{18} molecules/cm^2)	2.43	2.39	2.51	2.6	2.33	2.28
2006	AI	1.49	1.35	1.55	1.5	1.64	1.63
	CO (10^{18} molecules/cm^2)	2.42	2.33	2.53	2.44	2.26	2.24
2007	AI	1.56	1.59	1.69	1.55	1.75	1.69
	CO (10^{18} molecules/cm^2)	2.55	2.45	2.43	2.58	2.3	2.22
2008	AI	1.65	1.57	1.55	1.44	1.77	1.78
	CO (10^{18} molecules/cm^2)	2.53	2.43	2.48	2.52	2.23	2.22
2009	AI	1.52	1.42	1.57	1.56	1.69	1.71
	CO (10^{18} molecules/cm^2)	2.43	2.32	2.43	2.53	2.22	2.22
2010	AI	1.51	1.37	1.58	1.63	1.78	1.8
	CO (10^{18} molecules/cm^2)	2.41	2.32	2.36	2.46	2.24	2.23
2011	AI	1.45	1.32	1.46	1.43	1.6	1.59
	CO (10^{18} molecules/cm^2)	2.43	2.34	2.43	2.49	2.22	2.18
2012	AI	1.65	1.48	1.79	1.65	1.79	1.87
	CO (10^{18} molecules/cm^2)	2.48	2.33	2.46	2.47	2.28	2.22

Table 2b. *Cumulative averages of the aerosol parameters*

Latitude/Longitude		Lagos	Rivers	Kwara	Abuja	Sokoto	Borno
		6.4°N/3.3°E	5°N/7°E	8.5°N/4.1°E	9°N/7°E	13°N/5°E	12°N/13°E
Jan–Dec	AI	1.65	1.56	1.73	1.66	1.82	1.87
	CO (10^{18} molecules/cm^2)	2.46	2.37	2.47	2.52	2.26	2.24
Nov–Mar (Dry Season)	AI	2.2	2.15	2.11	2.08	1.78	1.82
	CO (10^{18} molecules/cm^2)	2.78	2.68	2.87	2.99	2.44	2.42
Apr–Oct (Rainy Season)	AI	1.18	1.06	1.41	1.31	1.85	1.9
	CO (10^{18} molecules/cm^2)	2.19	2.11	2.13	2.12	2.11	2.09
$AI_{differnce}$		1.02	1.09	0.7	0.77	–0.07	–0.08
CO (10^{18} molecules/cm^2)$_{differnce}$		0.59	0.57	0.74	0.87	0.33	0.33

Generally, these results show in all the locations studied: AOT, AI and CO exhibit a seasonal behavior, with the aerosols peaking in the dry season for southern and the middle belt parts of Nigeria while AOD peaks during the rainy season for Borno and Sokoto as shown in Figure 4. It could also be inferred that often time aerosols are advected from one location to be deposited on another location far off from where they were generated as shown in the Hysplit back trajectory on Figure 5. Bressi et al. (2014) attributed the sources of fine aerosols in Paris to include heavy oil combustion, road traffic, biomass burning, marine aerosols, metal industries etc, which are also very strong factors in Nigeria. Consequently, Chen et al. (2002) suggested that domestic cooking activities are some of the sources of fine aerosols. This implies that high population density areas are likely to contribute more aerosols as is the case in this study. A critical look at these sources of aerosol enunciated above especially in southern Nigeria and Abuja shows that they are energy related and therefore need to be looked into in order to sustain the environment.

In a detailed analysis, Dike et al. (2011) established a relationship between industrial cluster emissions, traffic density and diurnal variation of CO mass concentration in different tropical urban environments. The diurnal nature of the CO suggest that CO concentrations are high by a factor during the morning and evening hours when the traffic density is high as compared to the afternoon hours when there is less traffic. This CO concentration corresponds to vehicular exhaust emissions due to traffic density at these times. On the other hand, there is mass concentration of CO within the environs of the industrial cluster when they are operating on diesel generating sets. In another study, Chen et al. (2002) found out that diesel vehicles contribute more fine particles than gasoline powered vehicles. They suggested that temperature affects the efficiency of diesel engines through the changing intake of air fuel ratio. Kowalczyk et al. (1982) used the CMB model and identified the sources of fine aerosols to include limestone, coal and refuse among others. Therefore, we are advocating clean renewable sources of energy to power our industries, transport sector and domestic affairs. According to the ECN–UNDP (2005), clean renewable energy options abound in Nigeria which include, solar, wind and geothermal. These outlined renewable energy potentialities in Nigeria are as follows; the geothermal plants if operational can generate electricity ranging from 20 MW to 60 MW, solar radiation intensity varies from 7.0 kwh/m^2 at the extreme north to 3.5 kwh/m^2 in the extreme south, wind speed in the south ranges from 1.4 to 3.0 m/s and from 4.0 to 5.12 m/s in the Northern Nigeria. If these energy options are harnessed we would be able to power the industries, houses and the transport sector (trains), thereby discouraging the haulage of goods by road, acquisition of personal vehicles and the use of electric generating sets for industrial and domestic purposes. Furthermore, the concentration of CO aerosols which are fine in nature has varying impact both on the environment and health. (Draxler and Hess, 1998; Chen et al*.,* 2002) reported in separate epidemiological studies an association between short term increase in aerosol concentration and daily mortality/morbidity. They also attributed the formation of smog or haze within an environment to the presence of fine aerosols in the atmosphere.

3.3. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model result

The result showed a seven–day back trajectory for various locations at 13:00 h and at an altitude of 500, 1 000, and 1 500 m AGL. During the dry season the northern states are besieged by the north east trade wind which brings along with it dust particles from the Sahara and Bodele depression, while the southern and middle belt states have aerosol contribution from the Sahara, the Atlantic Ocean and the local environment. Figure 6 shows that during the rainy season air mass is contributed from the Atlantic Ocean for the southern part of the country, while the northern part has air mass contributed from both the north east and south west trade winds creating a convergence zone around latitude 9°N as shown in Figure 6.

3.4. Hurricane analysis tool result

Like the other data in this study the dry season is between November of the preceding year to March of the succeeding year. During the dry season the wind velocity is very strong from the north east especially Borno and Adamawa axis at 6 m/s. From latitude 10°N, the wind velocity decreases conspicuously towards the south western and down parts of the country. It should be recalled that during the dry season the prevailing wind in the country is the north east trade wind originating from the Sahara desert. It carries with it an extremely dry dusty wind that blows from the Sahara toward the western coast of Africa, more especially between November and March (dry season). This phenomenon is known as Harmattan (Nwofor et al., 2007; Nwofor, 2010). For the entire period of this study the central part of this country has a near neutral wind velocity. Below latitude 9°N the wind velocity does not have any definite direction. This implies that the aerosol in Nigeria during the dry season originates from the Sahara desert and Bodele depression. Furthermore, the dust aerosol particles reaching the southern parts are basically of small size while the ones up north are coarse in nature. This is because small particles have very small fall speed and are engaged in long range transport. This is in line with (Draxler and Hess, 1997) statement that, the larger particles are deposited quickly and only the smallest particles are subject to long–range transport, fine dust particles inclusive.

Meanwhile Ichoku et al*.* (2002) simulated aerosols and found out that the average travel speed of an aerosol front is of the order of 50 km/h, we observed a travel speed of 6 m/s for the dry season and 2 m/s for the rainy season (see Figure 6). This implies that the aerosols generated during the rainy season did not travel far away from where they are generated.

The period of rainy season in this study is from April–October each year. During the rainy season, the prevailing air mass is the south west trade wind which carries with it moisture from the Atlantic Ocean inland of West Africa. This wind brings along with it rain water which aids in wet deposition and wash out of aerosol. At latitude 11°N this wind regime is counteracted by the north east trade wind changing the direction of the wind to be parallel to the meridians. This counteraction is responsible for the prevailing high aerosol values at latitude 11°N–14°N and the restriction of CO aerosol in the south during the rainy season, although within this study period there exists some moments of variation in the wind velocity and circulation. But generally, latitude 11°N creates a destructive wind interference zone. This implies that aerosols advected by the north east trade wind will be concentrated from latitude 11°N upwards, while the aerosols generated in the lower latitudes will be concentrated from latitude 11°N downwards.

4. Conclusions

In this paper we have in fair quantitative terms used MODIS satellite image to determine the spatial and temporal variability of aerosol and the contribution of dust and CO related aerosols in the Urban and Rural Settlements of Nigeria with the following conclusions:

- The maximum AOD was recorded during the dry season between January and March each year, when the meteorology is windy, and dry with high temperature.
- The highest values of AOD were found to have occurred in the southern part of the country and decreased towards the north.
- The major contributors of aerosols in the north are found to be the Sahara dust, Bodele depression and biomass burning, while in the south in addition to the three sources mentioned above, vehicular and industrial emissions are included.
- Finally, there is a linkage between CO aerosol and energy consumption in Nigeria in line with Dike et al. (2012). This is because Nigeria is a fossil based energy economy where industries are powered majorly by diesel generators, men and goods are moved by diesel vehicles, Dike et al. (2011). Also, at the domestic arena foods are cooked by kerosene stove or fuel woods and homes are powered by generators as a result of epileptic power supply from the national grid.

Acknowledgments

We are grateful to the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT model used in this study. Also, the images used in this paper were sourced and acquired using GES–DISC's interactive online visualization and analysis infrastructure ("Giovanni") as a part of NASA's Goddard Earth Sciences (GES) Data and Information Services Centre (DISC).

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