

Analysis of the Atmospheric Aerosol Loading over Nigeria

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Abstract: This study, which was established with published data between March 2007 and February 2008 utilised the number of aerosol optical thickness recorded using satellite imageries. Backward air mass trajectories by means of the HYSPLIT simulation model was used to evaluate the aerosol transport patterns. It was deduced that precipitation, wind speed and relative humidity alters the level of aerosol loadings at different times of the year yielding an inverse relationship between these properties. Aerosols also alter temperature resulting to a direct relationship between both properties. In addition, the meteorology of the lower troposphere has been identified to be fully responsible for both local air pollutions and long-range aerosols transport.

Key words: Aerosols loading, backward trajectories, HYSPLIT model, precipitation, meteorology, air pollution

INTRODUCTION

The atmosphere contains more than just molecules of gases, there are also small (micro and submicron) sized solid or liquid particles, which are called aerosols. Aerosols come from natural sources such as condensation, freezing of water vapour, volcanoes, dust storms, forest and grassland fires, vegetation and sea spray. These particles affect the composition of the natural atmosphere (IPCC, 2001). Aerosols are also, formed from human activities such as burning fossil fuels and biomass, ploughing or digging up soil (Hess and Schult, 1998). This anthropogenic contribution to the atmospheric aerosol loading is not well established, neither is the level of the total aerosol loading currently well defined (Andreae, 1996). Atmospheric aerosol particles consist of a mixture of different substances (Andreae, 1996) such as organic matter, dust and sea-salt. Organic matter constitutes an important fraction of aerosol mass, both in remote and urban locations; the presence of organic compounds in aerosol particles is due to primary emission and secondary organic aerosol formation (Gilarioni *et al.*, 2007). Atmospheric dust constitutes of Na, Mg, Al, Si, P, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ba, As and Pb (Bates *et al.*, 2008). Sea-salts are made-up of K^+ , Mg^{+2} , Ca^{+2} , Cl^- , SO_4^- and HCO_3^- (Witek *et al.*, 2007). These aerosol types exert a strong influence on solar radiation, cloud formation,

meteorological variables and chemistry of the marine atmosphere. Sea-salts are considered to be one of the major contributors to the total solid particles also referred to as particulate matter present in the atmosphere (Witek *et al.*, 2007). In the atmosphere, aerosols are regarded as pollutants because, they influence the Earth's climate system; both solar and terrestrial radiation budget impair visibility by scattering and absorption and indirectly by providing the condensation nuclei for cloud droplets. As well as influencing tropospheric photochemistry (Ina *et al.*, 2002; Highwood *et al.*, 2007; Roberts *et al.*, 2007; Bates *et al.*, 2008; De Gouw *et al.*, 2008). Aerosols >1 and μm in diameter (coarse particles) are derived from soil dust and sea salt (Raes *et al.*, 1995). Aerosols with diameters $<1 \mu m$ (fine particles) are formed mainly by combustion or the chemical conversion of gaseous precursors into liquid or solid products (gas-to-particle conversion). Aerosol size is the most important parameter used in characterising the physical properties of aerosols (Hinds, 1982). The fine fraction aerosols are primary influences in terms of radiative forcing, having low impaction efficiencies and sedimentation velocities and a high scattering efficiency. The fine fraction aerosols can travel long distances and be taken up to higher altitudes, where they are able to interact with clouds (Raes *et al.*, 1995). Furthermore, aerosol particles are known to affect cloud properties such as albedo, lifetime, extent and precipitation.

Upon deposition, aerosols can harm humans, sensitive aquatic as well as terrestrial ecosystems

(Smirnov *et al.*, 2002; Bates *et al.*, 2008). A measure of the extent to which aerosols affect the transmission of sunlight is known as atmospheric aerosol thickness (James, 1995; David, 1998). The intensities of aerosols within an area are an indication of the levels of loading across that region. Atmospheric aerosol loading is known to be associated with alterations in seasonal weather pattern. This was based on observations during the evaluation of the global climate balance (WMO, 1991; Charlson *et al.*, 1992; James, 1995). Therefore, in order to ascertain the extent of alteration in the weather pattern over Nigeria, the aerosol loadings across the country will serve as a useful estimation tool. This study was thus aimed at investigating the atmospheric aerosol distribution over Nigeria through simulation of the volume of air mass transport at different heights Above Ground Level (AGL) across the country. This simulation was achieved using a Lagrangian wind-field trajectory model known as the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model based on archived meteorological data over the study region. HYSPLIT model package had been used in predicting the transport, distribution and the dynamics of air pollutants (Ingrida and Laura, 2006; Igbafe, 2007).

MATERIALS AND METHODS

Data acquisition: The meteorological and atmospheric aerosol data across the study region were obtained from the archives of the National Oceanography and Atmospheric Administration (NOAA, 2007), Air Resources Laboratory and the National Aeronautical and Space Administration (NASA, 2007) Goddard Space Flight Centre (www.arl.noaa.gov; www.disc.sci.gsfc.nasa.gov).

In comparison with ground-based measurement of combined analytical techniques, observations via satellite imageries and remote sensing of meteorological variables are known to provide higher precision data for evaluating phenomenon in air quality studies (Patris *et al.*, 2007).

Study region: Nigeria with a total area of 923,800 km² occupies about 14% of land area in West Africa. The country lies between 4 and 14°N and between 3 and 15°E, it is bordered by the Republic of Cameroun to the East, Niger to the North, Benin Republic to the West and the Southern boundary is formed by the 800 km Atlantic coastline, which includes the East sector of the Gulf of Guinea (Fig. 1). Nigeria is divided into Southern and Northern sub regions by the Niger and Benue River valleys (NFNC, 2003). The sub region exhibits a great



Fig. 1: Map of Nigeria

variety of relief features encompassing uplands of 600-1300 m AMSL on the Jos Plateau, the North-central and the Eastern highlands and lowlands of <20 m AMSL from the shoreline, covering an average distance of about 1120 km from the South to the North of the country (NFNC, 2003).

Nigeria's climate is characterized by strong latitudinal zones, which exhibit dry weather conditions from the South coastal areas towards the North. Across the country, rainfall is one of the key climatic variables and there is a marked alternation of wet and dry seasons in most areas. Temperatures are predominantly higher in the Northern region compared to the Southern region. The mean minimum temperatures (night-time temperatures) over the entire country ranges from about 21-33°C, while, the mean maximum temperatures (daytime temperatures) ranges from about 25-40°C (NFNC, 2003).

Atmospheric circulation over the region is governed by a northward moving maritime air coming from the Atlantic Ocean resulting in the rainfall and moist conditions and the dry continental air coming to south from the sub-Saharan African. In the southern region of Nigeria, the wet season occurs between March and September, whereas the dry season is between October and February. In the northern sector of Nigeria, the wet season occurs between June and September, while, the dry season takes place between November and May (NFNC, 2003).

Backward trajectory analysis: In the atmosphere pollutants sources and sinks have been in recent times, determined using source/receptor models. Source/

receptor modelling allows for tracking of pathways taking by pollutants in the mixed layer during transport. To quantitatively and qualitatively determine the source to sink relationship of air pollutants, backward trajectories have been used (Igbafe, 2007; Ebhohon, 2008).

In this study, air mass trajectories were evaluated using the Hybrid Single-Particle Lagrangian (HYSPLIT) simulation package. The HYSPLIT operate on a principle, which is based on the integration of the position of air mass with regard to time (Ingrida and Laura, 2006). Backward air trajectories from the HYSPLIT package are displayed in graphical forms indicating the pollutant sources and vertical heights AGL as well as the sinks. In this study, monthly backward air trajectories were calculated between April 2007 and February 2008 on hourly intervals of (06:00, 12:00, 18:00 and 24:00 h) for the wet and dry seasons. Each air mass trajectory was routed through three different heights (3000, 1500 and 500 m) AGL.

This is to identify pollutants, which are conveyed by air parcels near ground level (≤ 500 m) and those that may be associated with long-range transport (≥ 3000 m). HYSPLIT simulated trajectories for this study were

conducted for the aforementioned heights to show surface horizontal distribution of pollutants on a cartographical map (Ebhohon, 2008).

RESULTS AND DISCUSSION

The results discussed are valid only for average meteorological conditions while, individual cases may yield deviations.

Seasonal characteristics: It is evident that rainfall has distinct seasonal variation for the wet season compared to the dry season, hence revealing the local contrast in precipitation from one year to another. High rainfall occurred between the months of May- September with the maximum of 400 mm, while, rainfall occurrence between October and March were significantly low reaching 0.0 mm in December 2007 and February 2008.

The annual variation in the average temperature is almost constant between June and September. However, temperatures in the months of October to May were significantly high reaching its highest, 37°C in February 2008. While, from June-September, temperatures becomes

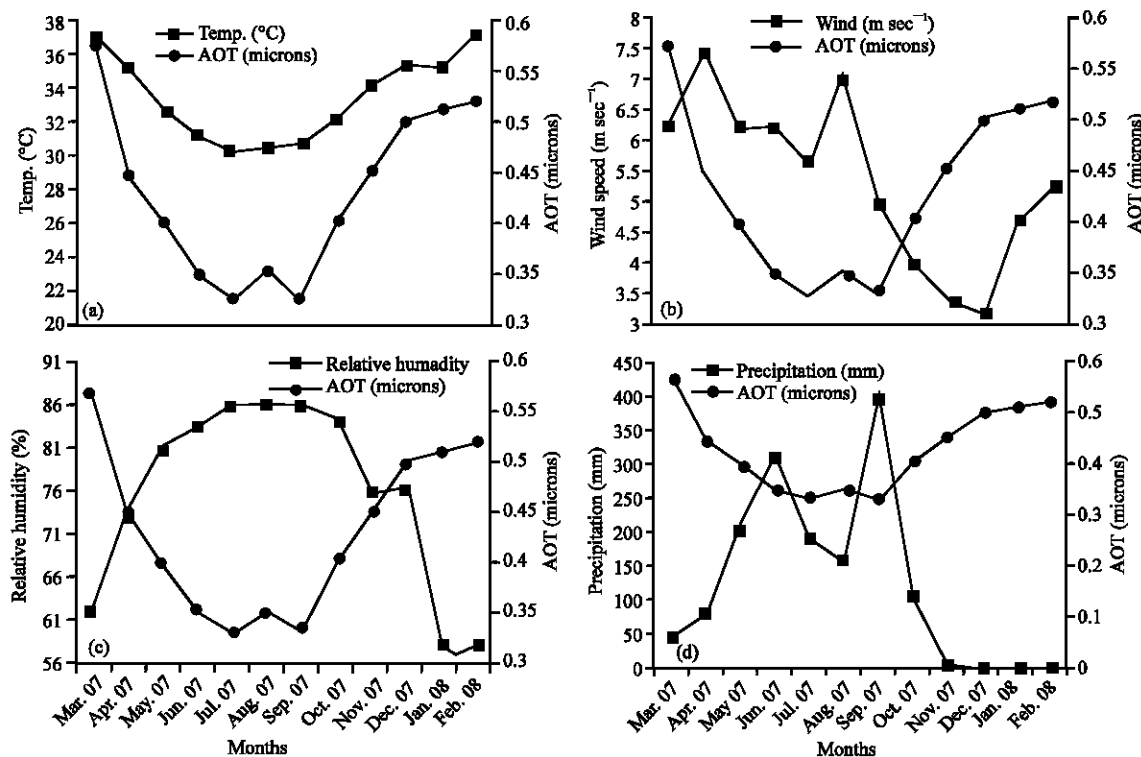


Fig. 2: a) Temperature, b) Wind speed, c) Relative humidity and d) Precipitation AOT in Nigeria between March 2007 and February 2008

considerably low attaining its lowest, 30.1°C in July 2007 (Fig. 2a). January-September records high wind speed, this wind speed approaches its peak, 7.4 m sec⁻¹ in April 2007. While, October-December recorded appreciably low wind speed reaching its lowest, 3.4 m sec⁻¹ in November (Fig. 2b). Relative humidity fluctuates between 58% (lowest) in January and February, then 86% (highest) from July-September. April-December recorded high relative humidity, while, January-March recorded low relative humidity (Fig. 2c). The months of October-May records extensively high atmospheric aerosols, which reached its peak, 0.57 microns in March 2007.

This could be due to the increasing natural and anthropogenic aerosol activities. Such as dust stump and bush burning. While, June-September recorded low (almost constant) aerosol distributions; this is probably due to high precipitation during this period (NFNC, 2003).

July and September recorded the lowest, 0.33 microns. Thus, having evaluated the meteorological situation during the period under review, it was identified that conditions to alter atmospheric aerosol distributions in dry and wet seasons were sufficient. AOT levels also, increases as wind speed decreases and decreases as wind speed increases (Fig. 2b). This means that the scenery of the wind speed alters the aerosol concentration of an area at any point in time.

Atmospheric aerosol increases as precipitation reduces, this means that precipitation is inversely proportional to aerosol distribution (Fig. 2d).

AOT is directly proportional to temperature (Fig. 2a). It means that AOT increases or reduces as temperature increases or reduces.

The plot between relative humidity and AOT as well, shows an inversely proportional relationship (Fig. 2c). AOT increases as relative humidity decreases and decreases as relative humidity increases.

Aerosol distribution analysis through air mass trajectory: Pollutants reaching Lagos, Nigeria, on the 21 April 2007 are most likely evolving from local sources, which may be the Atlantic Oceans. Since, air mass parcel at 1000 m AGL within 96 h approaches ground level (500 m AGL) it means that pollutants may have possibly been scavenged to the surface by wet depositions. It is observed that the South-west maritime wind dominates (Fig. 3a).

While, those reaching ground level in Borno Northern Nigeria, may have evolved from the Sub-Saharan Africa. The North-east trade wind dominates (Fig. 3b). Pollutants at high altitudes (1500 and 3000 m AGL) will pass-by and may approach ground level in some other sink locations. The wind patterns over Nigeria differ with

seasonal variations. Wet season dominates by southerly winds, while, dry season dominates by easterly winds.

Figure 4a shows that air mass parcels approaching ground level in Lagos are also surfacing from the Oceans 2000 km away. Pollutants at 3000 and 1500 m AGL are from Chad (North-east of Nigeria) and the Atlantic Oceans respectively. While, in the North there is a noticeable seasonal interference (Fig. 4b).

As the wet season approaches, pollutants approaching ground level may have appear from Cameroon at about 600 km. All pollutants reaching altitudes 3000, 1500 and 500 m AGL are sprouting from the same altitude, 2000 m AGL and are likely from Chad, Democratic Republic of Congo (South-east of Nigeria) and Cameroon, respectively. In August 2007, pollutants approaching ground level in Lagos (Fig. 5a) and Borno (Fig. 5b) are evolving from the Oceans at about 2100 and 1800 km away, respectively. Figure 5a and b show, a more dominant southerly wind. Aerosols across the country during this period could be predominantly sea-salt aerosols.

The southerly wind still dominates as pollutants approaching ground level in Lagos are sprouting from the Atlantic Oceans about 1700 km away (Fig. 6a). While, in the North of Nigeria, the north-east trade wind dominates as long-range pollutants are surfacing from Algeria via Libya (both of which are North of Nigeria) and Chad as they approach ground level (Fig. 6b). There could have possibly been a cyclone here.

On 21st December 2007, pollutants approaching ground level in Lagos are also sprouting from the Atlantic Oceans over 1200 km away as the north-easterly wind begins to gain dominance (Fig. 7a). While, in Borno as the north-easterly wind still dominates, pollutants approaching ground level are evolving from Egypt via Libya and Chad (Fig. 7b).

Although, the north-easterly wind dominates within this period, pollutants scavenged to the surface in Lagos are still evolving from the Oceans. At about 600 km away and an altitude of 1000 m AGL (Fig. 8a).

While, pollutants approaching ground level in Borno during the same period are most likely from the Middle-East via the Mediterranean Sea, Egypt, Sudan and Chad. Its altitude is over 1000 m AGL (Fig. 8b).

The industrial areas in both Northern and Southern Nigeria play a major role in the production and transport of aerosols. The township, industrial/urban and agricultural areas in Nigeria are important source emitters of sulphur, carbon, nitrogen and their corresponding oxides. The spatial distribution of aerosol loading over Nigeria has been analyzed. This was done between March 2007 and February 2008.

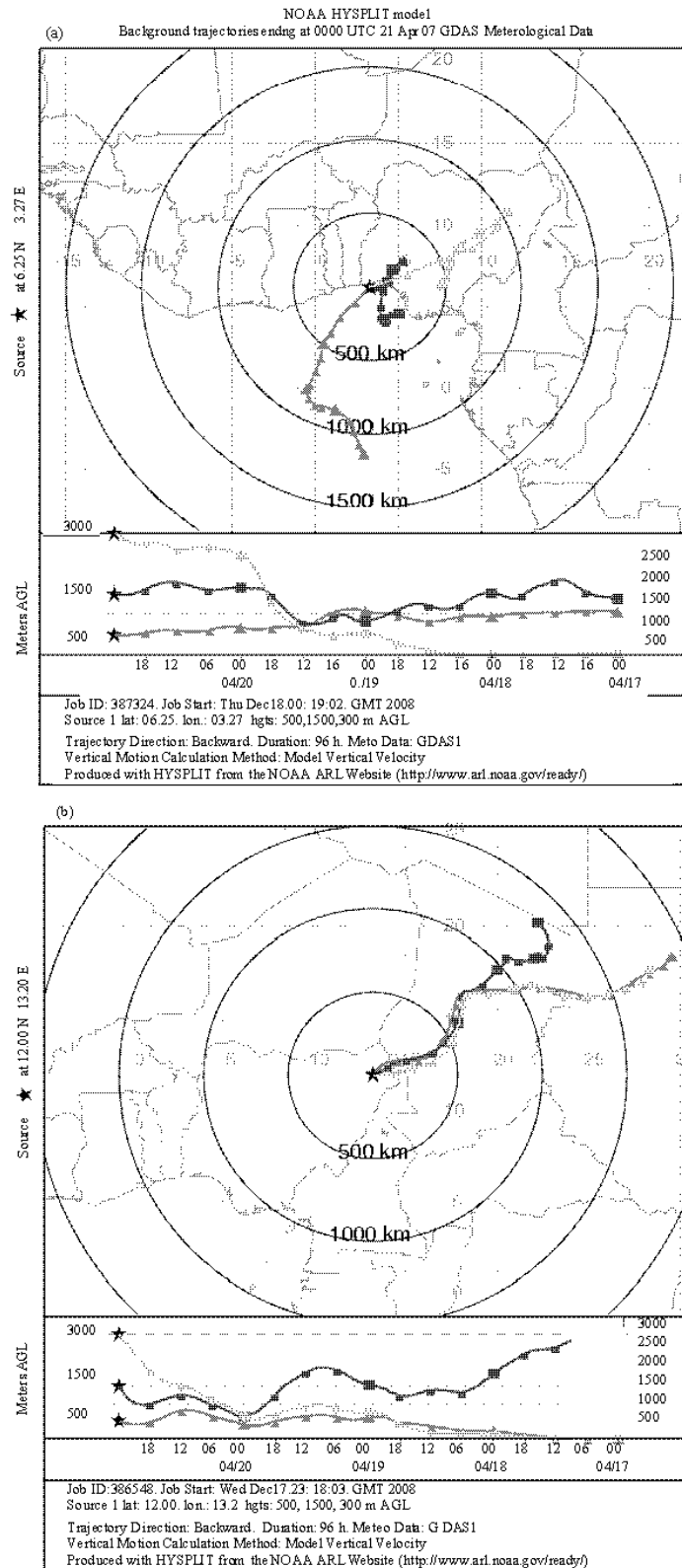


Fig. 3: Backward trajectory analysis (96 h) at three altitudes, start of run at 00:00, 21 Apr. 2007

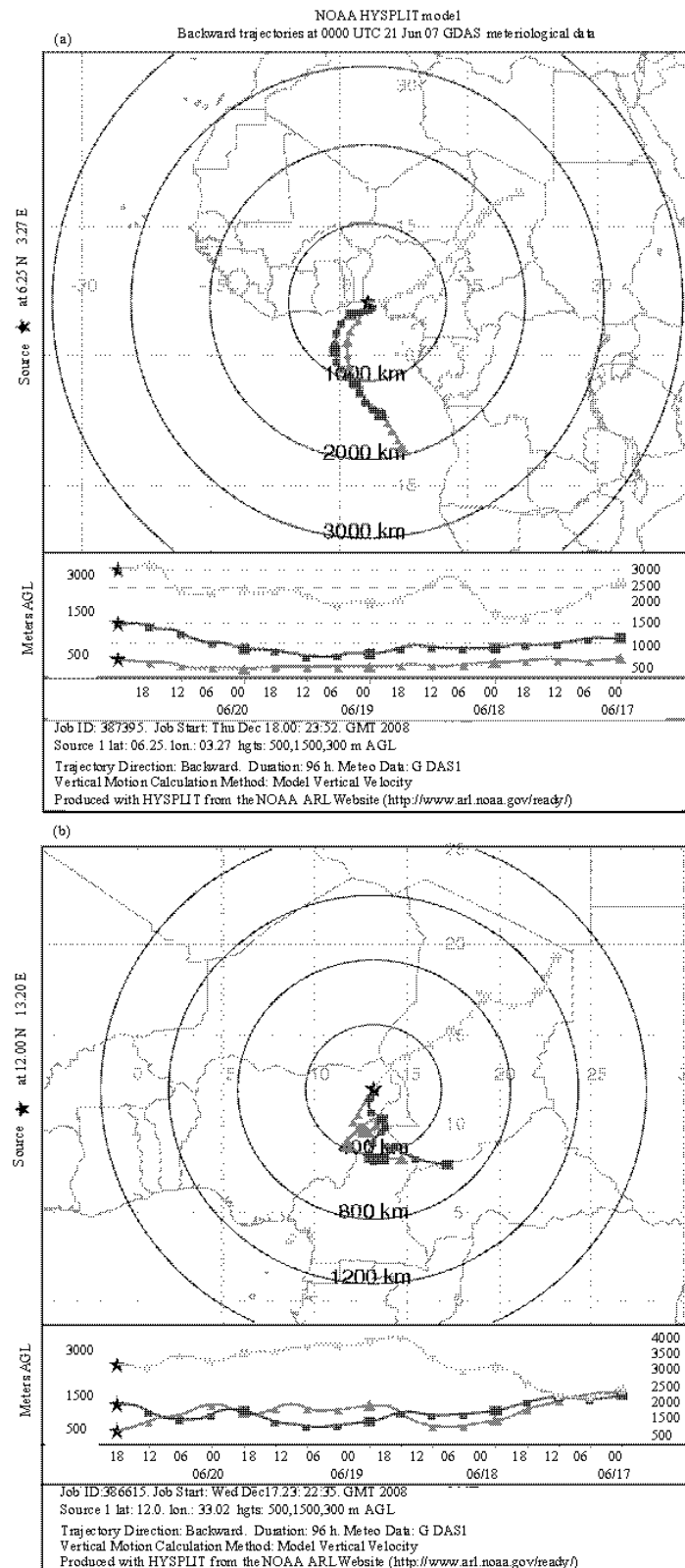


Fig. 4: Backward trajectory analysis (96 h) at three altitudes, start of run at 00:00, 21 June 2007

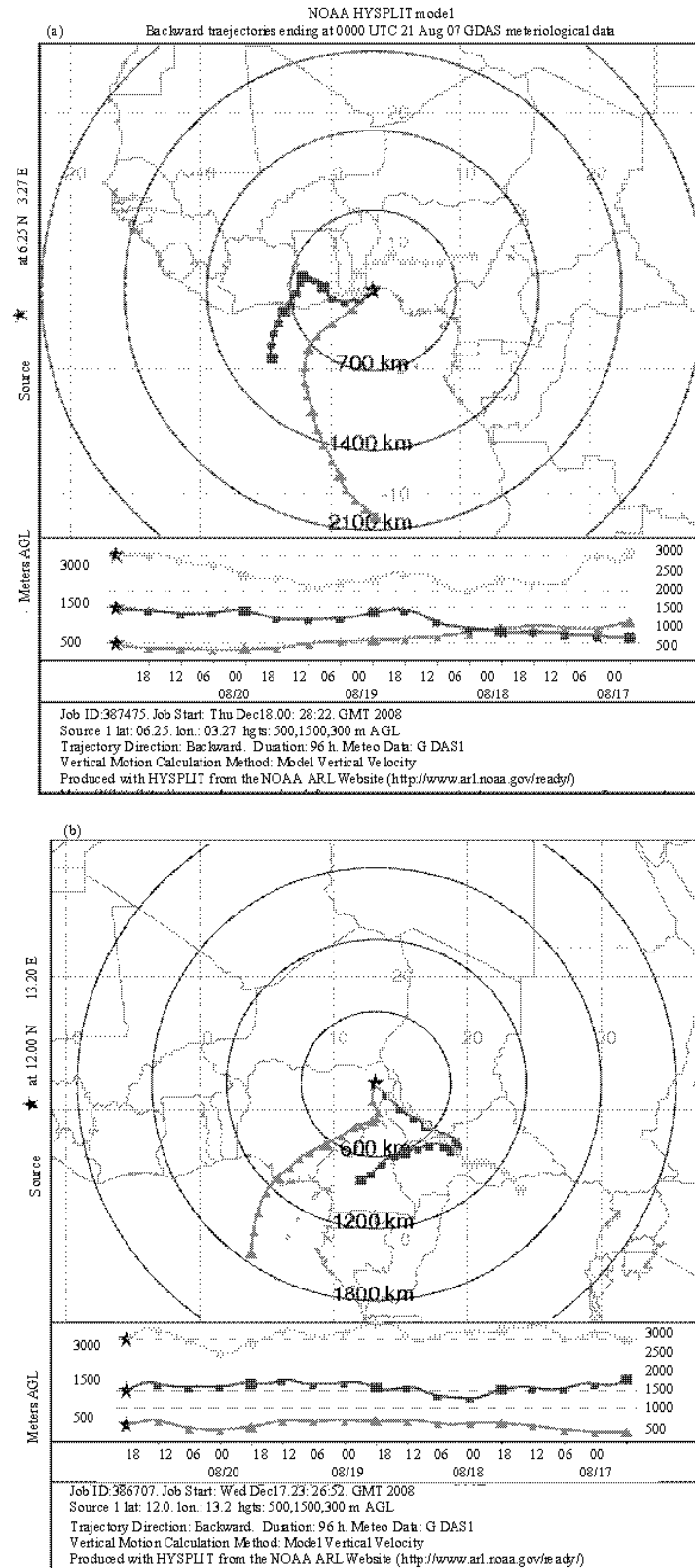


Fig. 5: Backward trajectory analysis (96 h) at three altitudes, start of run at 00:00, 21 Aug. 2008

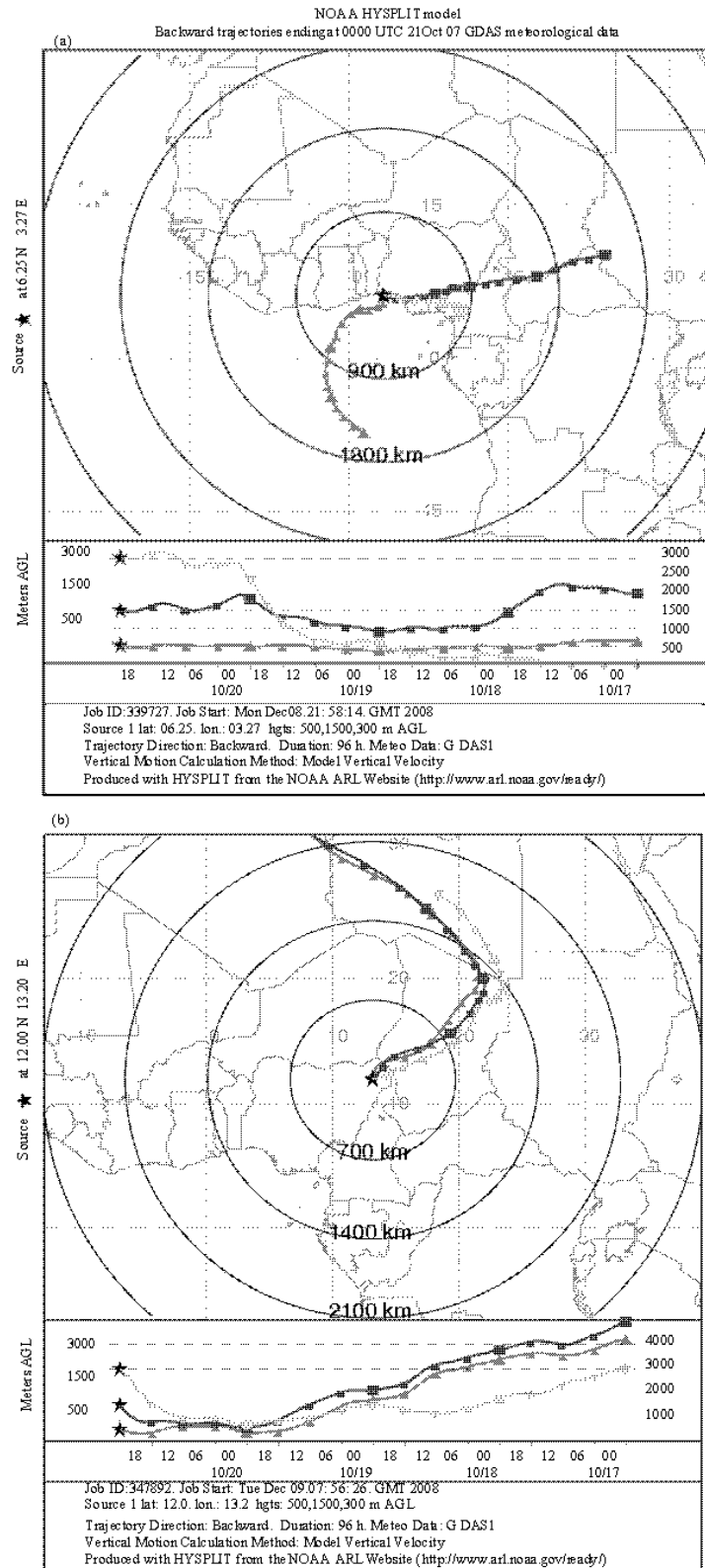


Fig. 6: Backward trajectory analysis (96 h) at three altitudes, start of run at 00:00, 21 Oct. 2007

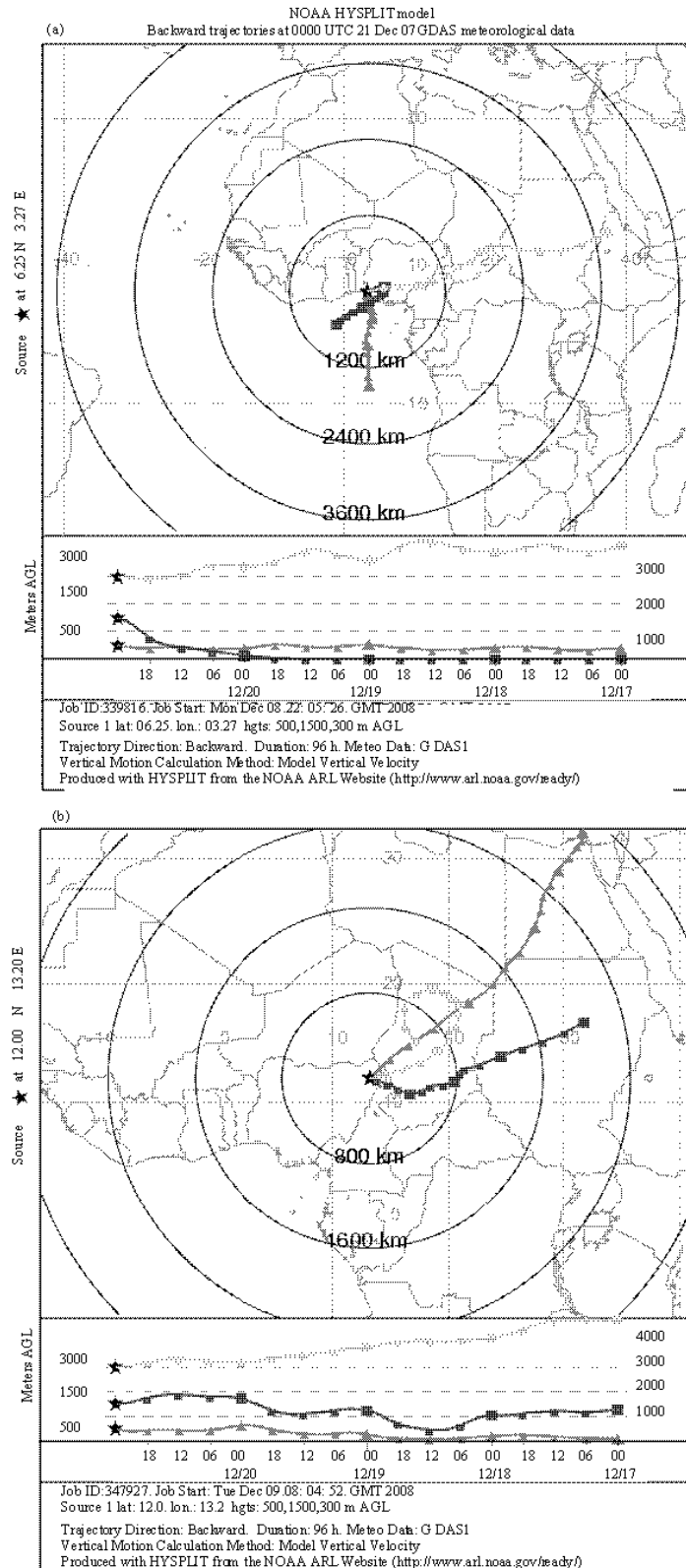


Fig. 7: Backward trajectory analysis (96 h) at three altitudes, start of run at 00:00, 21 Dec. 2007

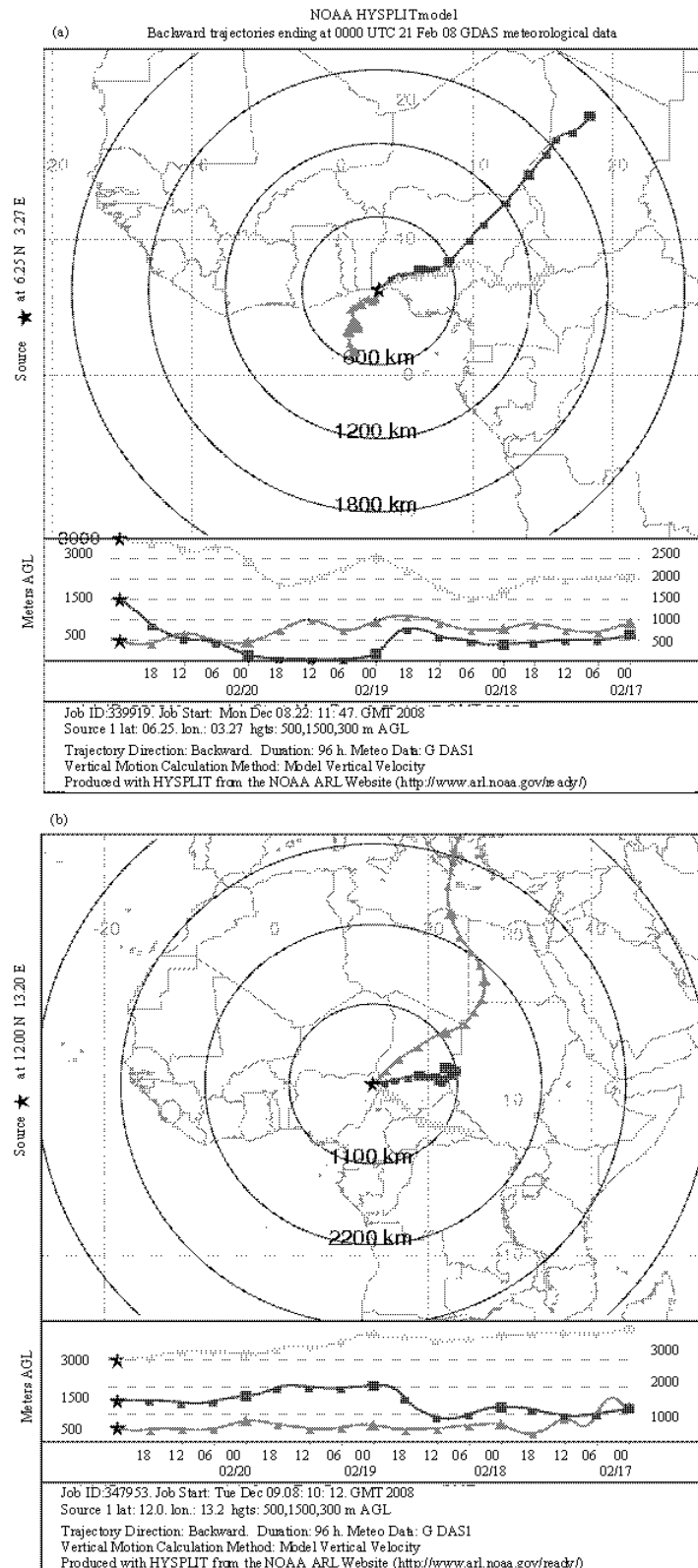


Fig. 8: Backward trajectory analysis (96 h) at three altitudes, start of run at 00:00, 21 Apr. 2007

CONCLUSION

The principal findings of this study show that the atmospheric aerosols distribution in the troposphere influences the weather pattern leading to seasonal variations.

The dry season is usually a hot season, which recorded high temperatures and heat by means of elevated aerosol optical thickness numbers. Anthropogenic activities such as bush burning, burning of biomass and soil excavation for agricultural and construction purposes. Which are on the increase both in the rural and urban areas during this season, amplified the level of aerosols in the atmosphere. Therefore, it is established that dry and sunny weathers would be essential for the transport of aerosols. This makes the dry season a very vulnerable season to aerosol.

Consequently, having persistent heat related health problems such as cerebro-spinal meningitis, heat stroke and even high mortality rate are most likely to be expected during this season. Mostly by those in the Northern region of the country. The problems of poor visibility and stuffy weather are also not ruled out.

Aerosols that occurred in the way of the air mass parcels during the wet season are scavenged to the surface by wet deposition. This accounted for the reason why the wet season recorded low aerosol levels. Therefore, it is expected that weather will be clearer and healthier during the wet season.

RECOMMENDATIONS

It is recommended that anthropogenic activities leading to the incessant emission of atmospheric aerosols be reduced to its barest minimum during the dry season. This will subsequently improve the atmospheric condition and create a purer and more favourable environment for habitation.

ACKNOWLEDGEMENTS

All glory to God Almighty for His love. My humble acknowledgement goes to Dr. A.I. Igbafe.

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