Journal of Pollution Effects & Control
ISSN: 2375-4397

DOI: 10.4176/2375-4397.1000192

Journal of Pollution Effects & Control

Research Article Open Access

Role of Meteorology in Major Dust Pollution Outbreak of 20th-29th March 2010 over South Coast of West Africa

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Abstract

Pathogens in the dust suspended in the atmosphere are known to cause sickness such as cough and throat problems. An unusual dust episode occurred over the coast of West Africa Gulf of Guinea between March 20th and March 29th in 2010. The occurrence was seen as unusual because of the time of occurrence. The cause of the dust outbreak was investigated using wind data at various pressure levels from ECMWF Re-Analysis (ERA) interim dataset. Data of horizontal visibility from two near the coast locations were used to calculate the dust load during the period. Results show that dust load during the episode was about 15 × 10^5 kg and 3 × 10^5 kg per square kilometer over Akure and Lagos respectively. Also that winds at the African Easterly Jet level (core at 750 hPa) suddenly changed from westerly to easterly thereby causing the reversal of Planetary Boundary Layer (PBL) winds. Since the dusts are embedded in within the PBL, wind reversal brought load of dust to the south coast of Gulf of Guinea at very unusual time of the year. The study concludes that watching and monitoring winds at the AEJ level could help in predicting dust pollution outbreak over West Africa.

Keywords: West African dust; Wind regime; African easterly jet; Tropical easterly jet

Introduction

Dust episode over Nigeria and indeed over West Africa is a well-known characteristic of dry season between November and January extending sometime (but in rare occasion) to the end of February over the south coast of Nigeria. Dust is usually mobilized and transported, from the source region of Bodélé depression and other neighboring source region, south-ward during the boreal dry season.

Climatologically, the dust ceases in the southward penetration at the end of January or at worst, before the mid of February due to establishment of south westerly flow close to the coast. Contrary to this know climatology, there was occurrence of severe dust events between 20th and 29th March 2010. This occurrence is therefore unprecedented. Although, there are cases of dust outbreaks in March which are usually suspended high in the atmosphere, the direction of transport has been generally to the Western Sahara and not to the south coast of West Africa [1]. While in several decades before this period in question there have been no report of such episode of dust emission transported so wide to reach the Southern coastal cities of West Africa, there is also no such re-occurrence of 'special' outbreak since then to the present time. The interest in this dust episode is borne out of its 'once in life time' experience. Dust aerosol is one of the atmosphere constituents that have been well studied because of its radiative property [2]. Well known effect of dust on radiation is the scattering of rays of light to produce cooling or reduce horizontal visibility [3-7]. Dust particles also modify the atmosphere to suppress or enhance cloud growth depending on size and amount present. Over West Africa, the problem of dust has been reduction in horizontal visibility with economic consequences to aviation industry. Enormous loss accrued to aviation due to reduction in horizontal visibility ranges from delays, cancelled flights and outright crashes as in the case of Kenya airline that crashed off the coast of Ivory Coast on 30 January 2000 [8].

Primary concern in the case of unusually dust outbreak of 20th to 29th March is health issue. Although, Nigeria Meteorological Agency (NIMET) made rain forecast a day before, there was apprehension about such rain of dust (which some locals termed as acid rain) at such period of the year. Accordingly, everyone ran for cover when the rain began to wash out the dust as predicted by NIMET. Sample of dust was collected and analyzed by Adeonipekun and John [9]. The Palynological result of the study confirmed that the dust was of Saharan origin. Harmattan dust from Sahara desert is known to cause health problems such as coughing and dry throat in addition to bronchial and nasal diseases prevalent during seasonal dust outbreak. In Ghana, as reported by Afeti and Resch [10], outbreak of cerebrospinal meningitis (CSM) disease is directly associated with dust outbreak due to inhalation of hazardous chemical compounds contained in the dust. Results of investigation into what caused the reversal of wind or what conditions brought back the dust at such odd time of the year is still very scarce. This study attempts to investigate the phenomena by considering the meteorological causes of the dust outbreak.

Study Area

West Africa extends roughly from longitude 20° W to 20° E and latitude 2° N to 25° N. This area covers different climate classifications from the south (Figure 1). At the fringe of Atlantic Sea coast in the south, is the swampy mangrove transiting to rain forest roughly at latitude 7° N. There is also transition from rain forest to Guinea savannah, Sahel savannah to Sahara climate in that order. Two major wind regimes determine seasonal changes in West Africa. South-Westerly flow originating from the Atlantic Ocean prevails during the wet season while North-Easterly flow originating from Sahara desert prevails during the dry season. The transition between these two wind regimes is controlled by Inter tropical discontinuity (ITD) zone [11,12].

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Received April 24, 2017; **Accepted** June 26, 2017; **Published** June 30, 2017

Citation: Oluleye A (2017) Role of Meteorology in Major Dust Pollution Outbreak of 20th-29th March 2010 over South Coast of West Africa. J Pollut Eff Cont 5: 192. doi: 10.4176/2375-4397.1000192

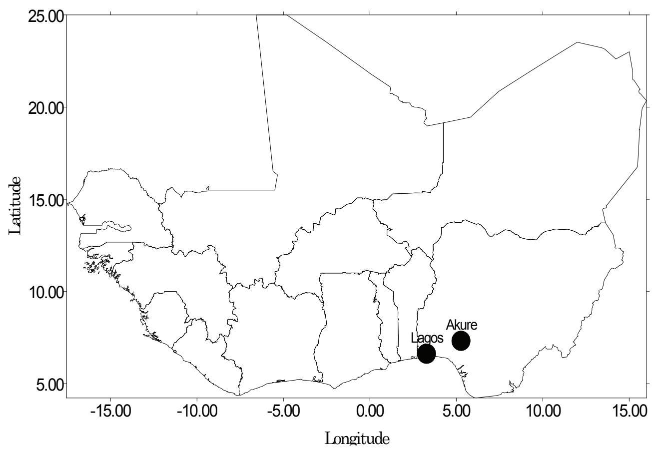

Figure 1: West Africa showing two sample locations used in the calculation of dust load during the period of dust episode.

At any time of the year the area south of ITD is moisture laden while area north of ITD is dry and in most of the time, dust laden. Rainfall regime over West Africa is defined by the propagation of the line of ITD. This system of separation as result of ITD appears to controls dust pollution over the region. Another important factor of seasonal weather over the region is the Jet. Jets are strong wind cores that control the mean wind direction over a particular area. Prominent Jets over West Africa are the African Easterly Jets (AEJ), Tropical Easterly Jet (TEJ) and the Low Level Jet (LLJ). The cores of these jets are located at different levels in the atmosphere. Over West Africa the approximate locations of the cores are 850 hPa, 750 hPa and 200 hPa for LLJ, AEJ and TEJ respectively. The dynamic influence of these jets on West African weather is detailed by Prospero and Nicholson [13].

Data and Methodology

Air quality due to clearance of dust in the atmosphere depends on the strength of the wind and its direction, and also on the time of the year. Thus, for this study wind speeds at various pressure levels were obtained from ERA interim reanalyzed datasets. The data obtained consists of daily zonal and meridional components of wind speeds over West Africa at a resolution of $0.75^{\circ} \times 0.75^{\circ}$ latitude and longitude. The grid resolution is considered reasonable for a large scale flow covering the entire West Africa. Several users of ERA interim dataset have confirmed the reliability and accuracy of the wind data from the dataset [14]. Wind streamlines at the level of important jets that modulate the region's weather were obtained from the analysis of wind data. In addition, Planetary Boundary Layer (PBL) wind vectors were obtained for the purpose of determining dust transport at this height in the atmosphere. PBL is important because dusts trapped in the PBL are the source of pollution at the surface as a result of the interactions between PBL land surfaces. Also used was the horizontal visibility data for locations downwind close to the coast of Gulf of Guinea. The data, which are visual range in ×kilometers, were obtained from the archive of Nigeria Meteorological Agency (NIMET). The visibility data (for 900 GMT and 1500 GMT) were used to calculate the dust load over the locations during the episode of dust outbreak following the method [15]. Average horizontal visibility V_p at the time of observation is related to mass concentration m of dust according to equation (1)

$$V_p = k/m \quad (1)$$

Where k is constant equals 1.8 gm^{-2}. The dust load Dl in kilogram within a boundary layer of 1000 m deep over space of a square kilometer is thus calculated from equation (2)

$$Dl = m \times vol \quad (2)$$

Where *vol* is the volume of air per square kilometer.

Finally daily Ultra-Violent Aerosol Index (AI) data from Ozone Monitoring Instrument (OMI) during the period were also utilized. OMI AI is useful parameter for detecting the presence of absorbing aerosols. OMI replaced TOMS instruments which has a longer record of AI. Both OMI and TOMS use similar retrieval algorithm to detect atmospheric aerosol. Details of retrieval algorithm can be found in Buchard et al. [16].

Results and Discussions

Atmospheric dust load

On March 20th 2010, the resurgence of dust over location close to the Gulf of Guinea became a major concern to the population because the load of dust deposited in the atmosphere impaired the quality of air resulting to hospitalization. Figure 2 shows the temporal trend of dust load over Lagos (long 3.3° E and lat 6.6° N) and Akure (long 7.3° E and lat 5.3° N). These two locations were chosen because of available data and nearness to the Gulf of Guinea. Over both locations, dust loads have subsided after the Harmattan period and the rainy season was beginning to set in. A sudden deterioration of air quality resulted from more than 15×10^5 kg per square kilometer of dust brought to Akure and about 3×10^5 kg brought to Lagos atmosphere by reversing winds. Few days afterward, the dusts cleared out as result of rain. Wet scavenging of the dust due to rain event that took place on the 21st of March when about 4.0 mm of rain fell. Apart from general panic that pervaded the air about the usual pollution, the heavy dust load has both health and environmental concerns. The dust episode resulted into dust concentrations of between 1.4×10^3 gm^{-3} and 2.6×10^3 gm^{-3} per day over Lagos and between 1.5×10^3 gm^{-3} and 6.0×10^3 gm^{-3} per day over Akure. Adebayo (1988) reported that a dust concentration of about 3.0×10^{-4} gm^{-3} corresponding to 6000 m horizontal visibility in the atmosphere is considered to be very high for polluted cities. Within 3 to 4 days of March 20th-29th there was heavy pollution over locations downwind. During these periods, visibility became poor with increased chances of flight cancellation in the international airport in Lagos and the fear of "acid rain".

Wind streamline during the dust episode

In the winter months of December, January and February northeasterly winds prevail over the sub-continent, thus during winter, dust from Sahara became south-bound resulting into deterioration in air quality with its attendant diseases [13]. Also during this period ITD mean position is over the ocean. Early in March the ITD begins its northward movement due to building pressure over the st. Helena, which is also known as st. Helena high, thus the gradual advancement of ITD results in the clearance of dust from the coast due to the strengthening of southwesterly winds. Presented in Figure 3 is the wind flow for some selected days before and during the dust episode. Beginning from on 8th and earlier, the direction of boundary layer wind (averaged at 850 hPa) from the south of the region has turned south-westerly to east of longitude zero degree. East of this longitude, the wind direction is easterly almost parallel to the coast. However the wind speed at higher latitude is stronger and the directions are both easterly and westerly separated approximately at longitude 15° W over the north Atlantic. Now, the wind east of longitude zero degree

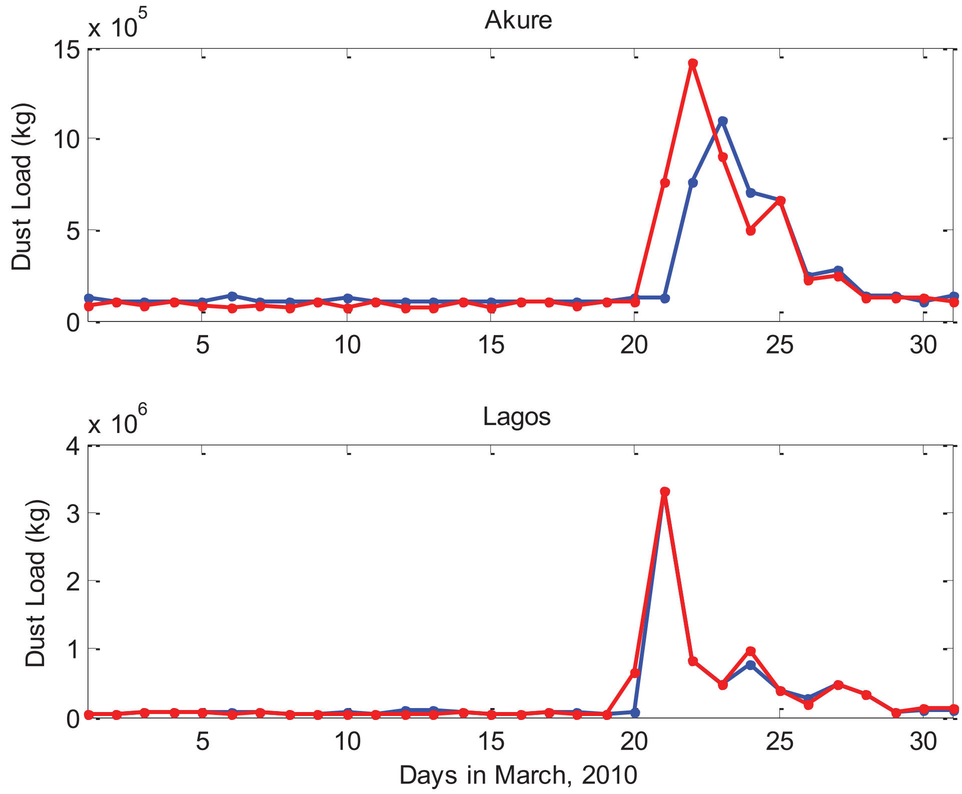

Figure 2: Dust load in the atmosphere per square kilometer over Lagos and Akure, two stations located close to the Southern coast of Nigeria. Red and blue lines indicate the dust load in the morning (900 GMT) and afternoon (1500 GMT) respectively.

originating from the Atlantic Ocean has pushed northward reaching latitude 8˚N. The implication of this is that areas under the coverage of this wind are no longer experiencing dust and in fact should be looking forward to the onset of the seasonal rainfall in accordance to other indicators [17,18]. However, it must be noted here that the wind from the south are weaker than the northern counterpart. At this point in time, dust transport is now limited to latitude 11˚N and beyond. On the 9th and subsequently, winds at higher latitude became stronger and coincidentally the south counterpart became weaker. By 17th of March or thereabout (the exact date is discussed later in this work), the winds at higher latitude have suddenly changed from easterly to westerly gaining more strength with further weakening of southern winds. Thus, beginning from 19th stronger north easterlies are approaching the south coast of Gulf of Guinea emanating from dust rich region of Chad. The incursion of these winds persisted and spread over Gulf of Guinea coast. Accompanying these winds are loads of dust that persisted in the next two day before washing out. The unusual dust episode experienced can therefore be attributed to the sudden change in wind speed and direction occasioned by yet unknown meteorological features over the sub-continent. Several features are responsible for daily changing conditions of atmosphere over West Africa. Prominent among them are the Jets occurring as result of large scale temperature gradient. Over the Sahara desert in the North, temperatures are always very high compared to temperature over the Gulf of Guinea in the south. The difference in temperature set up a wind maximum otherwise known as Jets. In other words, these jets are as a result of thermal wind relationship. In the next section, the temporal evolutions of AEJ and TEJ are considered.

Roles of African Easterly Jet (AEJ) and Tropical Easterly Jet (TEJ)

The sudden change in the wind direction and the strengthening of wind speed over the northern fringe of West Africa as described above cannot be unconnected to the evolution of both AEJ and TEJ. The locations of these jets have been established by various authors [13]. Although both AEJ and TEJ are thermal winds their origins differ. While AEJ is thought to occur as result of contrasting temperature between the Sahara desert and Gulf of Guinea, TEJ is stronger and forms as result of contrasting temperature between the Himalayas and the warm surface of India Ocean. Temporal evolutions of both jets are presented in Figures 4a and 4b. The most prominent observation is the sudden change in wind direction between 15th and 20th of March. At the end of February, the core of AEJ which has hitherto strong and westerly (negative zonal winds) is becoming weakened and turning easterly. Although, AEJ became easterly around 15th of March, its core was weak with a speed of 2 ms^{-1}. The period of weakening of AEJ corresponds to the period of northward advancement of south westerly winds from the Gulf of Guinea. AEJ became westerly again and strengthened to 9 ms^{-1} within 3 days. This effect trickled down to the PBL resulting to the scenario under discussion [19]. Meridional component of the wind strengthened slightly in southerly directions. During the same period TEJ only slowed down without any change in directions.

Episode captured by TOMS instrument

Two Nigerian locations depicted the severity of the dust episode from the record of poor horizontal visibility in the range of 100 m to

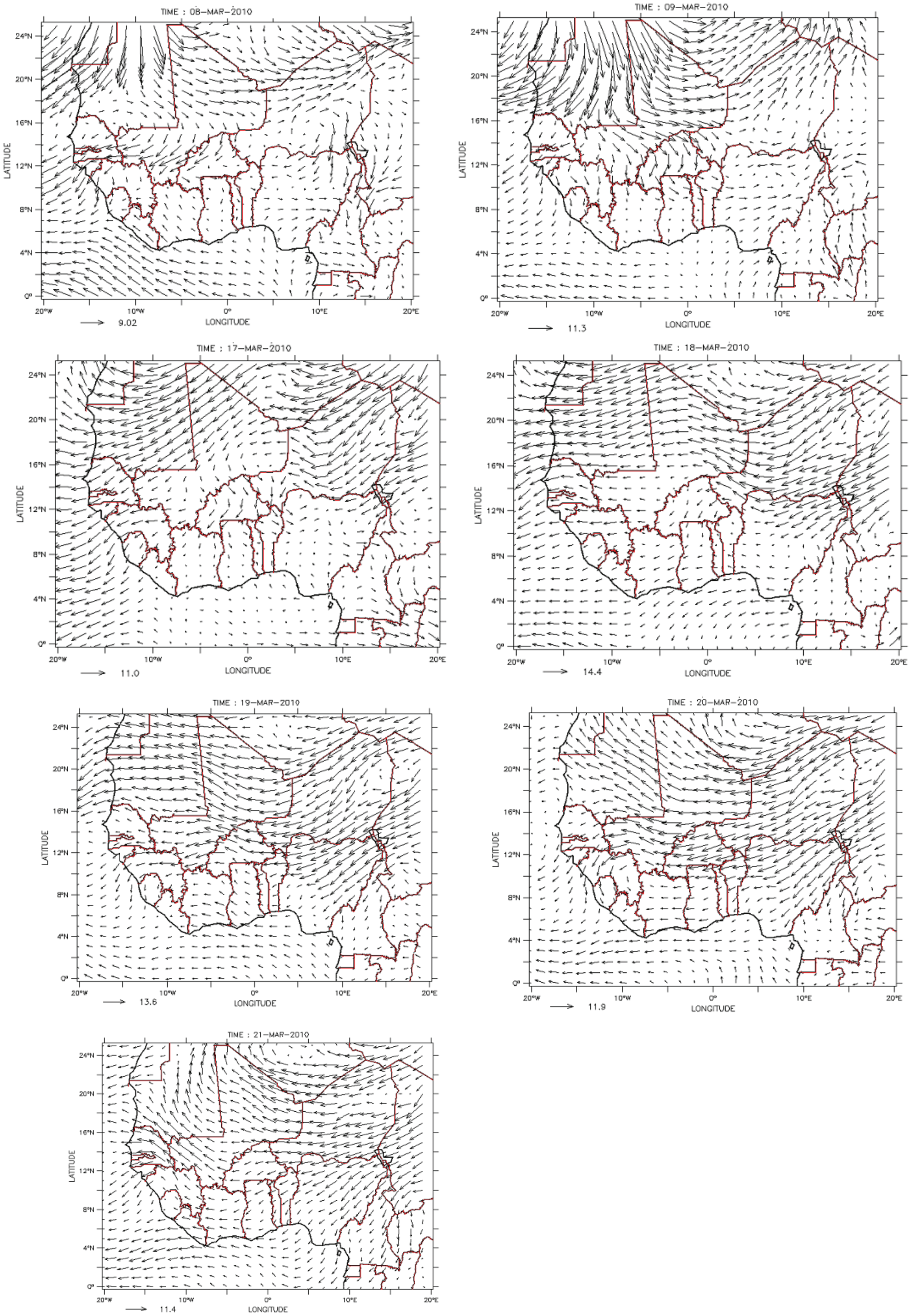

Figure 3: Wind field over West Africa of before and during the sudden resurgence of dust plume.

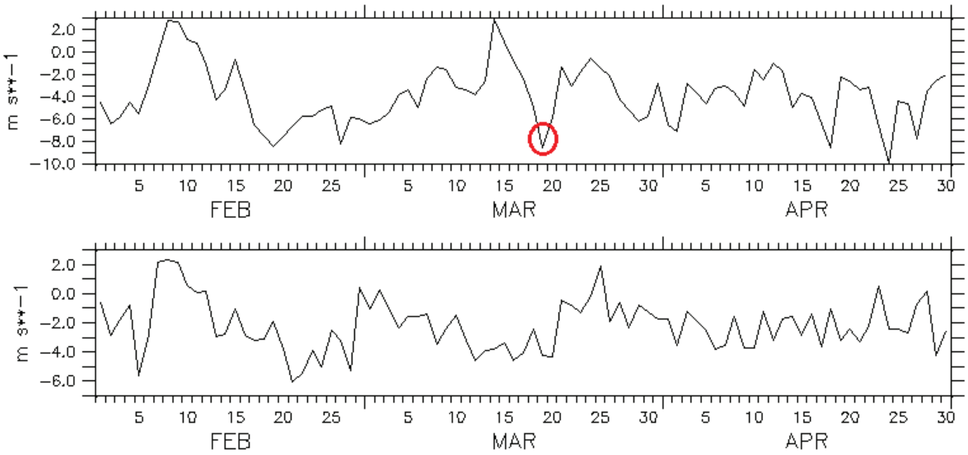

Figure 4a: Zonal and meridional component of the African Easterly Jet (AEJ) centred at 700 hpa. Red circle marked the day when dust plume reached some locations near the coast of Gulf of Guniea.

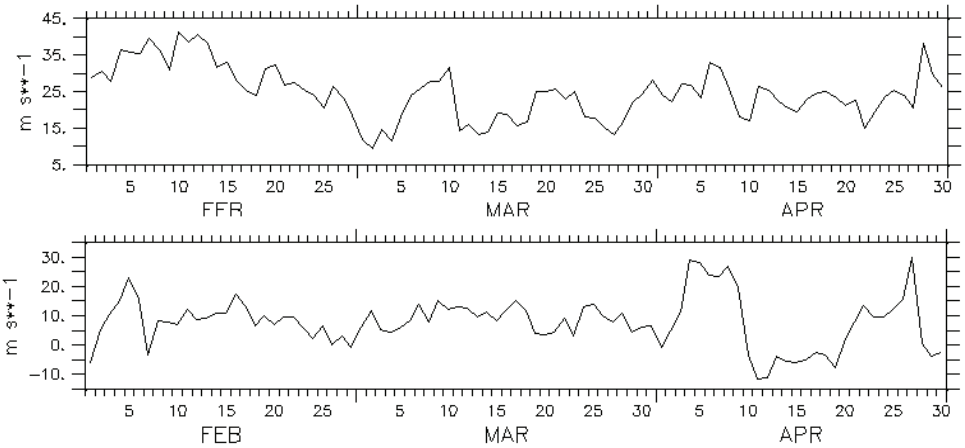

Figure 4b: Zonal and meridional component of the Tropical Easterly Jet (TEJ) centred at 200 hpa.

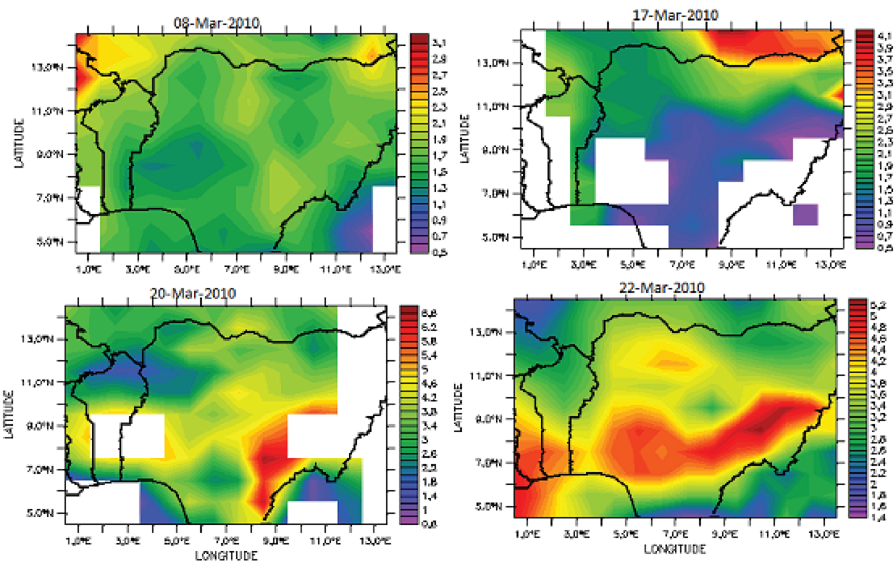

Figure 5: Aerosol Index (AI) as measured by Ozone Monitoring Instrument (OMI). The masked portions are missing data.

1000 m. How Total Ozone Mapping Spectrometer (TOMS) capture the episode over Nigeria (where the two locations are taken) is displayed in Figure 5. TOMS has long term record of daily average Aerosol Index (AI) spanning from November 1978 till 2006. The record temporarily stopped between 1993 and 1996. The record of TOMS was finally discontinued due to faulty instrument and in 2004; Ozone monitoring Instrument (OMI) took over from where TOMS's records stopped. Daily average of AI on 8th March over Nigeria showed dust clearing after a period of Harmattan with gradual improvement in visibility and air quality. This situation continued till 17th March with much clearance. However, on 20th March the dust returned as a result of wind reversal as discussed earlier. The fact that OMI captured the dust attests to the severity of the dust episode during the period.

Conclusion and Summary

Aerosols in the atmosphere are very important not only because of their radiative properties but because dust trapped or transported within the PBL reduced visibility to a dangerous level for aviation operators and also carries pathogens that cause sickness. The case of sudden occurrence of dust pollution over the coast of Gulf of Guinea between the 20th and 29th of March 2010 has been investigated. The major cause of resurgence of dust was found to be the sudden reversal of wind directions and strengthening of wind speeds at the AEJ pressure level. This reversal caused the PBL wind to change direction in response to change of wind directions aloft. The dust was therefore brought to the coast of the Gulf of Guinea by the strengthening north easterly. This occurrence is "odd" because similar episodes are not common. The cause of the sudden wind reversal may be connected to mid-latitude pressure and temperature changes and could be a subject of further discussion. However, watching out for the reversal of winds could serve a way of predicting dust outbreak in an unusual time over the sub-continent.

Acknowledgements

Data used for this work were sought from different sources. Horizontal visibility data were obtained from Nigeria Meteorological Agency (NIMET), Wind data were obtained from ERA interim dataset and Aerosol index from OMI. The author deeply thanks those who have facilitated the accessibility to the data.

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