Centre for Atmospheric Research

2018 MONOGRAPH OF ATMOSPHERIC RESEARCH

Edited by A.B. Rabiu and O. E. Abiye

A Publication of
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PREFACE

The Centre for Atmospheric Research was established in January 2013 with a compelling mission to improve our understanding of the behaviour of the entire spectrum of the Earth's atmosphere; promote capacity development in relevant atmospheric sciences as a way of facilitating international competitiveness in research being conducted by atmospheric scientists; and disseminate atmospheric data/products to users towards socio-economic development of the Nation. CAR's extant core research focus includes: space weather, tropospheric studies, atmospheric research software and instrumentation development, microgravity and human space technology, and atmospheric chemistry and environmental research.

Pursuant to the above, The *Monograph of Atmospheric Research* published by the Centre for Atmospheric Research (CAR), is a collection of peer-reviewed manuscripts in Atmospheric Sciences and closely related fields. This maiden edition comprises articles presented during two separate workshops; *1st National Workshop on Microgravity and Environmental Research* (26 - 29 November, 2017) and *1st National Workshop on Air Quality* (13 - 16 March, 2018). Such workshops are integral part of CAR's capacity building program and they were primarily aimed at advancing the course of atmospheric research in Nigeria towards sustainable development. The Microgravity workshop was geared towards introducing new research opportunities in space life science by simulating microgravity conditions here at the earth's surface as a means of investigation space biological environment. The Air Quality workshop was organized in collaboration with Ministry of Environment and Nigerian Meteorological Agency (NIMET). The workshop analysed current Air Quality scenario in Nigeria, explored new opportunities for collaborative research and offered novel means of improving the present quality of life of the populace without jeopardizing the chance of the future generation. Cumulatively 196 participants participated in these two workshops and about 52 articles were eventually submitted for publication consideration in this monograph. The twenty-one articles in this very monograph are the articles that eventually made it through the rigorous peer-review process. We remain grateful to the reviewers for doing thorough work on the articles.

Thus, we are very pleased to present the *2018 Monograph of Atmospheric Research* which contains twenty-one articles, including some review papers, to readers in all spheres of interest across Nigeria and beyond. It is our hope that this effort will continue and will serve as a reference to atmospheric researchers in Nigeria.

Prof. A. B. Rabiu and Dr. O. E. Abiye,
Editors

Centre for Atmospheric Research

On the understanding and estimates of dust deposition in the West Africa region

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ABSTRACT

Rainout and washout deposition are important features of dust investigation in the West Africa region. In this work, International Centre for Theoretical Physics (ICTP), Regional climate model version 4 (RegCM4.6) was employed to simulate seasonal cycle of dust deposition in the West Africa region with special focus on Sahara dust storm during 2005. An experiment was performed with the activated dust module while the dust deposition were analysed along with other atmospheric responses. The results were compared to satellite data from MERRA-2 and MISR datasets. It was found that RegCM4 were able to capture the mineral dust emission point across the Sahel with the highest emission point at Bodele and Muritania as well. Annual mean wet deposition peaks was found in the coast and inland part of Nigeria. The 0.01-10 and 2.5-5.0 µm of Dust has peak value between 1.45 – 1.85mg m^{-2} day^{-1} and decreases Northward with minimum values of 0.55 mg m^{-2} day^{-1} driven by dynamics of ITD while there were Southward migration of mineral dust dry deposition from the Sahel to the Guinea coast with deposition velocity varying between 0.001-0.01 m/s across the region from Winter to Summer. It was concluded that the spatial distribution and seasonality of deposition of dust vary greatly according to dust size and are also influenced by precipitation amount and seasonal distribution and as well as wind velocity increases in the winter.

Key words: deposition, velocity, washout, rainout and dust

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INTRODUCTION

Mineral dust deposition mechanism either through wet or dry deposition is a very important feature of dust characteristics in the West Africa region. Topographic configuration of West Africa from coastal areas in the South to Savanah zone in the North as well as emission of dust particles from the Sahara desert, which together are the earth's largest source of mineral dust (Prospero et al., 2002) attracts formidable research. Certainly, dust production depends on surface wind, precipitation and changes in the vegetation cover (Tegen *et al.,* 2000). About half of the dust that is transported westward from West Africa is deposited on coastal areas, Southern Europe and into the tropical North Atlantic Ocean (Kaufman *et al*., 2005), where it modifies biogeochemistry and carbon export (Tagliabue *et al*., 2014). Dust input adds nutrients to the surface of the seas which stimulate phytoplankton production. Also, climatic importance of mineral dust particles includes the absorption and scattering of radiation in the atmosphere and the modifications of the optical properties of clouds and snow/ice surfaces (Tegen, 2003 and Aoki, *et al.,* 2006). The direct aerosol climatic impact of −0.27 W m −2 and the indirect effect of −0.55 W m −2 were estimated in the most recent IPCC report, yet the forcing uncertainty remains the highest among all the other factors Boucher, *et al*., (2013).

In contrast however, mineral dust outflows off the West African coast impact offshore biogeochemical processes and can be regarded as natural hazards to human activities and ecosystems. For example, dust storms affect aviation operations reducing flight visibility, causing engine mechanical damages and flight path reassessments.

Recent studies also suggests that dust deposition in the Atlantic intertropical convergence zone (ITCZ) controls the latitudinal distribution of nitrogen fixation through its supply of iron and phosphorus to the ocean's mixed layer Schosser *et al* .,(2014). African dust that is transported across the Atlantic during boreal winter and spring provides essential nutrients for the Amazon rainforest Swap, *et al* ., (1992). Wet deposition is caused by both precipitation scavenging and surface deposition of fog and cloud droplets. Unlike dry deposition, a phenomenon that occurs in the lower layer of the Planetary Boundary Layer (PBL), precipitation scavenging affects all volume elements aloft inside the precipitation layer. Following Seinfeld (1986), the wet flux of a pollutants to the surface while dry deposition is commonly measured by the deposition velocity

An important component that affects the transport and the radiative properties of dust in climate modelling is the number of transport dust size bins. Small dust particles, due to their weight, can travel over long distances and can efficiently reflect/backscatter the incoming shortwave solar radiation, while larger particles, with a shorter atmospheric life, can effectively absorb and re-emit in the long wave spectrum. Thus, both the partitioning and the number of dust transport bins, used in atmospheric models, should carefully distinguish dust particles with contrasting radiative properties and transport characteristics.

This work aim at simulating mineral dust deposition according to dust size parameterization scheme in the Regional Climate Model (RegCM4) in order to visualize spatial and temporal dust deposition across West Africa region and to also investigate the impact of precipitation and wind velocity on the wet and dry deposition of mineral dust in the region

METHODOLOGY

Study Area

The study area is West Africa domain with major sources of dust aerosol in the Sahel. The climate of the region is governed by the north–south movement of the Inter-tropical Discontinuity (ITD). The West Africa domain is divided into three climatic zones. The Sahel zone, with irregular annual rainfall that does not exceed 500 mm, and a maximum rainfall occurring in August. This zone is located roughly at 12.5° N latitude and its climate is semi-arid the Sudan zone with a precipitation amount less than 200 mm in the north of Nigeria and 1000 mm in the north of Mali. The climate is sub-humid and located approximately between 9° N and 12.5° N. The tropical humid Guinea Cost zone located along the Gulf of Guinea, characterized by annual mean rainfall higher than 1500 mm. Figure 1 presents the land use and land cover classification of West Africa.

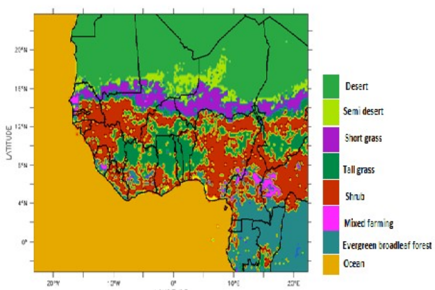

Figure 1: Land use/cover map of West Africa Regional depicting different surface characteristics from the Ocean in the Southern part to the Sahel in far north of the Region

Data and Model Set-Up

The Regional Climate Model (RegCM) is a space-limited numerical model developed at the National Center for Atmospheric Research (NCAR) and the Abdus Salam International Centre for Theoretical Physics (ICTP). Notably, it was the first area-limited model used for long-term climate simulations *Giorgi and Anyah, (2012)*.

Here we employ RegCM4, which is described in detail in *Giorgi et al. (2012)*. The hydrostatic core of the model, which is based on the fifth version of the PSU/NCAR meso scale Model (MM5; Grell *et al.*, 1994), restricts the minimum horizontal resolution of the model to 10 km. Thus, the regional-scale convective precipitation on RegCM4 is resolved through various convective scheme parameterizations. The vertical computation of the atmosphere is applied on sigma levels. Land–atmosphere interactions are analysed with the Biosphere-Atmosphere Transfer Scheme (*BATS; Dickinson et al., 1993*). The chemical part of the model contains gas-phase chemistry (*Shalaby, et al., 2012; Steiner, et al., 2014*) as well as natural and anthropogenic aerosols (*Solmon, et al., 2006 and Zakey et al., 2008*).

Most of the natural aerosols, such as dust and sea salt, are driven by RegCM4 meteorology, while all anthropogenic aerosols, organic carbon, black carbon and pollen require emission datasets. The dust emission scheme is activated in a grid cell when the friction velocity, resolved as a function of RegCM4 simulated wind speed and surface roughness, is higher than the minimum friction velocity threshold. Removal processes through wet and dry deposition are included in the model. Dry deposition includes gravitational settling (a function of particle size and density), Brownian diffusion (acts mainly on small particles close to the ground) and turbulent transfer, as well as impaction, interception and particle rebound. Wet deposition processes include a size-dependent washout scavenging parameterization which occurs at a small fraction of dust of 10 % considered soluble.

The dust module include four particles (k = 4) categories, resulting from the structure of desert soils based on the content of clay, small silt, large silt, and sand. For each size category k, typical radius (R_k), density (ρ_κ), and the ratio between the mass available for uplift and the total mass (γ_κ) are estimated. The mass of the clay particles are estimated to be 1 to 2 orders of magnitude smaller than particles in range 1–10 μm. It was assumed that a fraction of erodible clay is between 0.02 and 0.17 and $\gamma_1 = 0.08$.

The radius of silt particles are in the range from 1 to 25 μm. Small airborne particles with a diameter of 10 μm or less and 25 μm or less, respectively, are mainly removed through the wet and turbulent dry deposition processes. Particles larger than 10 μm are basically removed by gravitational settling.

The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)

MERRA-2 is a reanalysis data product from NASA/GMAO. It is currently being produced with the GMAO/GEOS-5 Data Assimilation System Version 5.12.4. MERRA-2 is intended to replace the MERRA reanalysis product (which was created with GEOS-5.2.0). It has a native resolution of 0.5° lat x 0.625° lon x 72 hybrid sigma/pressure levels. MERRA-2 data is stored on the same vertical grid as the GEOS-5 "forward processing" (what we call GEOS-FP) and MERRA met field product.

EXPERIMENTAL SETUP

The key parameters of the RegCM4 configuration for simulations are Horizontal resolution of 50 km, Top layer pressure of 50 hPa, Meteorological boundary conditions of ERA-Interim (Dee et al., 2011), Surface model of BATS (Dickinson *et al.*, 1993), Chemical boundary conditions of CAM + EC-EARTH, Cumulus convection scheme of Tiedtke (Tiedtke, 1989), Planetary boundary layer scheme of Modified Holtslag (Holtslag *et al.*, 1990) and Dust tracers of 4 bins isolog options.

RESULTS AND DISCUSSION

(a) Annual and Seasonal Mineral dust Optical Characteristics in West Africa Region

Figure 2 presents the annual dust emission with the Sahelian dust bands with minimum AOD value of 0.2 – 0.4 and maximum value of 1.0 – 1.4 in the dust case experiment at Bodele and Maritania point source. Coarse particles travels far in the earth's atmosphere and can be carried downwind where the concentration is lesser. They also retained in the atmosphere which possibly results in Cloud Condensation Nuclei (CCN) because of indirect radiation forcing. In the same vein the seasonal dust case for June-July-August-September (JJAS) revealed dust loading with an average AOD value of 0.8 during dust case, figure not shown.

It is quite evident that the mineral dust transportation during June-July-August-September are of less magnitude than annual dust transportation. Similar results was found by Mahowald and Kiehl (2003) who discovered that inter-annual variability of dust transport is larger than that of inter-seasonal dust transport.

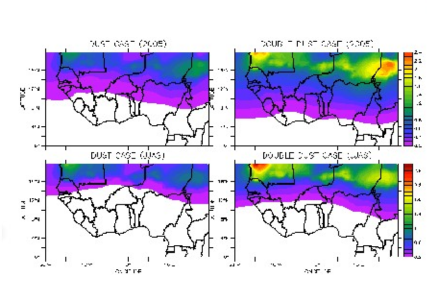

Figure 2: Emission and Transport of Mineral dust in the dust band in the Sahel region of West Africa

However, figure 3 presents annual and mean variation of wet and dry deposition in the West Africa region. The upper panel is the mean and annual wet deposition with the highest size deposition of 0.1-1 micron meter dust and with the highest concentration in June and July while the lower panel shows the mean and annual dry deposition variation of dust in the West Africa region.

(b) Annual wet deposition of dust in West Africa region

Annual deposition of dust with respect to size parameterization in the regional climate model is presented in this section. Dust01 varies in size from 0.01 – 1μm and of the clay particle source. This specie of mineral dust travels far distance and retain in the atmosphere before further reactions take place in the medium or being deposited through washout by precipitation, a process known as scavenging. Precipitation over West Africa is a function of ITD/ITCZ meridional movement, the northernmost position of the ITD/ITCZ depicts the time of highest precipitation period which induced wet deposition in the Southern part of the region.

From figure5, the annual mean dust deposition shows a similar southward shift in its maximum, from about 4°N in the Guinea coast of West Africa to 12°N at 15°W-15°E. Dust deposition generally decreases northward, consistent in the Guinea coast but decrease in deposition is less pronounced, especially between 12°N and 20°N. There is a sharp high deposition between 5°E-10°E of about 1.52 – 1.85 mg m^{-2} day^{-1} The strong reason for this is that convective rainfall intensity aids dust deposition with weaker winds thereby limiting dust transport and deposition to the southern part of the West Africa region.

Another important feature is DUST02 in figure 4 which indicate high concentration of dust deposition in the Guinea coast from 15°W-15°E extending to the Atlantic ocean in the South with dust amount to 2.85 mg m^{-2} day^{-1} on the offshore and about 1.25 mg m-2 day -1 on the Atlantic ocean respectively. Consistent rainfall around this region is one of the strong reasons for high deposition of dust and more importantly the particle size of this species also has high retainance capacity in the atmosphere. In another hand DUST04 in figure 1 has the least dust annual deposition of about 0.55 mg m^{-2} day^{-1} because of heavy size particle specie associated with sand source particles originated from Saharah desert.

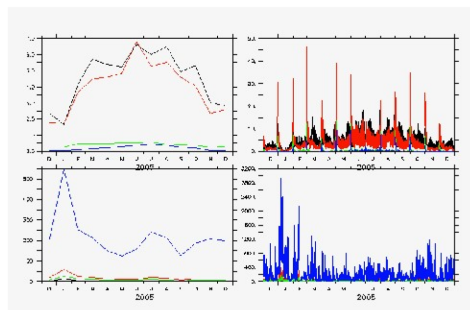

Figure 3: Mean and annual variation of mineral dust variation in the West Africa region

(b) Annual dry deposition of dust in the West Africa region

Here, we presents the annual dry deposition of dust across West Africa region. The four dust bin with respect to particle size were simulated and it was discovered that wind play a major role in the deposition of dust in the region. From figure 5, there is a band of dust deposition at 15°N-20°N and between 15°W - 20°E that is caused by North Easterly wind increasing from 0.021 m/s – 0.024 m/s resulting in meridional divergence of dust mass (figure not shown). The dust mass was maximum between 15°E-20°E and 18°N-20°N with value of 1.5 mg m^{-2} day^{-1}.

The dust deposition may be caused by meridional uniform dust height. All the four dust bin have similar dust deposition trend except for DUST01 with slight increase in mass deposition.

The deposition velocity over the West Africa region varies greatly. From figure 7, seasonal deposition velocity decreases from 0.024 m/s in December to 0.0015 m/s in January for all the four bin. Comparing MERRA-2 annual dry deposition of dust, the simulated output shows higher mass of dust

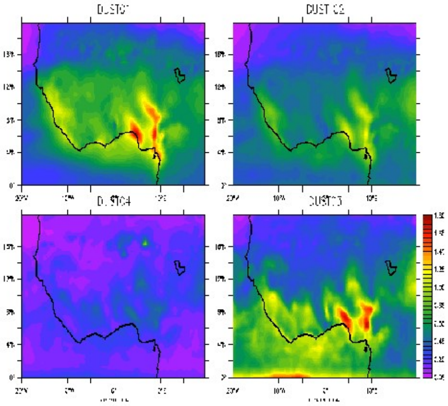

Figure 4: Annual Wet deposition flux over West Africa

deposition than the RegCM4.

(c) Mean seasonal wet deposition of dust flux

In this section, we presents seasonal climatology of dust deposition with respect to the size bin from DUST01 to DUST04. Generally, DUST01 with size 0.01-10 micrometer appear to have highest deposition in the summer. Figure 6 revealed the increase in mass deposition by rain for both DUST01 and DUST 02 respectively, in winter (DJF) there were traces of wet deposition in the Guinea coast extend to the ocean from 10°W-10°E with maximum deposition value of 1 – 1.2 mg m^{-2} day^{-1}. These increase also observed in Spring (MAM) but with spatial extension inland with deposition peak of 1.8 mg m^{-2} day^{-1}. The summer season however, has the highest spatial but lesser mass deposition of DUST01 with the highest value of 1.4 mg m^{-2} day^{-1}. The dust band covers and extends from 8°N -20°N and 20°W-20°E. As earlier inferred smaller particles has highest retaining in the atmosphere and washed by rainfall intensity. In the same vein DUST02 behave the same but with maximum deposition in spring with about 1.8 mg m^{-2} day^{-1} but with less spatial coverage.

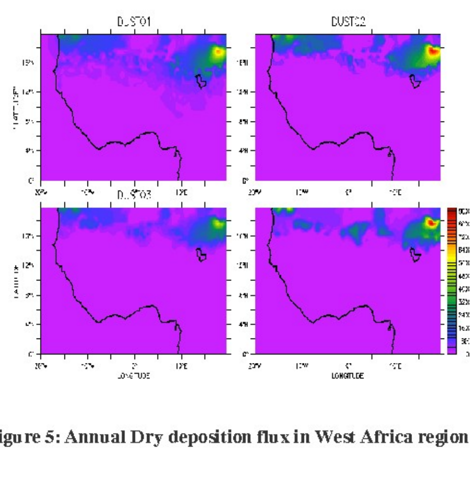

Figure 5: Annual Dry deposition flux in West Africa region

DUST03 and DUST04 exhibit less deposition characteristics with minimum value of 0.4-0.8 mg m^{-2} day^{-1} and spatial coverage in Summer.

Figure 7 shows MERRA-2 datasets output for DUST01 and DUST02 from December-January-February (DJF), March-April-May (MA) and June-July-August-September (JJAS). MERRA-2 shows the same wet deposition trends along the coastal areas increasing deposition trend from December-January-February (DJF) offshore to inland in June-July-August-September (JJAS) seasonal period with approximately dust deposition value of 0.007 – 0.02 mg m^{-2} day^{-1} . Similarly, comparing dry dust deposition from MERRA-2 output datasets in figure 4, there appear the same trends of deposition of dust migration from DJF seasonal period with wider spatial coverage in the Sahel extends to Guinea coast in March-April-May (MAM) period with widest spatial coverage. There were less dry deposition in June-July-August-September (JJAS) seasonal period. The reason for this could be linked to moist South westerly prevalence in the summer thereby reduced the amount of dry deposition in the region.

(d) Dust deposition with respect to precipitation amount

Figure 9 presents wet deposition of mineral dust with DUST01 and DUST02 classes of dust bin simulations with precipitation amount. Here we will be focusing on the scavenging impacts of precipitation on dust deposition since dust mass deposition varies with precipitation amount. December-January-February (DJF) revealed precipitation amount of 0.5-2.0 mm/day around the coastal area of West Africa where maximum dust deposition was noticed and this is peculiar to smaller particle size of 0.01-10 and 2.5-5.0μm. Similarly, precipitation amount between 5-10 mm/day were recorded with highest seasonal dust deposition of about 1.8 mg m^{-2} day^{-1} for DUST01 as earlier mentioned.

The JJAS revealed spatial distribution and extension of dust deposition with average precipitation above 10 mm/day. With the trend of mineral dust deposition rate with respect precipitation amount as observed from the simulation output, we infer that convective induced precipitation impact dust deposition more than monsoon.

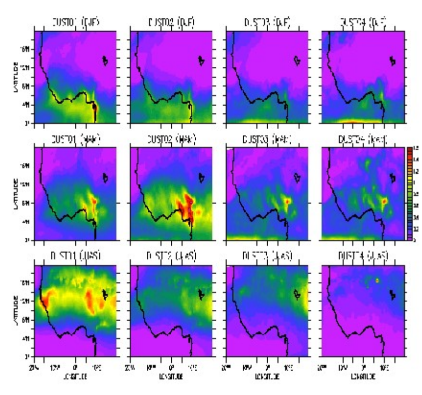

Figure 6 Seasonal deposition of dust wrt dust size from

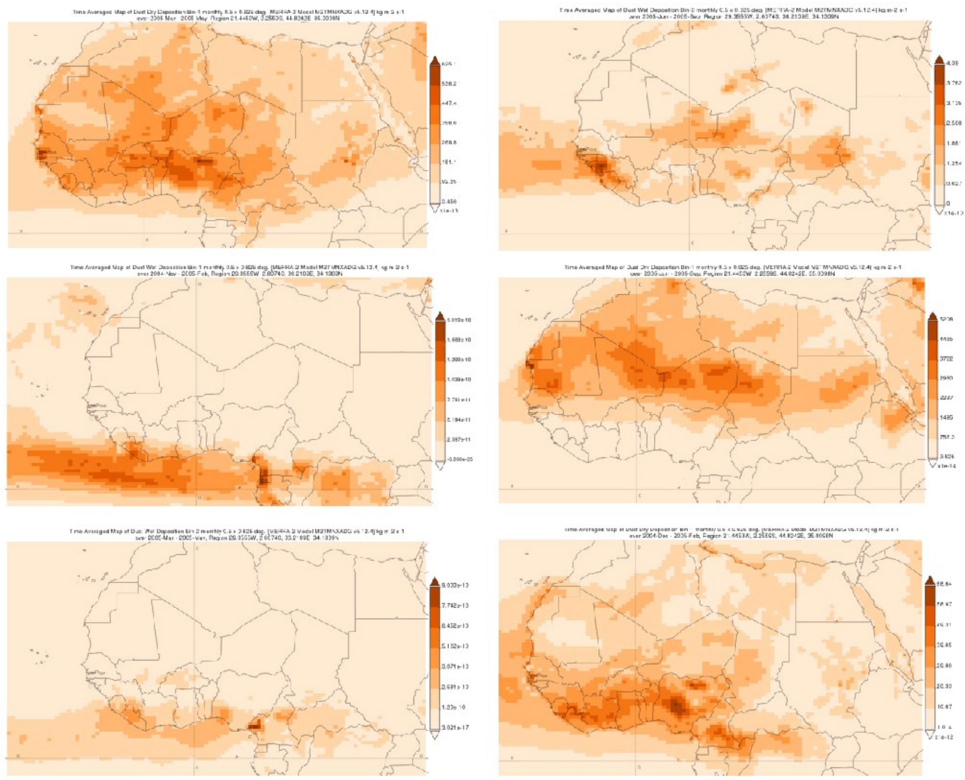

Figure 7: Seasonal wet and dry deposition of mineral dust from MERRA-2 datasets

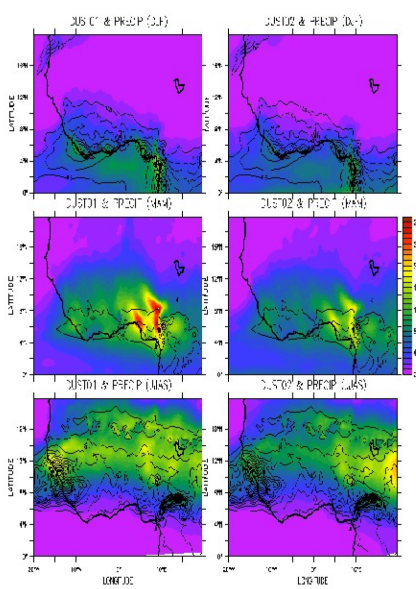

Figure 8: wet deposition in relation to precipitation amount

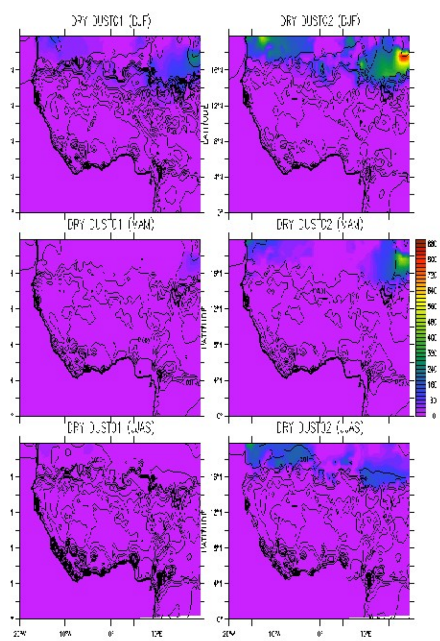

Figure 9: Dry deposition of mineral dust with deposition velocity

(e) Dust deposition and the deposition velocity

Figure 10 presents dry deposition of mineral dust with respect to wind velocity considering only DUST01 and DUST02 respectively. There were increasing deposition velocity of 0.000- 0.001m/s from the Guinea coast to the Sahel region for DUST01 and deposition velocity of 0.001- 0.01m/s for DUST02 in December-January-February (DJF) seasonal period. In over all, there were no laudable changes in the deposition velocity of both dust size from DJF to JJAS seasonal period.

CONCLUSION

We concluded that mineral dust size between 0.01-10 and 2.5-5.0μm recorded maximum deposition with spatial migration from the Guinea coast extend to the Northern region (Savanah and Sahel) from Winter to Summer seasonal period majorly driven by the dynamics of ITD/ITCZ, while there were Southward migration of mineral dust from the Sahel to the Guinea coast with deposition velocity varying between 0.001-0.01 m/s across the region from Winter to Summer when there were least mineral dust deposition

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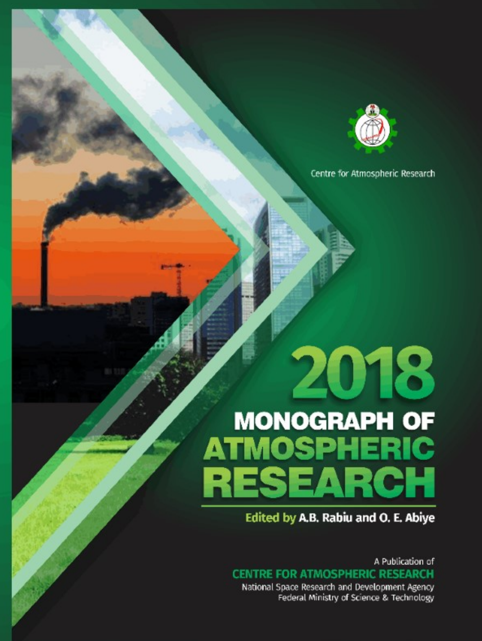

Our Mandates

The Center for Atmospheric Research, CAR, is a research and development center of NASRDA committed to research and capacity building in the atmospheric and related sciences. CAR shall be dedicated to understanding the atmosphere—the air around us—and the interconnected processes that make up the Earth system, from the ocean floor through the ionosphere to the Sun's core. The Center for Atmospheric Research provides research facilities, and services for the atmospheric and Earth sciences community.

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