Dust induced changes on the West African summer monsoon features

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ABSTRACT: Dust generation and transportation from North Africa are thought to modulate the West African Monsoon (WAM) features. In this study, we investigated the relationship between the Saharan Air Layer located above Atlantic Ocean (OSAL) and WAM features, including Monsoon flow, African Easterly Jet (AEJ) and Tropical Easterly Jet (TEJ) over West Africa using the RegCM4 regional model at 30 km grid resolution. Two sets of experiments with and without dust load were performed between 2007 and 2013 over the simulation domain, encompassing the whole of West Africa and a large part of the adjacent Atlantic Ocean. An intercomparison of the two simulations shows that dust load into the atmosphere greatly influences both the wind and temperature structure at different levels, resulting in the observed changes in the main features of the WAM system during summer. These changes lead to a westward shift with a slight strengthening of AEJ core over tropical Atlantic and weakening of both TEJ and monsoon flux penetration over land. In addition, despite running the RegCM4 with prescribed sea surface temperature, a correlation has been found between Aerosol Optical Depths in OSAL and WAM features. In this study, we investigated the relationship between the Saharan Air Layer located above Atlantic Ocean (OSAL) and WAM features, including Monsoon flow, African Easterly Jet (AEJ) and Tropical Easterly Jet (TEJ) over West Africa using the RegCM4 regional model at 30 km grid resolution. Two sets of experiments with and without dust load were performed between 2007 and 2013 over the simulation domain, encompassing the whole of West Africa and a large part of the adjacent Atlantic Ocean. An intercomparison of the two simulations shows that dust load into the atmosphere greatly influences both the wind and temperature structure at different levels, resulting in the observed changes in the main features of the WAM system during summer. These changes lead to a westward shift with a slight strengthening of AEJ core over tropical Atlantic and weakening of both TEJ and monsoon flux penetration over land. In addition, despite running the RegCM4 with prescribed sea surface temperature, a correlation has been found between Aerosol Optical Depths in OSAL and WAM features, indicating a mechanistic link between dust and WAM well reproduced by RegCM4.

KEY WORDS West African monsoon; RegCM4; dust; impacts

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1. Introduction

The optical and radiative properties of atmospheric aerosols due to their non-uniform distribution can alter atmospheric and ocean circulation (Ming and Ramaswamy, 2011). West Africa is one of the most important regions of the world where different types of aerosols abound in the atmosphere. Mineral dust particles emitted from arid and semi-arid regions (Sahara and Sahel), biomass burning aerosols (essentially emitted during dry season), sea salt and anthropogenic aerosols emitted from fossil fuel are frequently loaded in the regional atmosphere. It has been established that aerosols directly and indirectly affect Earth’s climate (Levin and Ganor, 1996; Miller and Tegen, 1998; Haywood and Boucher, 2000; Takemura et al., 2005; Choobari et al., 2014), therefore, aerosols loaded into West African atmosphere may likely interact with the regional climate system, especially during the West African Monsoon (WAM) period occurring during the boreal summer season. While biomass burning aerosols are quasi-absent during the monsoon period due to fire seasonality and high soil moisture as a result of rainfall (N’Datchoh et al., 2015), dust outbreaks are frequent with Bodélé region being one of the major sources (Prospero et al., 2002; Laurent et al., 2008). That is why mineral dusts represent a significant portion of aerosols that interact directly with the WAM system.

Considering the importance of dust-aerosol impacts on climate, attempts have been made to accurately estimate dust-aerosol impacts using both direct and indirect approaches (Field et al., 2014). However, over West Africa, aerosols observations are still limited. Thus global or regional climate model (RCM) simulation provides an alternative way to investigate aerosols transportation and climatic effects over the West Africa and surrounding regions. A larger number of modelling studies highlighted significant impacts of dust on WAM dynamics from event to seasonal and climate scales (Miller et al., 2004; Tompkins et al., 2005; Paeth and Feichter, 2006; Yoshioka et al., 2007; Konare et al., 2008; Lau et al., 2009; Mallet et al., 2009; Perlwitz and Miller, 2010; Stanelle et al., 2010; Lavaysse et al., 2011; Zhao et al., 2011; Touré et al., 2012; Marcella and Eltahir, 2014). Most of these simulations were performed using general circulation...
models (GCMs), and the results showed induced circulation anomalies over large geographical regions of the Atlantic Ocean (Lau et al., 2009).

Other studies have used RCMs, which have the advantages of high resolution for dust emission, transport processes, land surface gradients and weather system. Although RCMs cannot capture the full picture of dust induced anomalies because of their limited area. While most previous regional modelling studies focused on dust aerosols effect on surface mean climate and atmospheric processes, land surface gradients and weather system.

RegCM4 is interactively coupled with a dust scheme, which was implemented by Zakey et al. (2006). RegCM4 coupled with dust has been used in various studies (Konare et al., 2008; Solmon et al., 2008; Cavazos et al., 2009; Malavelle et al., 2011; Ji et al., 2015; Komkoua Mbienda et al., 2017). The dust model uses four dust bins (diameters: 0.1–1, 1–2.5, 2.5–5, 5–20 μm) that are coupled to the radiative transfer scheme both in the shortwave (SW) and long wave (LW) part of the spectrum (Solmon et al., 2008).

2.2. Experiment design

For the purpose of investigating the effect of dust on WAM circulation dynamics, two sets of experiments were performed over the West African domain (see Figure 1) one without the dust (referred to hereafter as CTRL) and other with the dust (referred to hereafter as DUST). The domain (Figure 1) is centred on 15°N and 3°E with 295×197 grid points with a horizontal grid spacing of 30 km and 18 sigma vertical levels. Both experiments covered a period of 7 years, spanning from January 2007 to December 2013. For forcing data, the prescribed sea surface temperature (SST) are from the National Oceanic and Atmospheric Administration Optimum Interpolation weekly 1 °x1° grid dataset (Reynolds et al., 2002), while the atmospheric initial conditions and 6-h lateral boundary conditions (LBCs) necessary to run RegCM4 are from the European Center for Medium range Weather Forecast (ECMWF) reanalysis ERA-Interim (Dee et al., 2011), available at the horizontal resolution of 1.5° over 32 pressure levels. Some basic assessments were carried out for the whole monsoon season (June–July–August–September; JJAS). Simulated precipitation from the CTRL experiment is compared against observation datasets from the Climatic Research Unit (CRU TS 3.2.1) of the University of East Anglia (Harris et al., 2014), the CMAP [CPC Merged Analysis of Precipitation; (Xie and Arkin, 1997)] and the Tropical Rainfall Measuring Mission (TRMM; (Huffman et al., 2007)], while near surface temperature is evaluated against the station-based observation from CRU.

2.3. Study domain

Figure 1(a) shows the West Africa study domain (12°S–39°N and 28°W–44°E) for dust impact on climate analysis. This domain covers the major sources in northern Africa, Guinean Gulf in south and a part of the Atlantic Ocean. Also various AERosol Robotic NETwork (AERONET) stations used for model validation are indicated, and the stations coordinates are summarized in Table 1. The climate of the region is governed by meridional movement of the Inter-Tropical Discontinuity (ITD) or Inter-Tropical Convergence Zone (ITCZ).

2.4. Data

2.4.1. Multi-angle imaging spectro radiometer (MISR)

MISR on the Earth Observation Science (EOS) Terra platform has been operational since late February 2000. The
Figure 1. (a) Study area used for dust simulations and AERONET observation sites. (b) Mean JJAS surface dust concentration in μg/kg showing the active sources in northern Africa during 2008–2013. [Colour figure can be viewed at wileyonlinelibrary.com].

Table 1. Observation sites coordinates used in the study.

| Observation sites        | Latitude | Longitude |
|--------------------------|----------|-----------|
| Agoufou                  | 15.21°N  | 1.29°W    |
| Banizoumbou              | 13.45°N  | 2.39°E    |
| Cape Verde Islands       | 16.45°N  | 22.57°W   |
| Dakar                    | 14.42°N  | 17.29°W   |
| Ilorin                   | 8.19°N   | 4.20°W    |
| Ouagadougou              | 12.22°N  | 1.31°W    |

2.4.2. AERosol Robotic NETwork (AERONET)

AERONET is an ensemble network of Cimel Sunphotometers. This observation network of instruments provides aerosols seasonal cycle and are widely used for validation of aerosols modelling studies and satellite observations because the measurement characteristics are well understood and documented (Dubovik et al., 2000). The direct solar radiation measurements are made every 15 min in eight spectral channels at 340, 380, 440, 500, 675, 870, 940 and 1020 nm (nominal wavelengths). The Cimel Sunphotometer is a solar powered, hardy, robotically pointed sun and sky spectral radiometer. AERONET provides a long term, continuous and public accessible data in several stations widely distributed across the world. The dataset contains AOD, microphysical and radiative properties for aerosols characterization, validation of satellite observations and other aerosols databases synergy. Three qualities of AOD data are available which are level 1.0 (unscreened data), level 1.5 (cloud-screened

instrument observes the earth’s surface using nine different view zenith angles, ranging from 70° both in forward and aftward direction along the spacecraft track, in four spectral bands (446, 558, 672 and 866 nm) and with a cross track ground spatial resolution of 275 m–1.1 km and a swath width of 400 km. Monthly observation data from Terra MISR at the spatial resolution of 0.5° × 0.5°, were extracted over the AERONET stations. These datasets are available at http://giovanni.gsfc.nasa.gov/aerostat/.
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Figure 2. JJAS precipitation comparison between (a) RegCM4, (b) CRU, (c) TRMM and (d) CMAP and the precipitation biases (e) RegCM4-CRU, (f) RegCM4-TRMM and (g) RegCM4-CMAP between 2008–2013. [Colour figure can be viewed at wileyonlinelibrary.com].

3. Results and discussion

3.1. Model assessment

Figure 1(b) displays the simulated dust concentration highlighting the active dust sources over North Africa. DUST simulation reproduces faithfully Bodélé, the main dust source during boreal summer. RegCM4 model’s ability to reproduce WAM precipitations during JJAS were assessed (Figure 2). RegCM4 simulated rainfall mean between 2008 and 2013 was compared to CRU, CMAP and TRMM rainfall observations for the same period. It is seen that RegCM4 reproduced quite well the rainfall pattern and magnitude. Despite a good spatial rainfall pattern over the study area, the RegCM4 model mostly overestimated the rainfall amount relative to the observations within the study area were used for monthly mean AOD validation.

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2.4.3. MODerate resolution Imaging Spectroradiometer (MODIS)

MODIS measures irradiances in 36 spectral bands from 0.4 μm–14.5 μm with spectral resolution of 250 m (bands 1–2), 500 m (bands 3–7) and 1000 m (bands 8–36) (De Meij and Lelieveld, 2011). MODIS is on board the polar Terra spacecraft and was launched at the end of 1999 but data acquisition became effective in February 2000. MODIS-Terra level 2 deep blue AOD at 550 nm over the stations within the study area were used for monthly mean AOD validation.

Also, AERONET data have been used to characterize aerosol distribution and seasonality over West Africa (Ogunjobi et al., 2012; Oluleye et al., 2012). For simulated AOD validation, the level 2.0 data across West African stations between 2008 and 2013 are used when these data are available. AERONET data are available from http://aeronet.gsfc.nasa.gov/.
Figure 3. JJAS temperature at 2m comparison between (a) RegCM4 and (b) CRU and (c) the corresponding biases over the study domain during 2008–2013. [Colour figure can be viewed at wileyonlinelibrary.com].

over the southern part of the region and underestimated over the central Africa part as shown by the systematic biases (Figures 2(e)–(g)). The temperature pattern and magnitude is well captured by RegCM4 despite observed biases especially over forest regions in the central and south-western Africa (Figure 3). Overall, RegCM4 is capable of capturing the basic spatial distribution of precipitation and temperature over West Africa, though some biases are still evident.

The performance of RegCM4 model to simulate dust was also investigated using AERONET ground base level 2 observations, MODIS-TERRA, and MISR satellite observations. Firstly, AOD at 500 nm time series between 2008 and 2013 are shown in Figure 4 for RegCM4, AERONET, MODIS and MISR. Results revealed that RegCM4 reproduced AOD variability, but consistently predicted values lower than what was observed from AERONET, MODIS-TERRA and MISR. These lower values could be attributed to the fact that other types of aerosols such as biomass burning and other anthropogenic sources are not included in these present experiments or simulations. Figure 5 represents the Taylor diagram for January to December of RegCM4 simulated AOD for selected AERONET stations located in [Ouagadougou (Burkina Faso), Banizoumbou (Mali), Cinzana (Niger), Ilorin (Nigeria), Agoufou (Mali), Cape Verde (Cape Verde) and Dakar (Senegal)]. In Ouagadougou, Agoufou and Ilorin, the correlations are close to 0.5 with associated Root-Mean-Square Error (RMSE) of 0.125, 0.125 and 0.25, respectively. Correlations remain weak for Cinzana (about 0.3) and Banizoumbou (0.38) with RMSE of 0.17 and 0.18, respectively. However, better correlations of 0.65 and 0.75 with lower RMSE of 0.08 and 0.075 were found for Dakar and Cape Verde respectively. This suggests that the model performs well in reproducing dust outflow over tropical Atlantic Ocean. This is in agreement with studies which suggested that models were able to better reproduce transatlantic dust transport and perform better during boreal summer (Huneeus et al., 2011; Kim et al., 2014). In general for Western Africa, the level agreement between RegCM4 and AERONET stations observation ranges between 20 and 70% at most locations despite differences in spatial and temporal sampling. The performance of RegCM4 in this study is above that of GCM used in Aerosol Comparisons between Observations and Models (AeroCom) project where range of performance estimated is between 20 and 40% when compared to AERONET observations over West Africa (Huneeus et al., 2011).

The spatial distribution of the JJAS zonal wind at 700 hPa averaged over the period 2008–2013 obtained from CTRL (no dust) and DUST simulations are presented in Figures 6(a) and (b), while the mean JJAS dust AOD and its standard variation are respectively displayed in Figures 6(c) and (d). The appearance of AEJ over Africa during the boreal summer is as a result of a strong south to north thermal gradient near the surface and a transverse
circulation controlled by the Saharan heat low (Burpee, 1972). It can thus be considered as a dynamical signal of land surface conditions. Both experiments show the core of the AEJ, which corresponds to the maximum wind speed (~10 ms⁻¹), around 15°N. All RegCM4 simulations capture reasonably well the main features (location, intensity) of the AEJ, which agrees with previous studies using either reanalysis or climate models (Kiladis et al., 2006; Sylla et al., 2011; Diallo et al., 2014). However, there are slight differences between the RegCM4 simulations (CTRL vs. DUST). For instance, result of this study clearly shows a strengthening of the AEJ off the coast in the eastern Atlantic, especially between 10° and 16°N when dust is taken into account (Figure 6(b)). Such strengthening of the AEJ core by dust has also been pointed out in previous studies with early version of RegCM, namely

Figure 4. Simulated and observed MISR, MODIS and AERONET AOD timeseries between 2008 and 2013 in some West African AERONET stations. (a) Ouagadougou (Burkina Faso); (b) Banizoumbou (Niger); (c) Cinzana (Niger); (d) Ilorin (Nigeria); (e) Agoufou (Mali); (f) Cape Verde (Cape Verde) and (g) Dakar (Senegal). [Colour figure can be viewed at wileyonlinelibrary.com].

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Figure 5. Comparison of simulated and observed MISR, MODIS and AERONET AOD in some West African AERONET stations. (a) Ouagadougou (Burkina Faso); (b) Banizoumbou (Niger); (c) Cinzana (Niger); (d) Ilorin (Nigeria); (e) Agoufou (Mali); (f) Cape Verde (Cape Verde) and (g) Dakar (Senegal). [Colour figure can be viewed at wileyonlinelibrary.com].

RegCM3 by Konare et al. (2008) as well as (Solmon et al., 2012).

Dust AOD extend westward during JJAS with maximum around the AEJ location, which is associated with a high standard deviation over the western part from Mauritania extending toward Atlantic Ocean (Figures 6(c) and (d)) and the Bodélé depression. The higher standard deviation over the western part may be explained by the important variability in both western sources activity and dust transportation. Similar results have been found by Mahowald and Kiehl (2003) which suggested that interannual variability in transport is larger than interannual variability in the sources activity in controlling dust concentrations.

3.2. Dust impacts

Figures 7(a) and (b) show the vertical cross section of the mean JJAS zonal wind for the period 2008–2013 averaged between 5° and 35°W for both CTRL and DUST experiments. The corresponding vertical profile of the temperature difference between DUST and CTRL averaged over the latitude (5°W and 35°E) and longitude (5°S–30°N) are presented in Figures 7(c) and (d). Both experiments illustrate the main WAM dynamical
features associated with Sahel precipitations for the summer season. Indeed, Figures 7(a) and (b) exhibit a stratified structure of atmospheric circulation surrounding the monsoon flow (0°–15°N) and Harmattan (above 18°N) in the low-level of atmosphere between the surface and 850 hPa. The AEJ is located in the mid-level altitude around 700 hPa centred at 12°N and the Tropical Easterly Jet (TEJ) in the upper troposphere around 200 hPa with core of maximum speed at 10°N. The AEJ appears over Africa during boreal summer due to the strong meridional surface moisture and temperature gradients between the hot Sahara and the Atlantic Ocean, and maintained by the juxtaposition of moist convection to the south and dry convection to the north (Cook, 1999; Thorncroft and Blackburn, 1999). Overall, for both experiments, the WAM dynamical features are well represented by RegCM4. However, some differences appear between the control and the dust experiments. Even though AEJ speed remains similar in both experiments, its spatial extent sustains some changes in the dust experiment. Dust induces a western extension of the AEJ core over the Atlantic Ocean associated to its southern shift. These changes in the AEJ core location is associated with a southern shift of monsoon flow front located at 16°N in the control experiment and 15°N in the dust experiment. Moreover, we noted that dust contributed to a decrease of monsoon flow of about 0.5 m s⁻¹ between 5° and 10°N while Harmattan fluxes are shifted southward which is in line with the southward location of the Intertropical front. The shift of the AEJ core southward in the dust experiment can be explained by dust cooling effect in the lower layers of atmosphere (Figures 7(c) and (d)) which in turn contributed to a reduction of the surface temperature gradient which related to a northward shift of AEJ and its strengthening (Jenkins et al., 2005; Steiner et al., 2009; Sylla et al., 2013). The contribution of dust to dryer conditions over Sahel is related to the southward shift of AEJ in addition to the weaker TEJ and monsoon flux. These findings agree with previous work (Jenkins et al., 2005; Diallo et al., 2013) concluding that the AEJ has a more equatorward position during dry years, when the TEJ is weaker than normal in both observations (Grist and Nicholson, 2001) and climate models (Skinner and Diffenbaugh, 2014; Diallo et al., 2016). Therefore Figures 8(a) and (b) show the impact of dust on JJAS precipitation during 2008–2013. A slight increment in precipitation (Figures 8(b)) about 0.3 mm/day was observed between 5° and 10°N, while a decrease of about 0.5 mm day⁻¹ occurred between 10° and 15°N (Sahel area). This is in line with the WAM characteristics changes discussed earlier (Figure 7). In all, the dust released is increased during boreal summer, when the WAM was established over West African region inducing dry conditions over Sahelian band and wetter conditions on the coastal areas.

We further investigate the relation between the portion of Saharan Air Layer over Ocean (OSAL) located at 10°–30° W, 10°–20°N and the simulated temperatures.
Figure 7. Vertical cross section of zonal wind during boreal summer (June–July–August–September, JJAS) averaged between 5°W and 35°E for the 2008–2013 period obtained from (a) the control and (b) DUST. Vertical cross section of temperature change induced by dust and averaged (c) between 35°W and 35°E and (d) between 5°S and 30°N. [Colour figure can be viewed at wileyonlinelibrary.com].

Figure 9 shows a horizontal correlation between daily AOD in the OSAL and daily air temperature at 850 hPa during JJAS for 2008–2013. Correlation patterns show a dipole formed by positive and negative correlation values. Maximum positive correlation of 0.5 between temperature at 850 hPa and AOD in OSAL is found over the north-eastern part of Atlantic Ocean, in particular between 18° and 25°W and 20° and 25°N. Conversely, negative correlation is located over land with a maximum over the coastal regions. The maximum temperature at this atmosphere layer reaches 298 K and is found over the OSAL, while lowest temperatures (≈288 K) are found over the land near to the coast. This suggests that atmosphere layers around OSAL remains warmer than the surrounding environment due to the presence of dust underlying the dust direct properties. This is due to the fact that as more dust particles are loading in OSAL, temperature will increase as a result of the presences of dust plume layer over eastern Atlantic. Thus, the strengthening of dust aerosols in OSAL is in turn associated with warming over ocean and cooling over the continent. This feature of dust layer within atmospheric layers is well reproduced by RegCM4 in the present experiment, although RegCM4 used a prescribed SST. A similar finding has been pointed out by Hosseinpour and Wilcox (2014) who used satellite data from MODIS AOD and reanalysis from Modern-Era Retrospective Analysis for Research and Application (MERRA).
Figure 8. (a) Dust impact on JJAS precipitations during 2008–2013. (b) JJAS precipitations reduction due to dust average between 15°W and 15°E during 2008–2013. [Colour figure can be viewed at wileyonlinelibrary.com].

Figure 9. Horizontal correlation between AOD in OSAL domain and temperature at 850 hPa. Contour lines show air temperature at 850 hPa. [Colour figure can be viewed at wileyonlinelibrary.com].

Figure 10 shows both meridional and zonal vertical profiles of correlations between OSAL and air temperature at different levels of atmosphere. Negative correlations are observed over the land (0°–15°N) from the surface to the middle altitude where lowest correlation was observed. Therefore, between 20° and 25°N, correlations are positive from the surface to higher levels of atmosphere. Maximum correlations are found in the middle and higher altitudes around 100 hPa. The meridional profile highlights the existence of correlations dipole between the land and Atlantic Ocean south to the OSAL and land located north to the OSAL. Vertical zonal cross section shows a positive correlation from 18° to 40°W (over Atlantic Ocean) with a maximum between 850 and 700 hPa and negative correlation from 630 to 400 hPa. The negative correlations remained weak and are observed towards the land. This correlation patterns suggest that the OSAL may modulate Atlantic Ocean warming while contributing to the cooling of the African continent. This warming of the ocean may influence hurricanes and cyclones genesis over western coasts of West Africa, known to be linked to African Easterly Waves (Diedhiou et al., 1999; Skinner and Diffenbaugh, 2014). It has been shown that AEWs maximum temperatures anomalies located near to the coasts, occur between 950 hPa and 750 hPa (Kiladis et al., 2006; Hosseinpour and Wilcox, 2014). Increasing of AOD in OSAL is associated to negative anomalies of air temperature above AEJ mean level position between 300 and 600 hPa and positive anomalies below the jet. The same structure has been underlined by Kiladis et al. (2006), who found that AEWs propagation is associated with warm anomalies below AEJ and cold anomalies above AEJ.

Figure 11 shows the vertical profile of correlation (shaded) between daily AOD in the OSAL domain and...
Figure 10. Vertical cross section of correlation between RegCM4 AOD in OSAL and temperature profile for JJAS during 2008–2013. (a) averaged correlation between 5°W and 35°E; (b) averaged correlation between 5°S and 30°N. [Colour figure can be viewed at wileyonlinelibrary.com].

Figure 11. Vertical cross section correlations between RegCM4 AOD in OSAL domain and anomalies of wind speed (m s\(^{-1}\)) for JJAS during 2008–2013. Contour lines represent mean wind speed (m s\(^{-1}\)). (a) Averaged correlation between 5°W and 35°E; (b) averaged correlation between 5°S and 30°N. [Colour figure can be viewed at wileyonlinelibrary.com].

daily JJAS wind anomalies superimposed to the mean wind speed (contours) averaged over the 2008–2013 periods. Meridional profile results show negative correlation values between 5° and 17°N and positive values between 20° and 25°N. Zonal profile reveals that correlations found between wind anomalies are positive from 20°W up to 60°W with a maximum correlation near AEJ (700 hPa). Moreover, there are negative correlations between wind anomalies and AOD in OSAL when moving towards the West African coast. These results suggest that dust loading in OSAL is associated with positive wind anomalies in middle altitudes within the AEJ region and over ocean while weakening the surface wind over the land.

Figures 12(a)–(c) present the temporal correlation between daily dust AOD for the entire domain and wind at different levels (950, 700 and 500 hPa, respectively). It can be observed that dust loading in the West African domain during JJAS contributes to a weakening of both wind speed in lower atmospheric layers as well as vertical motion in mid atmospheric layers. These thus lead to a decrease of
Figure 12. Horizontal correlations between daily AOD of the simulation domain and daily Wind at (a) 950 hPa, (b) 700 hPa and (c) 500 hPa. [Colour figure can be viewed at wileyonlinelibrary.com].
the inland monsoon flow penetration, which in turn may likely explain the dryness characteristic associated with dust loading during the WAM season, consistent with the finding of Konare et al. (2008); Camara et al. (2010); Touré et al. (2012); Solmon et al. (2012). Conversely, for the low level, at 700 and 500 hPa, a positive correlation was found between dust AOD and the wind. This indicates that dust loading in the atmosphere is greatly influenced by an increase in the wind speed over the atmospheric mid-levels surrounding the AEJ location, leading to a strengthening of the AEJ as discussed in Figure 6(b), consequently resulting to a weakening of the ITCZ. Overall, the presence of dust induces a weakening of the convection over the Sahel, which in turn enhance sinking motion.

4. Summary and conclusions

Mineral dust particles outbreak during JIAS in West African atmosphere may interact with the main WAM circulation features, which in turn could induce changes in the key features. This study investigated the relation between the Saharan Air Layer located above Atlantic Ocean and WAM features such as monsoon flow, AEJ and TEJ over a West Africa domain using the recent version of the Abdus Salam International Centre for Theoretical Physics RCM, namely RegCM4. To assess dust induced changes on WAM, two set of simulation experiments with and without dust scheme were performed between 2007 and 2013. Both simulations were run using LBCs from ERA-Interim reanalysis with a horizontal grid spacing of 30 km.

Our results show that the RegCM4 in addition to representing realistically dust emission over the West African region is able to capture well their interaction with WAM system during JIAS. Dust load into atmosphere impacts both wind and temperature at different levels resulting in the observed changes in WAM system during JIAS. Moreover, this work shows that dust induces westward shift of the AEJ core over tropical Atlantic Ocean. This shift is associated with slight strengthening of AEJ and weakening of TEJ and monsoon penetration over land associated with a surface cooling effect. In addition, the correlations values observed between AOD in OSAL and wind suggests an existence of a relation between dust and WAM features, which are well reproduced by RegCM4. Dust role in triggering mesoscale features and rainfall efficiency over West Africa need more investigations, since mesoscale convective system (MCS) contribute to more than 80% of the WAM summer rainfall.

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