TIME SERIES ANALYSIS OF AERSOL OPTICAL DEPTH OVER THE ARABIAN PENINSULA FROM MODIS DATA 2003-2018

Amna Alnaqbi (1), Abdelgadir Abuelgasim (1)

[1] National Space Science and Technology Center, Department of Geography and Urban Planning, College of Humanities and Social Sciences, United Arab Emirates University, Al Ain 15551, UAE

Email: a.abuelgasim@uaeu.ac.ae; 201314605@uaeu.ac.ae;

Abstract: This research provides a comprehensive time series analysis of the spatial and temporal variability of aerosol optical depth (AOD) over the Arabian Peninsula. The Arabian Peninsula is one of the driest places on earth similar to the Sahara desert in north Africa. It is home of two large extended desert regions, primarily the Empty Quarter and An Nufud desert connected by the Ad Dahna desert which combine to create one of the massive desert regions in the world stretching from Yemen in the south to Iraq in the north and from the west coast of Saudi Arabia to Oman. It is one of the major atmospheric dust sources in the world. The atmospheric dust emitted by the vast deserts in this area is transported locally and regionally and it is the primary major contributor to the overall aerosol optical depth in this area. Hence, studying atmospheric dust transport and its variability in this region is of particular importance as transport of dust aerosols affects human health, climate, oceanic conditions, water quality, and marine life in diverse ways.

There is a significant spatio-temporal variability of AOD in this area. This variability is controlled by a series of factors such as land cover, wind stress, seasonal climatology, major hydrocarbon industry, other industries and urban cities. Time series analysis of AOD product from the Moderate Resolution Imaging Spectroradiometer (MODIS) helps in the identification of the seasonal and inter-annual variability as well as the spatial distribution of AOD over the study area. The preliminary findings of the time series analysis show a distinctive variability that is found to be strongly related to land cover changes and seasonal climatology. The time series analysis land cover changes in the last two decades have significantly altered the land scape in the area leading to further urbanization and hence reducing the overall desert area and the available desert space and dust sources. The findings such that there is significant rise of AOD during the summer period due to increased wind speed resulting in scattered events of small to large scale haboobs within the study area, high temperatures and increased humidity. The increased humidity levels are due to increased temperatures in the summer season leading to significant evaporation from the neighbouring water bodies (mainly the Arabian Gulf, the Red Sea and the Sea of Oman) leading to significant increase in water vapour levels in the atmosphere further increasing the overall AOD. The inter-annual variability of AOD over the study area is found not to be showing significant differences but those related to sporadic dust storm events occurring in particular years.

Keywords: Aerosol optical depth, dust storms, haboobs, Arabian Peninsula

1. INTRODUCTION

Natural and anthropogenic aerosols over the Arabian Peninsula (AP) play a major role in regional and global climate change, influencing radiation budget, and affecting regional hydrological cycle. The interactions between atmospheric aerosols and solar radiation via the scattering and absorption processes significantly affect the Earth's radiative budget and introduce great uncertainties in global climate models (Ackerman et al., 2000). Moreover, high concentrations of aerosols at local scale due to natural or anthropogenic activities have adverse effects on human health including cancers, pulmonary inflammation and cardiopulmonary mortality (Atkinson et al., 2001; Pope et al., 2006). Aerosol optical depth is the degree to which aerosols prevent the transmission of light" in the atmosphere. It is a dimensionless quantity with extremely lower values referring to clear skies with maximum visibility and higher values indicating the presence of significant amounts of aerosols in the atmosphere that can significantly affect visibility. The presence of aerosols in the atmosphere have a huge impact on the earth radiation budget, climate and local weather. Depending upon their size, type, and location, aerosols can either cool the surface, or warm it. They can help clouds to form, or they can inhibit cloud formation.

Studying the formation, and spatiotemporal distribution of aerosols in the atmosphere is a fundamental part of atmospheric science. There are many applications where AOD data is important, such as air quality, health and environment, atmospheric correction of satellite data, earth radiation budget and climate change. Air quality monitoring is among the important applications of AOD data. Analysis of AOD data can help provide quantitative measures of particulate matter PM10 and PM2.5 for assessing health risk factors (Omari, et. Al. 2019). This particularly important in the UAE as air pollution is among the rising health hazards in the UAE in the past decade. The sources of air pollutants can be both natural and anthropogenic in the UAE, furthermore, transboundary transport pollutants add an additional source. Advancement in satellite remote-sensing techniques has opened new corridors for the monitoring and mapping of AOD over large regions. Currently, there are several satellites in orbit that have instruments suited for AOD estimation. This research attempts to provide a time series analysis of AOD over the Arabian Peninsula using MODIS AOD product highlighting the interannual and seasonal variability of AOD over the study area.

2. STUDY AREA, DATA AND IMAGE PROCESSING

2.1 Study Area

The Arabian Peninsula is located is the western part of Asia and is bounded by many water bodies. Namely, the Arabian Gulf from the east and northeast, the Sea of Oman and Arabian Sea from the south and the Red Sea from the west (Figure 1). It is predominantly a desert surface with a large series of mountains in the south eastern part. This is mostly the part that receives significant rainfall during the year than any other area in the Peninsula.

Figure 1: Study Area Map (https://www.nationsonline.org/oneworld/map/Arabia-Map.htm)

2.2 Satellite Data

Several satellites data are currently available that provides extensive coverage spectrally and temporally over the study area. This research uses data that comes from the Moderate Resolution Imaging Spectroradiometer (MODIS) (http://modis.gsfc.nasa.gov/about/) for mapping the AOD over the study area (Remer et. al., 2003). MODIS is one of the key sensor instrument aboard the Terra and Aqua satellites collection data over the entire globe every 1-2 days (Letelier and Abbott 1996). MODIS collects spectral data over the entire globe in 36 spectral bands in the visible, near-infra-red and short wave infra-red parts of the electromagnetic spectrum. Furthermore, MODIS collects data also in the thermal portion of the spectrum. The choice of the spectral ranges of MODIS spectral data was based on the different data applications intended. An AOD product is derived on continuous basis from MODIS spectral reflectance measurements over land and oceans (Levy et. al, 2007; Levy et. al., 2015). This research study uses the monthly mean derived aerosol optical depth product from the MODIS/Terra for the period 2006-2015.

2.3 Image Processing

Global AOD products were cropped to represent the study area only (Figure 2). The average monthly mean AOD was calculated for the area covering the period 2003-2018.

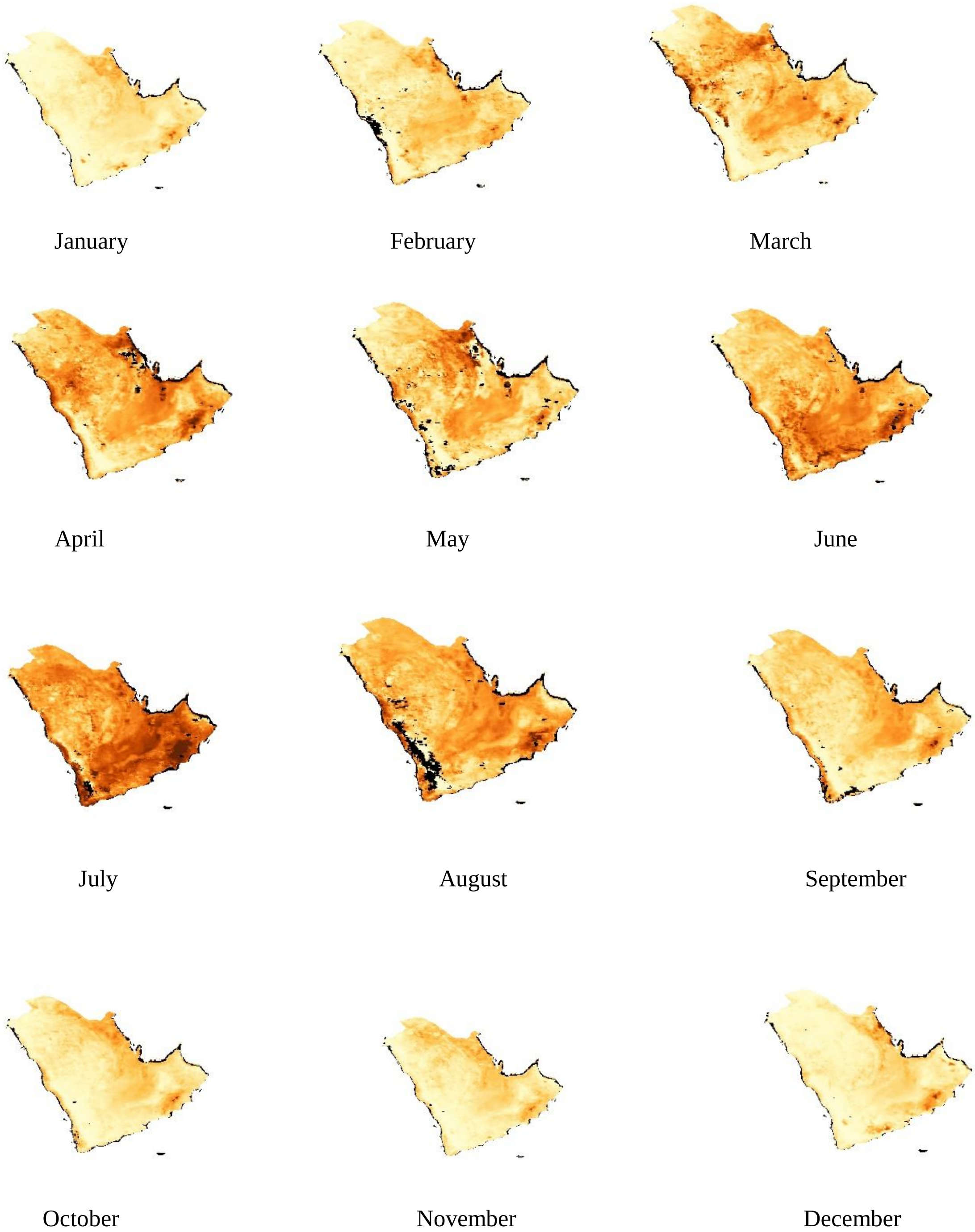

Figure 2: Monthly Average AOD Over the Arabian Peninsula 2017

3. RESULTS AND DISCUSSIONS

Figure 3 shows the temporal variability of AOD over the study area in the year 2018 (other years have been omitted for brevity).

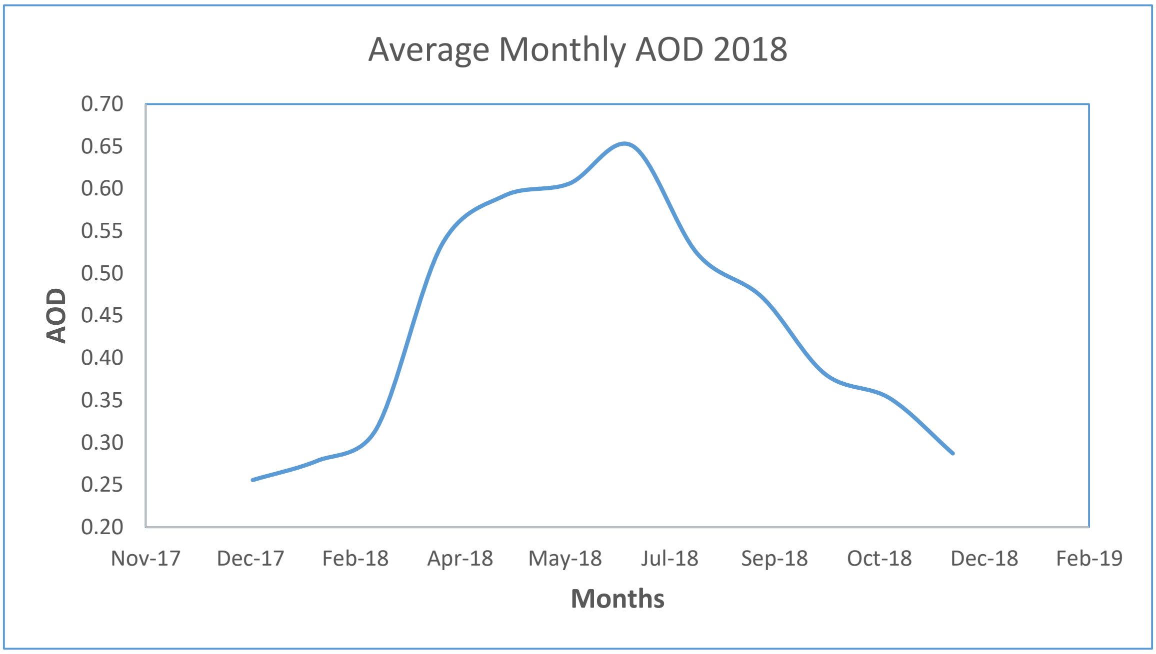

Figure 3: AOD Monthly Variability 2018

AOD within the study area is showing similar patterns observed in previous studies (Albaloushi et. al 2016). Its significantly low at the beginning of the year in January and starts to rise by late March and early April of each year. AOD continues its rise peaking during the summer time by late June and early July. This is likely associated with increased dust storms activity and a rise in water vapour within coastal areas. Dust storm activities during summer time are associated with strong wind activity leading to the rise and transport of dust within the Peninsula. This pattern is repeated annually, however. There is a growing trend while the annual AOD cycle is maintained its intensity and magnitude is annually increasing. Table show the descriptive statistics of the annual AOD. There is an increasing trend in the annual mean AOD in the study area from 2003 to 2018. This is evident in the absolute

Table 1: Descriptive Statistics of annual average AOD over the study area

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Mean	0.31	0.27	0.29	0.32	0.32	0.38	0.37	0.31
Minimum	0.09	0.17	0.17	0.20	0.18	0.17	0.18	0.17
Maximum	0.51	0.37	0.48	0.51	0.48	0.62	0.67	0.59

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Mean	0.38	0.40	0.34	0.30	0.36	0.31	0.35	0.44
Minimum	0.20	0.20	0.18	0.19	0.20	0.21	0.21	0.26
Maximum	0.68	0.59	0.55	0.45	0.70	0.45	0.60	0.65

values of the average mean, minimum and maximum AOD over the study area. This is also confirmed by figure 4 which shows the interannual variability for the period 2003-2018.

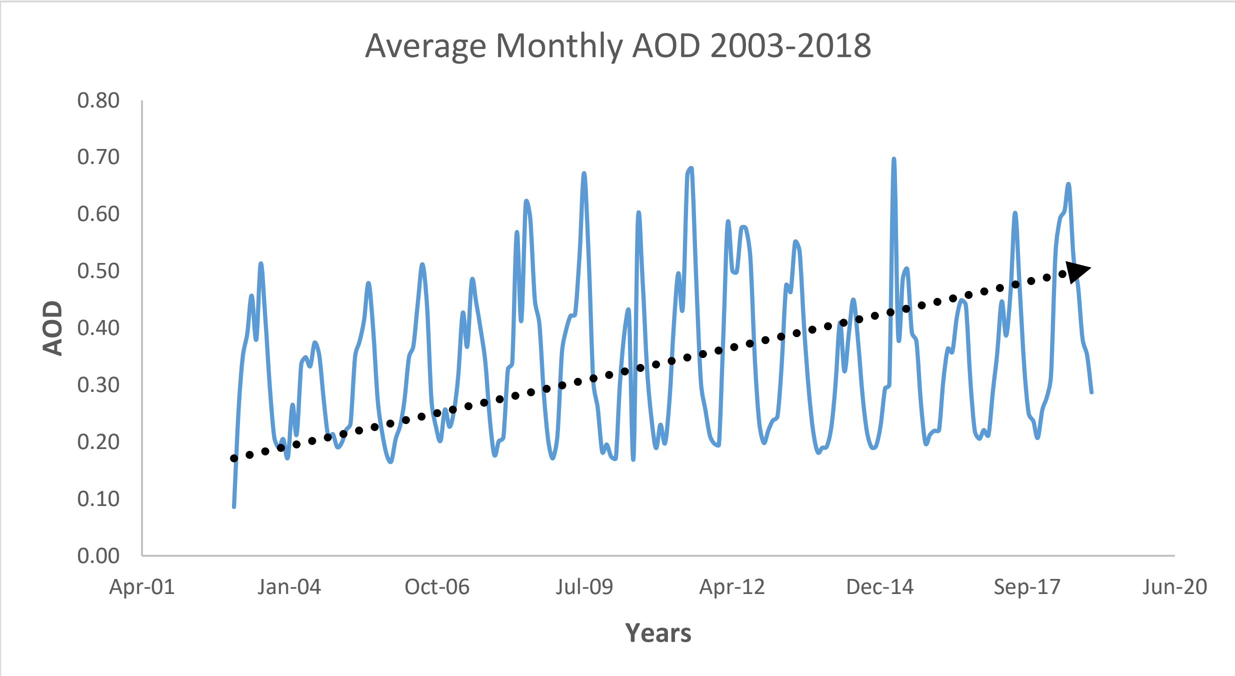

Figure 4: Interannual Variability of AOD 2003-2018

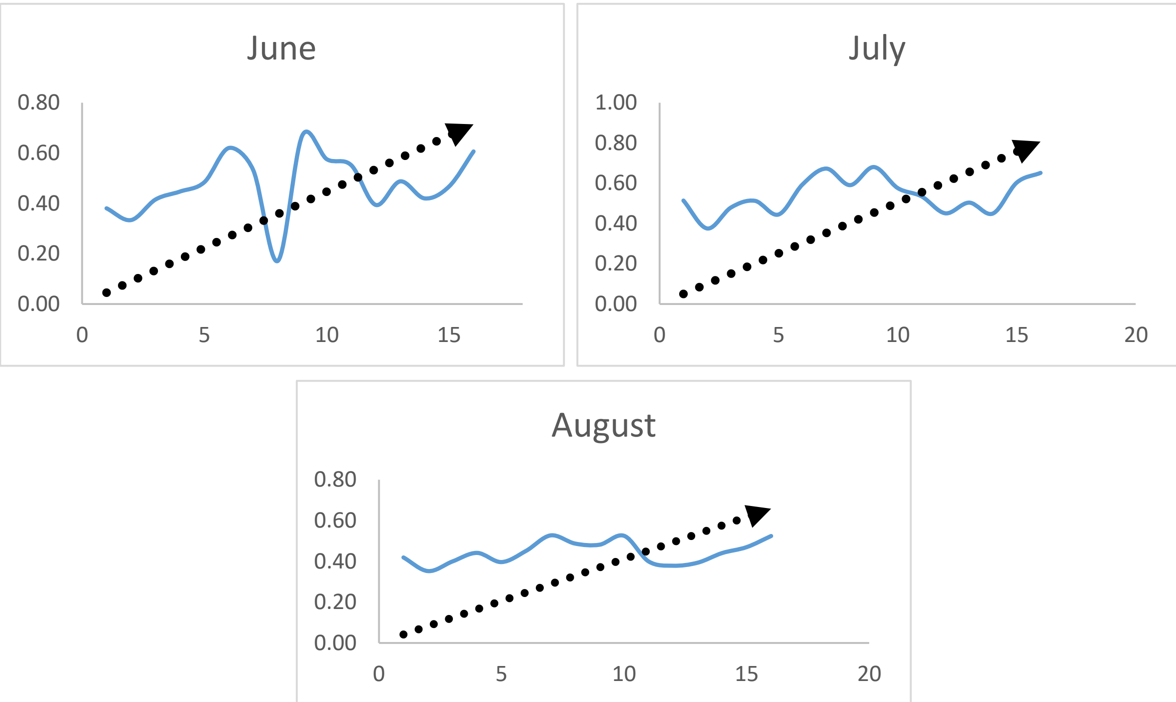

Figure 5 (a, b and c): Seasonal AOD Variability

Careful examination of figure 4 shows there is a steady increase in the average annual AOD over the study area of about 4% during the study period. This might likely be due to anthropogenic activities and land cover change within the area that occurred during 2003-2018. While the overall AOD is increasing in the study it will not be possible from figure 4 alone to identify which part of the years or seasons this increase is. Seasonal AOD variations through the study period show significant increase in AOD concentrations during the summer months of an average of 6%. Figure 5 (a, b and c) show the trend of AOD concentrations for the summer season through 2003-2018 which supports this finding that AOD has been increasing during the study period.

4. CONCLUSIONS

Satellite derived products of AOD show that the occurrence and intensity of AOD varies substantially at seasonal, annual and decadal timescales over the Arabian Peninsula. It has been observed that there was an approximate increase of 6% in AOD during the study period 2003-2018. Most of the increase is strongly related to increase in AOD during the summer months each year. This is likely due to the significant land cover changes that has occurred in the study area. It is expected that land cover change will continue due to the extensive urbanization in the region coupled with more other anthropogenic increases will lead to further increases in AOD concentrations.

5. REFERENCES

Ackerman, A.S., O.B. Toon, J.P. Taylor, D.W. Johnson, P.V. Hobbs, and R.J. Ferek, 2000: Effects of aerosols on cloud albedo: Evaluation of Twomey's parameterization of cloud susceptibility using measurements of ship tracks. *J. Atmos. Sci.*, **57**, 2684-2695, doi:10.1175/1520-0469(2000)057

Albaloushi R, Alghafri A, Ghazal S, Aljaberi A, and Abuelgasim A (2016) Investigations on the seasonal and inter-annual variations of the atmospheric aerosol optical depth in the United Arab Emirates using MODIS satellite data. 37th Asian Conference on Remote Sensing:Fostering Resilient Growth in Asia, ACRS 2016; Colombo, Sri Lanka October 16-21.

Letelier, R.M., Abbott, M.R., (1996) An analysis of chlorophyll fluorescence algorithms for the Moderate Resolution Imaging Spectrometer (MODIS) Remote Sensing of Environment 58 (2), 215-223.

Levy, R. C., L. Remer, S. Mattoo, E. Vermote, and Y. J. Kaufman, (2007). Second-generation algorithm for retrieving aerosol properties over land from MODIS spectral reflectance. J. Geophys. Res., 112, D13211, doi: 10.1029/2006JD007811.

Levy, R., Hsu, C., et al., 2015. MODIS Atmosphere L2 Aerosol Product. NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA: http://dx.doi.org/10.5067/MODIS/MOD04_L2.006.

Omari, K., A Abuelgasim, K Alhebsi, 2019, Aerosol optical depth retrieval over the city of Abu Dhabi, United Arab Emirates (UAE) using Landsat-8 OLI images, Atmospheric Pollution Research.

Pope, C. A. III and D. W. Dockery (2006), 'Health effects of fine particulate air pollution: lines that connect', Journal of the Air & Waste Management Association, 56 (6), 709-42.

Remer, A., L & J. Kaufman, Y & Tanre, D. (2003). The MODIS Aerosol Algorithm, Products, Validation and Applications. 62.