Original Research Article

Impacts of the Variations of Aerosols Components and Relative Humidity on the Visibility and Particles Size Distribution of the Desert Atmosphere: Validating Results Obtained from OPAC 4.0 Using MERRA-2 Model (Aangstrom Exponent and Extinction Coefficient) Data

ABSTRACT

In this work, data extracted from OPAC 4.0 was compared and validated with 11years data record from MEERA-2 model (average Aangstrom Exponent and average Extinction Coefficient). The 11 years MEERA-2 model data for 10 selected deserts was extracted at an average relative humidity (RH) condition of 78%RH while OPAC considers eight different (RH) levels (00% to 99%RH). Based on the investigation, MEERA-2 model has the highest angstrom exponent (α) values, which is greater than 1 (and this signifies the dominance of fine mode particles over coarse mode particles) when compared to OPAC 4.0, except for Chalbi (0.844595516), Karoo (0.481856832) and Sahara (0.41700109) deserts respectively which is less than 1(indicating the dominance of coarse mode particles over fine mode particles). But MEERA-2 (α) is still greater than that of OPAC and this shows that, contrary to the results obtained by OPAC 4.0 models, the deserts atmosphere can be dominated by fine mode particles. The angstrom exponent (α) for OPAC 4.0 fluctuate all through the four studied components except for WASO which increases with the increase in RH and particles concentration. Based on the results of the investigation (time series analysis), it was found that the model's significance (β) level is 0, which signifies that the model is very significant. The analysis further found that, the models parameter significance (δ) are not significant for all the deserts except for Ferlo and Lompoul deserts. It was also found that, the MEERA-2 visibility (km) is higher than that of the four OPAC 4.0 components (WASO, MINN, MIAN and MICN) respectively. The investigation further revealed that the Arabian, Syrian and Patagonian deserts have the highest visibility (km) for months of January, February, June, November and December. OPAC model underestimated the visibility (km) for the studied period when compared to MEERA-2 model.

Keywords: Angstrom exponent, Extinction coefficient, Relative humidity, Visibility, Aerosols.

1.0 Introduction

Dust consists of small solid particles. Dust particles are usually in the size range from about 1 to 100 µm in diameter [1]. Dust can be either suspended within the atmosphere as aerosols, or accumulate as sediment on the surface of the Earth [2]. Due to the variety of sources that can give rise to dust, it can be composed of many different substances, both organic and inorganic. Mineral dust pollution occurs in the gaseous form as aerosols [3]. In scientific terms, an aerosol is defined as a system of particles suspended in a gaseous medium, usually air in the context of occupational hygiene, is usually air. Aerosols may exist in the following forms: airborne dusts, sprays, mists, smokes and fumes [3]–[5]. all these forms are important because they are associated with the wide range of occupational diseases. Mineral dusts are of particular interest because they are well known to be associated with classical widespread of occupational lung diseases such as the pneumoconiosis, as well as with systemic intoxications such as lead poisoning, especially at higher levels of exposure [1]. But, in the modern era, there is also an increasing interest in other dust-related diseases, such as cancer, asthma, allergic alveolitis, and irritation, as well as a whole range of non-respiratory illnesses, which may occur at much lower exposure levels [5].

World health organization (WHO) considers the impacts of air pollution as a worldwide health emergency need [6]. Natural pollutants from particulate matter is liable for an estimated 1.4% of all mortality rates around the globe [5]. It is well know that the majority part of particulate matter is mineral dust [7]. Residue from the Sahara is the biggest source of mineral dust in the atmosphere [7]–[9]. It is a wonder of interest for meteorological material science as well as for general wellbeing too, because of the potential health effect of its air dispersal and flow in the atmosphere [10], [11].

In the natural environments the changes in the microphysical and optical properties observed at a given wavelength with respect to the corresponding change in relative humidity is a signs that measuring condition have changed [3], [8]–[10]. These changes can cause unbalance in the atmosphere by causing decrease in visibility or other harmful effects to man and his environment [9]. Many of the papers published to date that provide information on health/environmental related mineral and Saharan dust research have focused on the impact of anthropogenically generated mineral or airborne dust related (such as PM generated by combustion engines) [12], while relatively little work has looked at the impact of variations of the meteorological parameters and micro physical properties of the naturally generated dust (such as all forms of dust emanating from dust storms).

Estimates of the contribution of the different source of the Saharan dust also vary by study and are more difficult to make, especially as each source area follows a distinct seasonal cycle [13]. studies addressing the problems all agree that North Africa is the main source area (over 50 %) as said by ([14] and [15]. Regions of the world in the path of dust-laden wind record increased ambient air dust concentrations that are temporally associated with deteriorations in air quality and the strong possibility of negative impacts on human health [15],[16]. Generally speaking, a distinction is made between coarse and fine mode particles [17]. Thus, coarse particles are more likely to be deposited in the bronchial passages and thereby affect respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD), and pneumonia. In contrast, fine particles seem more likely to reach the alveoli and lead to cardiovascular events [18].

In this work, average aerosol extinction coefficient and average Angstrom Exponents (α) extracted from MERRA-2 Model data (for 10 selected deserts across the world) at 550nm and an average RH of 78% from 2010 to July 2021 will be used to validate results obtained from simulations carried out using OPAC 4.0 in our previous work [9] using time series analysis.

2.0 Data and Method

2.1 MEERA-2 Model

The MERRA-2 aerosols data collection system is based on the Goddard Earth Observing System Model, Version 5 (GEOS-5) [2]. This particular model is assembled with the GOCART chemistry module which simulates (black carbon, sand dust, organic carbon, sulfate, and sea salt) aerosols type [2]. For aerosol dataset, MEERA-2 model collect aerosol data from ground-based AERONET a and space-borne aerosol products from Advanced Very High-Resolution Radiometer (AVHRR), Multi-angle Imaging Spectro Radiometer (MISR) and MODIS [2]. MERRA-2 aerosol dataset includes the five types of aerosols' optical properties, emissions, deposition, and aerosol mixing ratios, vertically [19]. For example, aerosol optical property products include aerosol extinction optical thickness at 550 nm, aerosol scattering optical thickness at 550 nm and aerosol angstrom exponent (470–870 nm) for total as well as five aerosol components [19]. The temporal and spatial resolution of the data is 0.625 degrees × 0.5 degrees, and there are three temporal resolutions: monthly, hourly and every three hours. In the vertical direction, MERRA-2 aerosol dataset is divided into 72 different layers from surface to 0.01 hPa. MERRA-2 data cover the period from 1980 to the present, and they include 21 types of products, such as atmospheric aerosols, radiation, temperature, water vapor, precipitation etc.

In this study, we use the monthly average aerosol component column concentration data product (MERRA-2_400.inst3_3d_aer***) for average angstrom exponent and average total extinction coefficient to validate the data extracted from the OPAC software package.

2.2 The OPAC Software Package

The OPAC programming software comprises of two sections, the initial segment is a dataset of microphysical properties and the subsequent optical properties of cloud and aerosols components at various wavelengths and for different relative humidity conditions [3], [8]–[10], [20], [21]. The other part is a FORTRAN program that permits the user to separate information from this dataset, to compute extra optical properties, and to ascertain optical properties of the mixtures of the stored cloud and aerosols components. The dataset gives the microphysical and optical properties for six kinds of water clouds, three ice mists, and 10 aerosols components. the data is accessible at 61 wavelengths in the range of 0.25 and 40 μm for aerosols and clouds, and at 67 wavelengths in the range of 0.28 and 40 μm for ice clouds. The information is given for each case for 1 molecule cm^{-3}which portrays the compelling properties of the combination of all particles in the size distribution. For functional use, the values must be multiplied by the total number density. On account of those aerosols components that can take up water, data for eight values of relative humidities (0%, 50%, 70%, 80%, 90%, 95%, 98%, 99%) are given [3], [8]–[10], [22]. The information is stored as ASCII files, one record for each cloud or aerosols component and for each relative humidities. The computer code executes two tasks. First, single cloud or aerosols segments can be chosen, and all or a portion of their optical properties can be extracted or determined from the dataset. Second, it is feasible to choose one of those combinations of the aerosol's components, which are proposed as default values in OPAC, or to characterize an extra mixture and to obtain its optical properties [9]. Height placement of aerosols particles is given but may likewise be changed with information given by the user. For versatility, the program is disseminated as FORTRAN source code. All mandatory input to the program must be entered as an ASCII text document [9].

2.3 Data Analysis

This work chose MERRA-2 model because one of the driving force of the GEOS DAS products has historically been temperature and Relative Humidity. But it should be noted that this work did not include temperature components, it only considered atmospheric moisture (relative humidity) part. The work extracted total extinction coefficient and total angstrom exponent data for the period of 10 years and seven months (2010-july, 2021) at 550nm wavelength. The area average time series for Arabian (19.4914° N, 47.4490° E), Ferlo (15.8797° N, 15.2502° W), Lompoul (15.4626° N, 16.6910° W), Syrian (34.3504° N, 38.6600° E), Patagonian (41.3200° S, 69.3201° W), Registan (30.4563° N, 65.4004° E), Sahara (23.4162° N, 25.6628° E), Chalbi (34.6068° N, 49.3286° E), Danakil (11.8764° N, 41.9196° E) and Karoo (32.8146° S, 22.2384° E) deserts was extracted from MEERA-2 respectively. The extracted data was then averaged. The averaged extinction coefficient data at 550nm was then used to calculate the visibility using a relation derived by [23]. The angstrom exponent was also averaged and used to perform a time series analysis on the data for eachof the deserts to observe if the model fits the observed data using angstrom exponent (α) level and seasonality effects. The visibility and angstrom exponent computations was also performed on the data extracted from OPAC 4.0 at 550nm for 8 relative humidity's levels (00% to 99%RH) as done in our previous work [9] using time series analysis. The results obtained was then compared and validated using that of MEERA-2.

3.0 RESULTS AND DISCUSSIONS

The results of the analyzed data sets extracted from MEERA-2 model and OPAC 4.0 are presented in this section.

The results obtained from the analysis of both MERRA-2 and OPAC software package is presented in this section. The obtained results from OPACs models (water soluble WASO, mineral nuclei mode MINN, mineral coarse mode MICN and mineral accumulation mode MIAN) where compared and validated with MEERA-2 model. From the five models studied, models 1 and 5 were considered because all the models change in the same pattern and shows the same mode of distribution. Table 1 below shows the result of the time series analysis for the angstrom exponent extracted from MEERA-2 model. It can be seen that the model obtained was a simple season model. This model is appropriate for series with no trend and a seasonal effect that is consistent over time. The smoothing parameters involved are level (β) and season (α) respectively. This shows that the concentration of Aerosols particles over the desert's atmosphere did not change over the years and its seasonal effect is constant throughout the study period. For the R^2 values and the stationary R^2 for all the studied Deserts atmospheres show that the model under consideration is good and better than the baseline models, hence there is an agreement between the models. It can also be said that the data fitted the models well. From the values of model's significance in table 1, it can be seen that the models are very significant for β (level). Also, it can be observed that the seasonality (δ) model's significance for all the studied deserts are not significant except for Ferlo and Lompoul deserts which are very significant. Observing the values of the model's parameters significance, it can be seen that the models for Ferlo, Lompoul, Sahara and Patagonian deserts are not significant while that of Arabian, Chalbi, Danakil, Karoo, Registan and Syrian deserts are significant and can be used to make a forecast.

Table 1 Model Statistics and Exponential Smoothing Model Parameters from the time series analysis for Angstrom exponent

S/N	Deserts	Model	Estimate	Sig.	R^2	Stationary R^2	Model Sig.
1	Arabian	β(level)	0.40000	0.00000	0.75400	0.62800	0.00600
		δ(season)	0.00002	0.99900			
2	Chalbi	β(level)	0.99900	0.00000	0.97400	0.47400	0.00000
		δ(season)	0.00000	1.00000			
3	Danakil	β(level)	0.40000	0.00000	0.66300	0.60700	0.01100
		δ(season)	0.00001	1.00000			
4	Ferlo	β(level)	0.83500	0.00000	0.87200	0.53000	0.11400
		δ(season)	0.36070	0.00000			
5	Karoo	β(level)	0.70000	0.00000	0.80500	0.57200	0.03200
		δ(season)	0.00008	0.99800			
6	Lompoul	β(level)	0.83800	0.00000	0.87400	0.53100	0.19500
		δ(season)	0.36564	0.00000			
7	Registan	β(level)	0.50000	0.00000	0.78000	0.55900	0.00000
		δ(season)	0.00009	0.99600			
8	Sahara	β(level)	0.70000	0.00000	0.84900	0.59600	0.09700
		δ(season)	0.00002	0.99900			
9	Syrian	β(level)	0.50000	0.00000	0.79600	0.50500	0.02400
		δ(season)	0.00001	1.00000			
10	patagonian	β(level)	0.60000	0.00000	0.76200	0.56800	0.23800
		δ(season)	0.00000	1.00000			

Table 2 Average Visibility (km) and Angstrom Exponent (α) for MEERA-2 at 550nm

S/N	Deserts	Average Visibility(km)	Average Anstrom Exponent (α)
1	Arabian	128.6271661	1.353648112
2	Chalbi	27.58618686	0.844595516
3	Danakil	19.46854585	1.164668588
4	Ferlo	28.11175721	1.515039642
5	Karoo	18.64908207	0.481856832

6	Lompoul	28.76357629	1.504852986
7	Patagonian	77.66958216	1.045684297
8	Registan	27.08996425	1.195060063
9	Sahara	19.04847381	0.41700109
10	Syrian	81.03731911	1.099076596

Table 2 presents the average visibility (km) and the Average angstrom exponent from MEERA-2 model. It can be seen that the Arabian, Syrian and Patagonian have the highest visibility (km) over the rest of the deserts throughout the study period. It can also be noted from the α values that all the deserts have the angstrom exponent (α) values above 1 except for Chalbi, Karoo and Sahara and this signifies that Chalbi, Karoo and Sahara deserts atmosphere is dominated by coarse mode particles with some traces of fine mode particles while Arabian, Danakil, Ferlo, Lompoul, Patagonian, Registan and Syrian deserts atmosphere is dominated by fine mode particles with some traces of coarse mode particles.

3.1 Visibility

Figures 1a to 1h present the plots of MERRA-2 model computed visibility with that of OPAC for eight RHs (00% to 99%RH). It can be observed that Arabian, Syrian and Patagonian deserts have the highest visibility in the months of January, February, June, November and December respectively. It can also be seen that Ferlo, Lompoul, Registan, Sahara, Chalbi, Danakil and karoo Deserts followed same trend with OPAC models, have almost the same visibility values except that OPAC has higher values of the visibility compared to the MEERA-2 Model for the months of May, June, July, August and sometimes September respectively. It should also be noted that five OPAC models where considered for this study but only two are presented here (models 1 and 5). Among the four OPACs studied components, water soluble (WASO), Mineral Nuclei mode (MINN) and Mineral coarse Mode (MICN) has the highest visibility values (km) while Mineral Accumulation mode (MIAN) has the least. The visibility decreases with the increase in temperature for all the four studied components.

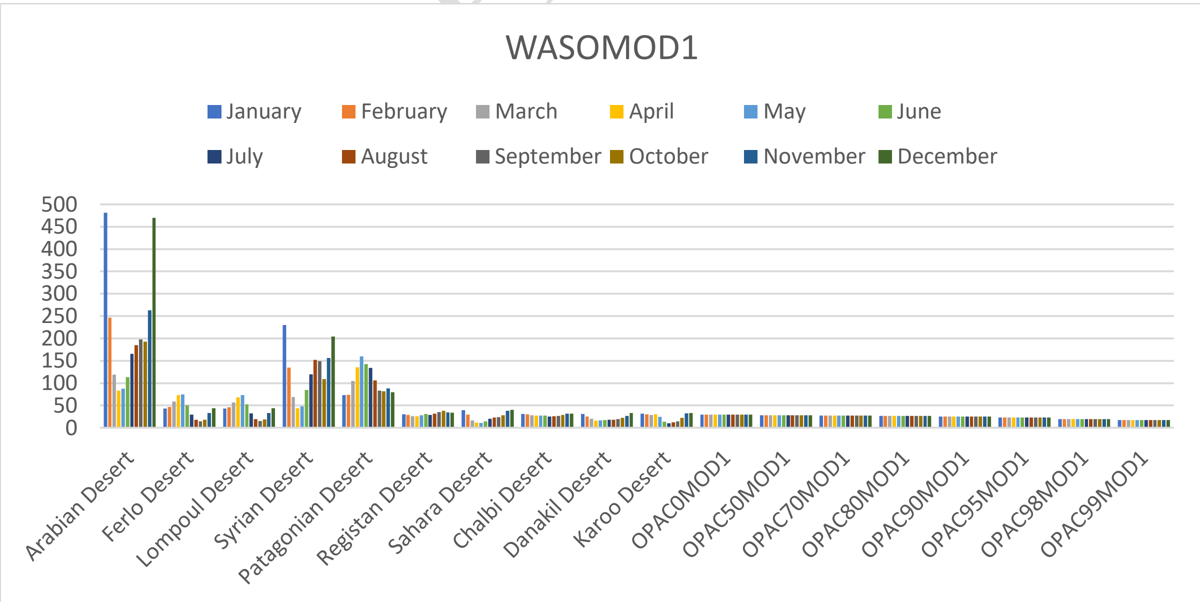

Fig. 1a Visibility plot for OPAC and MEERA-2 (WASO Model1) at 550nm

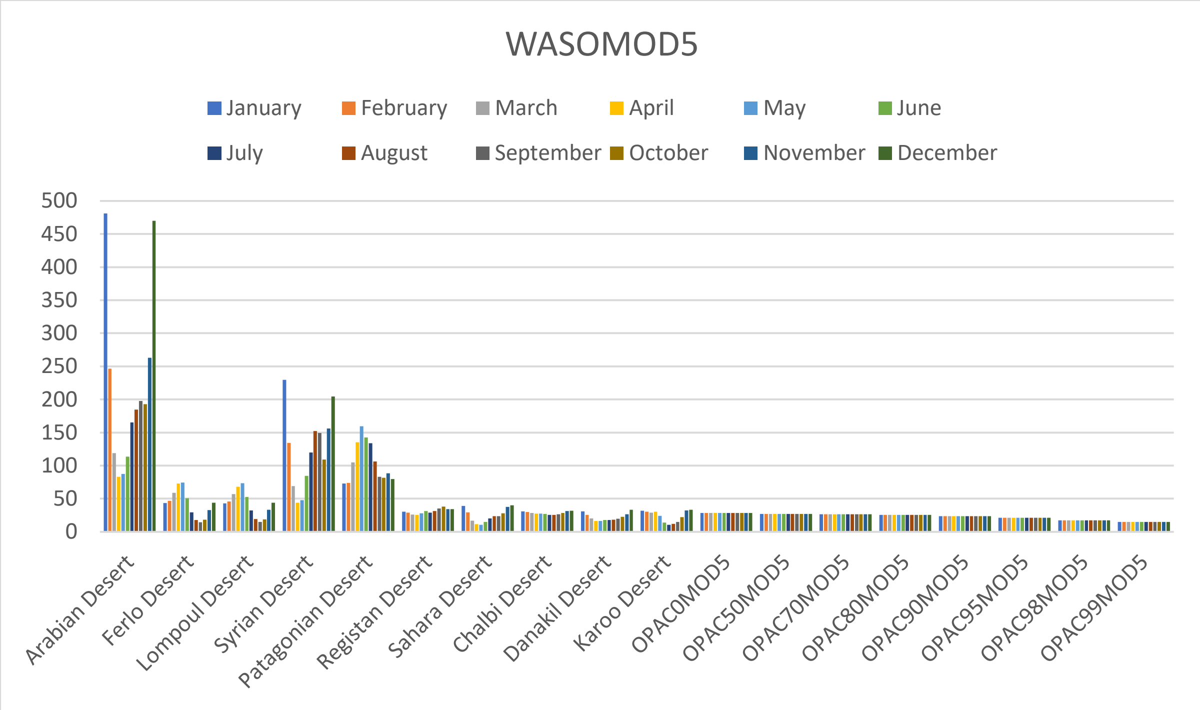

Fig.1b Visibility plot for OPAC and MEERA-2 (WASO Model5) at 550nm

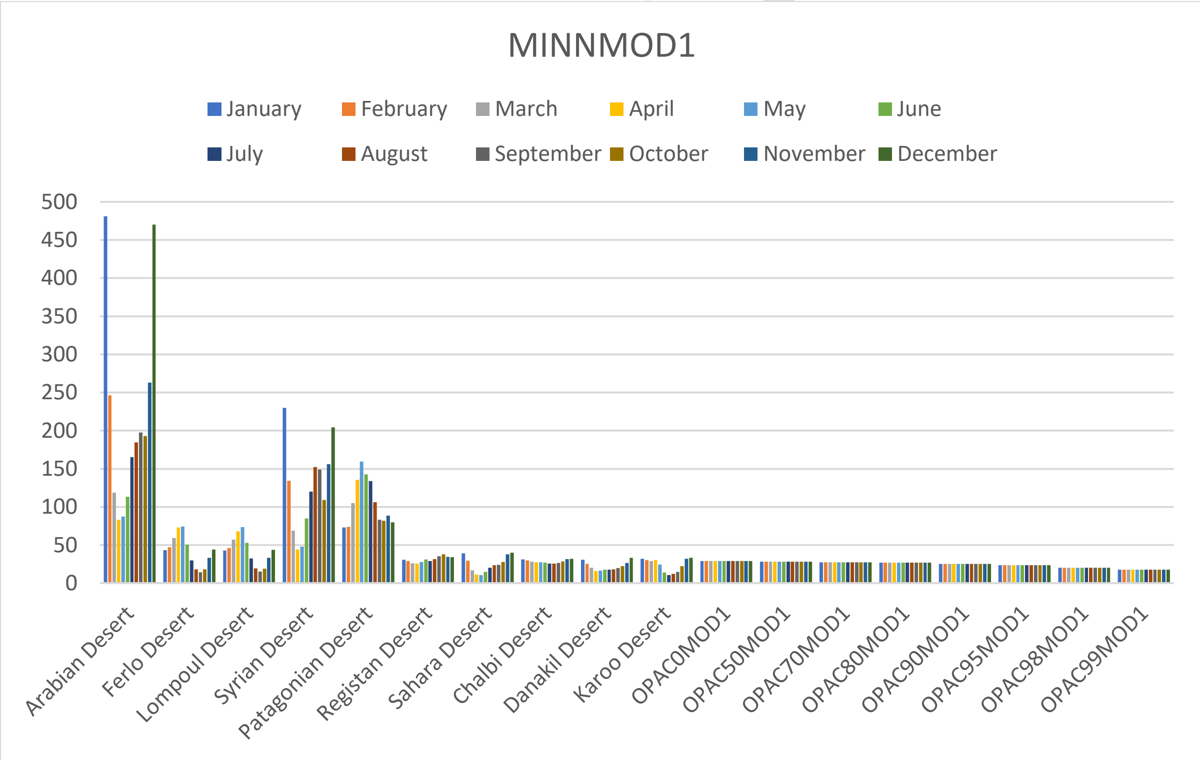

Fig. 1c Visibility plot for OPAC and MEERA-2 (MINN Model1) at 550nm

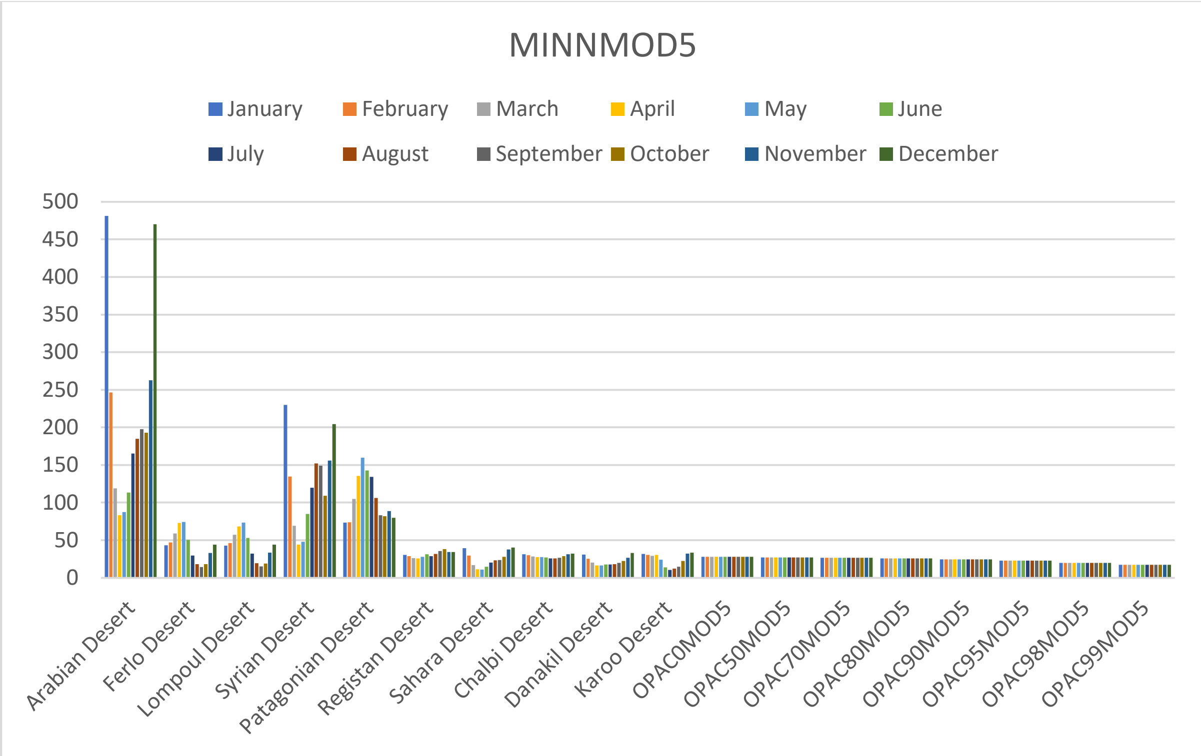

Fig. 1d Visibility plot for OPAC and MEERA-2 (MINN Model5) at 550nm

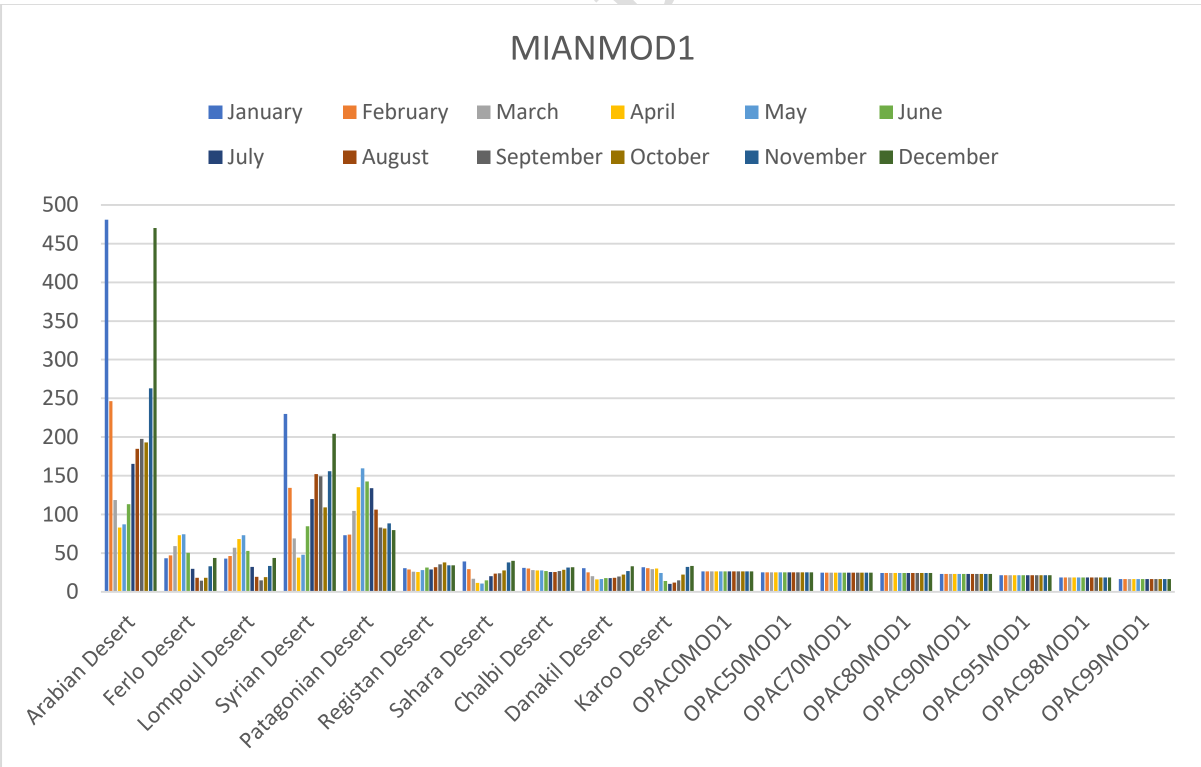

Fig. 1e Visibility plot for OPAC and MEERA-2 (MIAN Model1) at 550nm

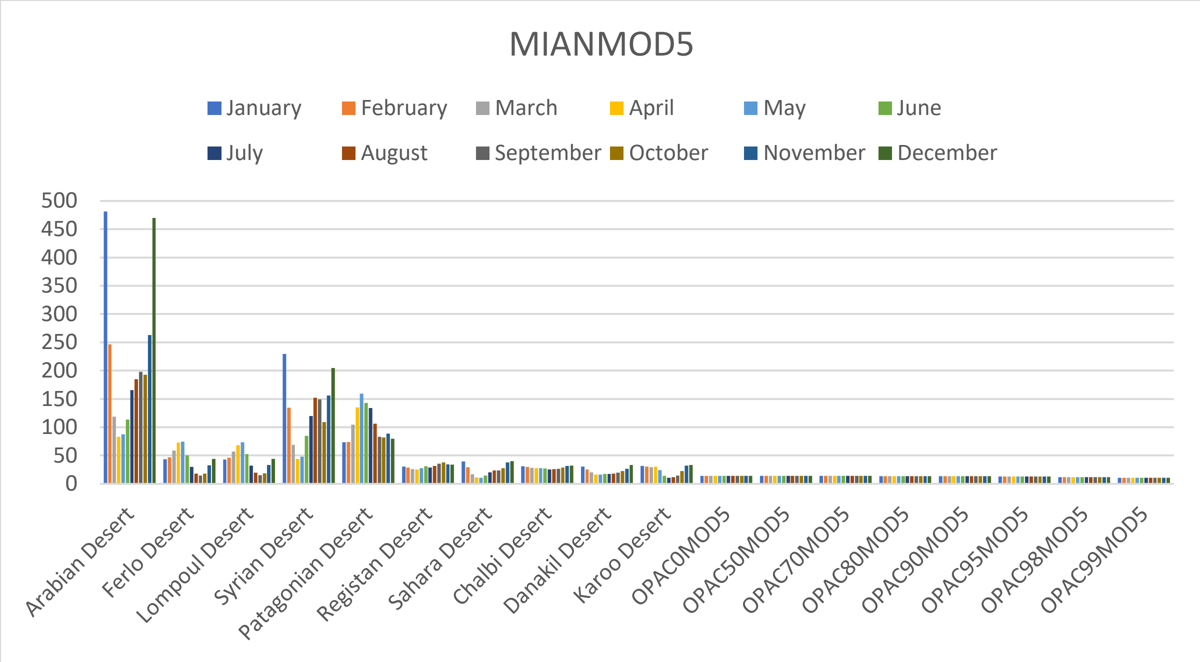

Fig. 1f Visibility plot for OPAC and MEERA-2 (Model5) at 550nm

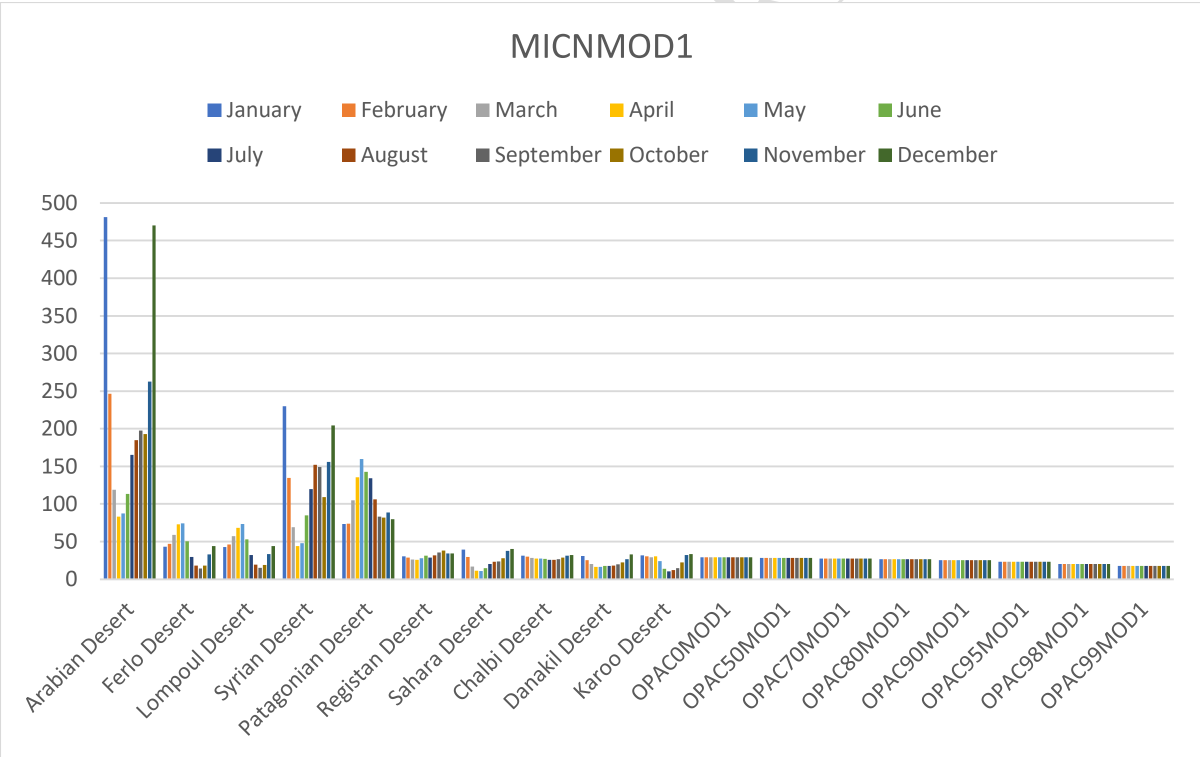

Fig. 1g Visibility plot for OPAC and MEERA-2 (MICNModel1) at 550nm

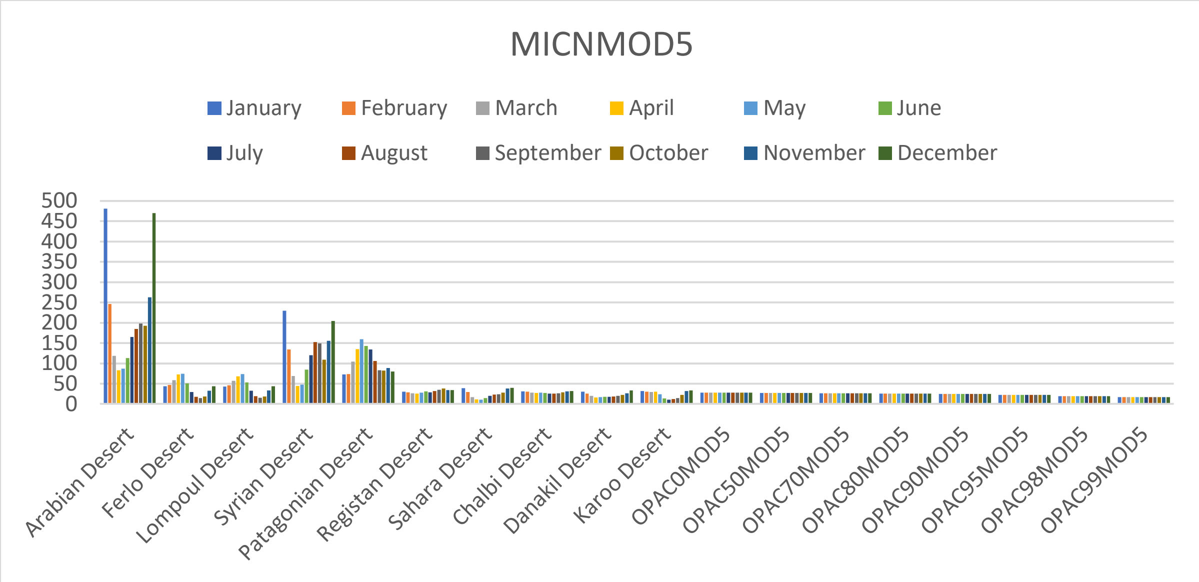

Fig. 1h Visibility plot for OPAC and MEERA-2 (Model5) at 550nm

3.2 Angstrom exponent (α) plots

Figures 2a to 2h present the comparison plots of angstrom exponent (α) for both MERRA-2 model and OPAC. It can be seen that Ferlo and Lompoul deserts has the highest α values which is greater than 1 and this signifies that Ferlo and Lompoul deserts atmosphere is dominated by fine mode particles with some few or less traces of coarse mode particles more than the rest of the studied deserts. it can also be seen that the moths of August, September and November has the highest angstrom exponent (α) values for all the study period. The angstrom exponent (α) for OPAC increases with the increase in relative humidity for all the four studied components. It should also be noted that MIAN has the least α values which signifies the dominance of coarse mode particles with little traces of fine mode particles in the case of MIAN component. In general, α values for the Deserts (MEERA-2 model) are greater than that of OPAC except for Sahara Desert (for the months of May, June, July and August) and Karoo desert (June, July, August, September, October and November).

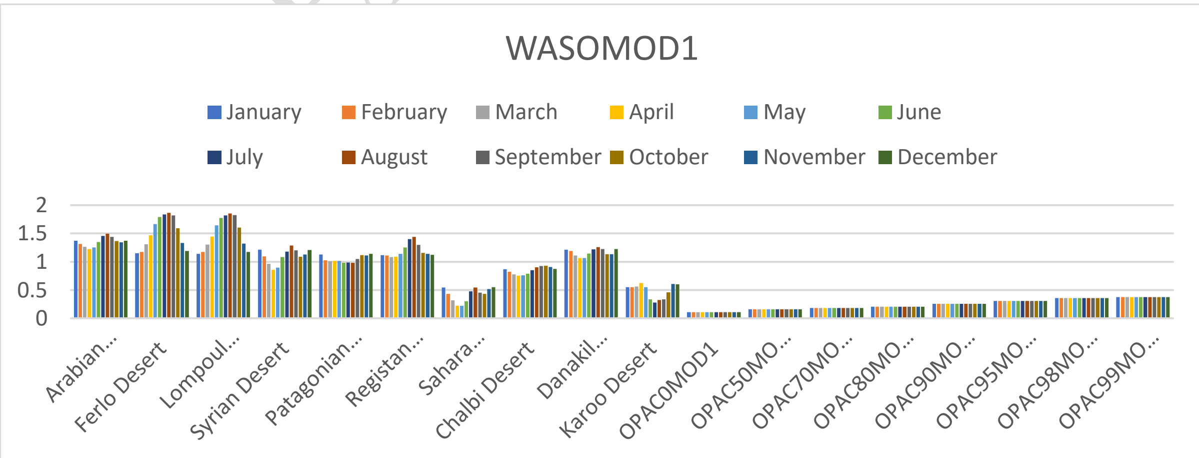

Fig. 2a Angstrom exponent α plot for OPAC and MEERA-2 (Model1) at 550nm

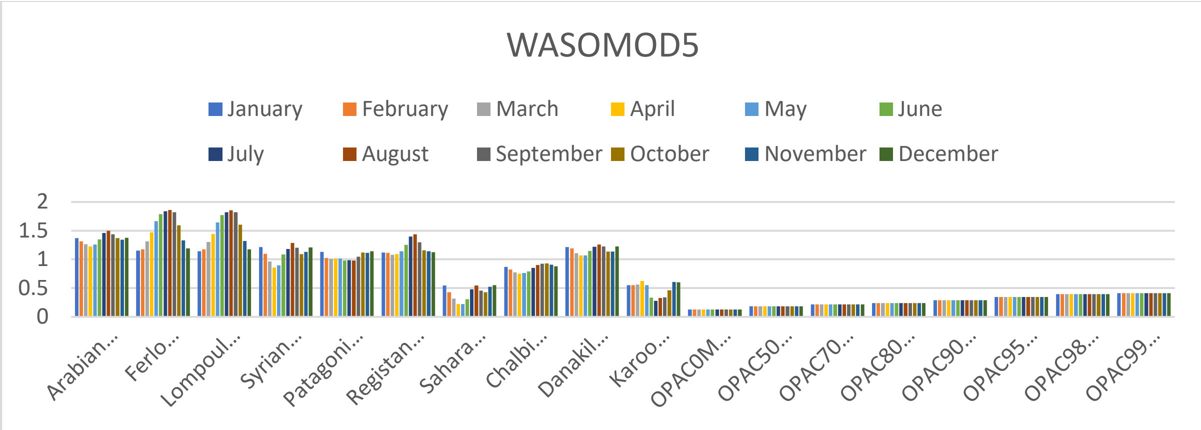

Fig. 2b Angstrom exponent α plot for OPAC and MEERA-2 (Model5) at 550nm

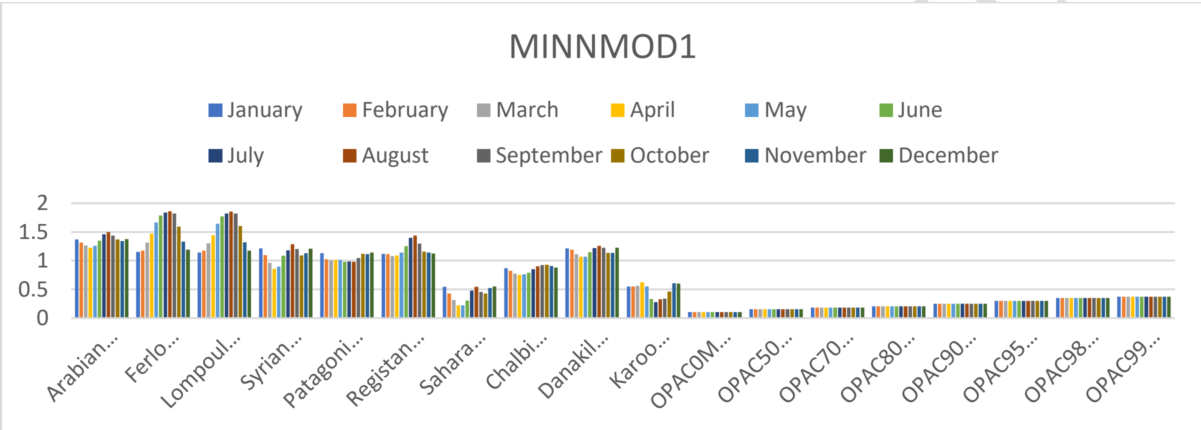

Fig. 2c Angstrom exponent α plot for OPAC and MEERA-2 (Model1) at 550nm

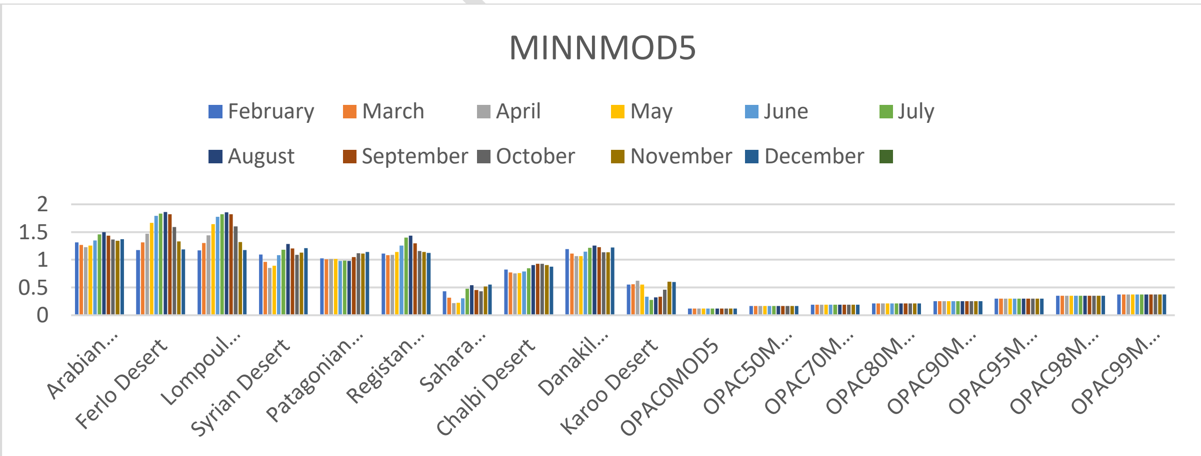

Fig. 2d Angstrom exponent α plot for OPAC and MEERA-2 (Model5) at 550nm

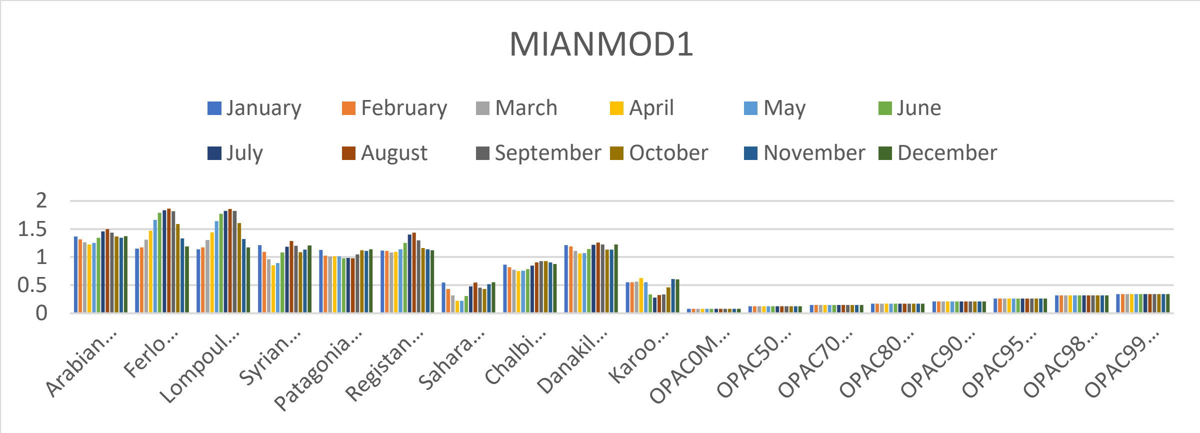

Fig. 2e Angstrom exponent α plot for OPAC and MEERA-2 (Model1) at 550nm

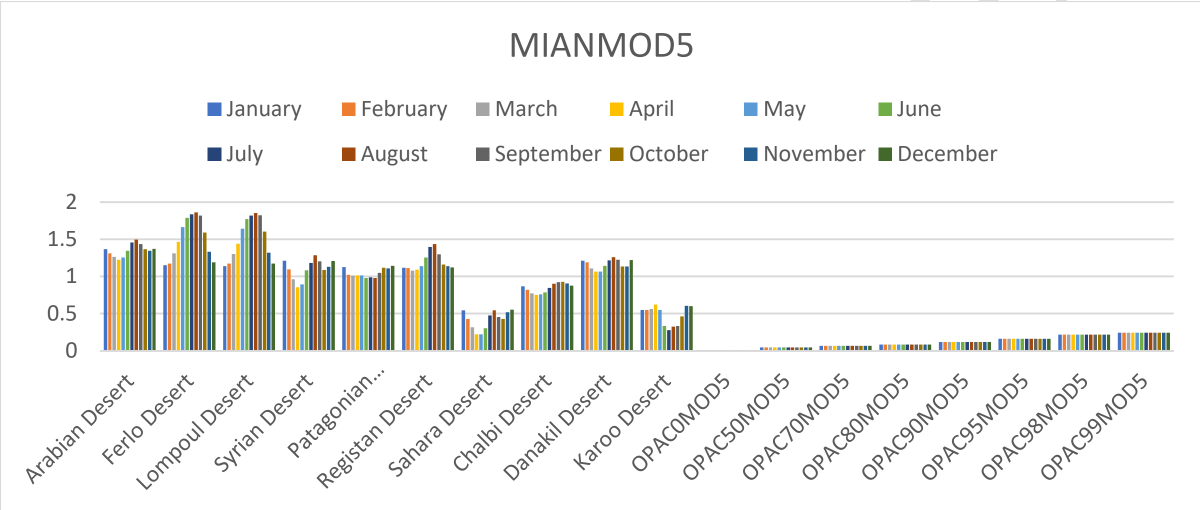

Fig. 2f Angstrom exponent α plot for OPAC and MEERA-2 (Model5) at 550nm

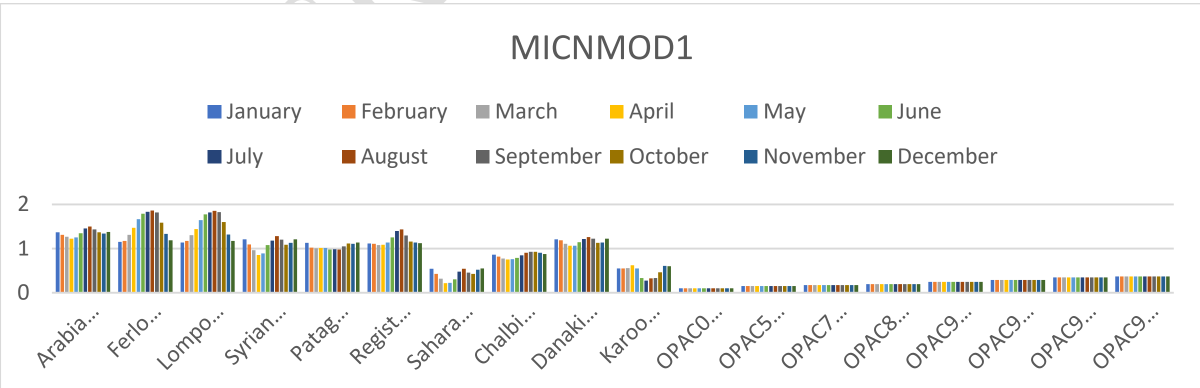

Fig. 2g Angstrom exponent α plot for OPAC and MEERA-2 (Model1) at 550nm

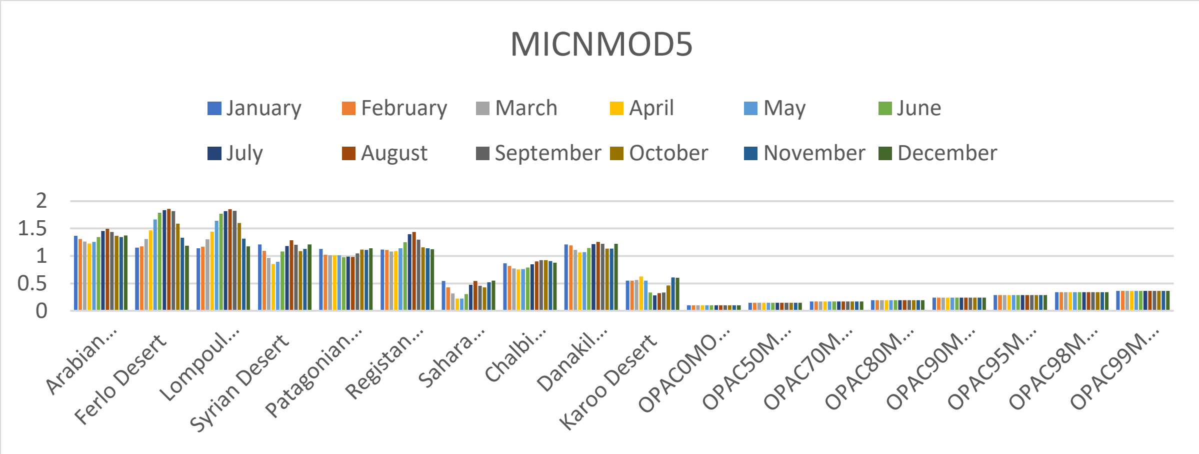

Fig. 2h Angstrom exponent α plot for OPAC and MEERA-2 (Model5) at 550nm

4.0 Summary

The work used MEERA-2 model extracted angstrom exponent and extinction coefficient to validate results obtained from the analysis of data extracted from OPAC 4.0 in our previous work [9]. It was gathered from the results of the analysis that

a) The R^2 values and the stationary R^2 for all the studied Deserts atmospheres show that the model under consideration is good and better than the baseline model.
b) The (β) level values of the model's significance are 0.0000 all through the ten studied deserts, which signifies that the model is significant.
c) The seasonality (δ) model's significance for all the studied deserts are not significant except for Ferlo and Lompoul deserts which are very significant.
d) From the plots, it can be said that the angstrom exponent (α) for both MEERA-2 model and OPAC 4.0 shows some agreements as they show same mode of variation over the studied period for (MEERA-2) and across the models for OPAC 4.0.
e) Ferlo and Lompoul has the highest angstrom exponent (α) values (highest concentration of fine mode particles) followed by Arabian, Registan, Danakil, Chalbi, and Karoo deserts. Sahara has the least (α) values.
f) The months of August, September and November have the highest (α) values for MEERA-2 Model which means that the highest concentration of fine mode particles is found in the months mentioned above.
g) For all the four studied components, MIAN has the least values of angstrom exponent (α) and that (α) increases with the increase in relative humidity.
h) The values of the angstrom exponent (α) for MEERA-2 model is higher than that of OPAC 4.0 except for Sahara and Karoo Deserts for the period of (May, June, July and August) and (June, July, August, September, October and November) respectively.
i) The arabian, Syrian and Patagonian deserts have the highest visibility (km) for the months of January, February, June, November and December respectively.
j) The visibility decreases with in RH across the models and the studied components.
k) MIAN component has the least visibility for both MEERA-2 model and OPAC 4.0.
l) Some of the deserts (Ferlo, Lompoul, Registan, Sahara, Chalbi, Danakil and Karoo) follows the mode of changes in visibility with OPAC except for the months of May, June, July, August and September.

5.0 Conclusion

Based on the results obtained from the analysis of the data extracted from both MEERA-2 model and OPAC 4.0, it can be concluded that the angstrom exponent (α) for MEERA-2 model is greater than 1, (which signifies the dominance of fine mode particles) for all the Deserts atmosphere except for Chalbi (0.844595516), Karoo (0.481856832) and Sahara (0.41700109) deserts which have (α) values less than 1 (which shows the dominance of coarse mode particles), But MEERA-2 model still has the highest angstrom exponent value, higher than that of OPAC. It can said that MEERA-2 model predicted that, it is possible for some deserts Atmosphere to have the dominance of fine mode particles over coarse mode particles which is contrary to the results reported in our previous work[9]. From the results of the investigation (time series analysis), it was found that the model's significance (β) level is 0, which shows that the model is very significant. The models parameter significance (δ) are not significant for all the deserts except for Ferlo and Lompoul deserts. Ferlo and Lompoul deserts shows statistical significance, this might be due fluctuations in the angstrom exponent which is not necessarily due to the change in particles size distribution or change in relative humidity. The MEERA-2 visibility is higher than that of the four OPAC 4.0 components (WASO, MINN, MIAN and MICN) respectively. The investigation further revealed that the Arabian, Syrian and Patagonian deserts have the highest visibility (km) for months of January, February, June, November and December. Mineral accumulation mode component has the least of the visibility (km) when compared to both MEERA-2 model with OPAC 4.0. the plots of visibility further showed that Ferlo, Lompoul, Registan, Sahara, Chalbi, Danakil and Karoo desert have almost same visibility values and follows almost the same trend except for the months of May, June, July, August and September.

References

[1] E. R. Alessandrini, M. Stafoggia, A. Faustini, G. P. Gobbi, and F. Forastiere, "Saharan dust and the association between particulate matter and daily hospitalisations in Rome, Italy," *Occup. Environ. Med.*, vol. 70, no. 6, pp. 432–434, 2013, doi: 10.1136/oemed-2012-101182.

[2] Y. Ou *et al.*, "Evaluation of MERRA-2 Aerosol Optical and Component Properties over China Using SONET and PARASOL/GRASP Data," *Remote Sens.*, vol. 14, no. 4, 2022, doi: 10.3390/rs14040821.

[3] S. U. Yerima, U. Y. Abdulkarim, B. I. Tijjani, U. M. Gana, M. Sani, and R. Aliyu, "Analysis of the Impact of Relative Humidity and Mineral Accumulation Mode Aerosols Particle Concentration on the Visibility and particle size distribution of Desert Aerosols," *Int. J. Sci. Eng. Res. Vol.*, vol. 12, no. 4, pp. 929–943, 2021.

[4] B. I. Tijjani, "The Effect of Soot and Water Soluble on the Hygroscopicity of Urban Aerosols," *Adv. Phys. Theor. Appl.*, vol. 26, no. 1, pp. 52–73, 2013, [Online]. Available: www.iiste.org.

[5] A. M. Neophytou *et al.*, "Particulate matter concentrations during desert dust outbreaks and daily mortality in Nicosia , Cyprus," no. February, pp. 275–280, 2013, doi: 10.1038/jes.2013.10.

[6] S. J. Venero-Fernández, "Saharan dust effects on human health: A challenge for Cuba's researchers," *MEDICC Rev.*, vol. 18, no. 3, pp. 32–34, 2016, doi: 10.37757/mr2016.v18.n3.8.

[7] A. Rocha-lima *et al.*, "A detailed characterization of the Saharan dust collected during the Fennec campaign in 2011 : in situ ground-based and laboratory measurements," pp. 1023–1043, 2018.

[8] S. U. Yerima *et al.*, "Analysis of the Impact of Relative Humidity and Mineral Nuclei Mode Aerosols Particle Concentration on the Visibility of Desert Aerosols," vol. 8, no. 1, pp. 114–131, 2021.

[9] S. U. Yerima, B. I. Tijjani, and U. M. Gana, "Impacts of the Variations of Aerosols Components and Relative Humidity on the Visibility and Particles Size Distribution of the Desert Atmosphere," vol. 4, no. 3, pp. 42–65, 2021, doi: 10.9734/AJR2P/2021/v4i330146.

[10] U. Y. Abdulkarim, S. U. Yerima, B. I. Tijjani, U. M. Gana, and M. Sani, "The Effect of Varying Soot Concentration and Relative Humidity on Visibility and Particle Size Distribution in Urban Atmosphere," vol. 8, no. 1, pp. 83–101, 2021.

[11] H. Maring, D. L. Savoie, M. A. Izaguirre, L. Custals, and J. S. Reid, "Mineral dust aerosol size distribution change during atmospheric transport," *J. Geophys. Res. Atmos.*, vol. 108, no. 19, 2003, doi: 10.1029/2002jd002536.

[12] F. de Longueville, P. Ozer, S. Doumbia, and S. Henry, "Desert dust impacts on human health: An alarming worldwide reality and a need for studies in West Africa," *Int. J. Biometeorol.*, vol. 57, no. 1, pp. 1–19, 2013, doi: 10.1007/s00484-012-0541-y.

[13] F. Kasten, "Visibility forecast in the phase of pre-condensation," *Tellus*, vol. 21, no. 5, pp. 631–635, Jan. 1969, doi: 10.3402/tellusa.v21i5.10112.

[14] P. Ginoux, J. M. Prospero, T. E. Gill, N. C. Hsu, and M. Zhao, "Global-scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS Deep Blue aerosol products," *Rev. Geophys.*, vol. 50, no. 3, pp. 1–36, 2012, doi: 10.1029/2012RG000388.

[15] R. Washington, M. Todd, N. J. Middleton, and A. S. Goudie, "Dust-storm source areas determined by the total ozone monitoring spectrometer and surface observations," *Ann. Assoc. Am. Geogr.*, vol. 93, no. 2, pp. 297–313, 2003, doi: 10.1111/1467-8306.9302003.

[16] D. Akpootu and M. Momoh, "The Ångström Exponent and Turbidity of Soot Component in the Radiative Forcing of Urban Aerosols," *Niger. J. Basic Appl. Sci.*, vol. 21, no. 1, pp. 70–78, 2013, doi: 10.4314/njbas.v21i1.11.

[17] K. S. Shaik, "Atmospheric Propagation Effects Relavant to Optical Communications," *Commun. Syst.*, 1988.

[18] S. Mallone, M. Stafoggia, A. Faustini, G. Paolo Gobbi, A. Marconi, and F. Forastiere, "Saharan dust and associations between particulate matter and daily mortality in Rome, Italy," *Environ. Health Perspect.*, vol. 119, no. 10, pp. 1409–1414, 2011, doi: 10.1289/ehp.1003026.

[19] Mary E. Dzaugis*, Arthur J. Spivack and S. D'Hondt, "NASA Public Access," *AIMS Geosci.*, vol. 3, no. 2, pp. 163–186, 2017, doi: 10.1175/JCLI-D-16-0609.1.The.

[20] and I. schult M. Hess, P. Koepke, "Optical Properties of Aerosols and Clouds: The Software Package OPAC," pp. 831–844, 1998.

[21] P. Koepke, J. Gasteiger, and M. Hess, "Technical Note: Optical properties of desert aerosol with non-spherical mineral particles: Data incorporated to OPAC," *Atmos. Chem. Phys.*, vol. 15, no. 10, pp. 5947–5956, 2015, doi: 10.5194/acp-15-5947-2015.

[22] U. S. Yerima, "Analysis by comparison of two automatic weather station in Akure, Ondo state Nigeria," *Nhk技研*, vol. 151, pp. 10–17, 2015.

[23] E. L. Koschmieder, "Symmetric Circulations of Planetary Atmospheres," *Adv. Geophys.*, vol. 20, no. C, pp. 131–181, 1978, doi: 10.1016/S0065-2687(08)60323-4.