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ASSESMENT AND COMPARISON OF MODIS AOD AND AE PRODUCT OVER ILORIN AERONET STATION USING THE STATISTICAL ANALYSIS OF EMPIRICAL ORTHOGONAL FUNCTION (EOF)

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ABSTRACT
In this Paper, Empirical Orthogonal Function (EOF) was used to assess the MODIS C006 LV2 aerosol AOD and AE products, and compared the data with AERONET AOD and AE observations. The data were taken from an AERONET station at Ilorin, Nigeria which were obtained from (MAPSS) and were averaged monthly using Microsoft excel spread sheets. The data period for the two satellite data were from Dec 2004 to May 2015 It was observed from the graphical representation that the seasonal variation of AOD peaks during the dry season from Dec to Feb and reaches minimum during summer in August 2008.The comparisons showed both underestimations in MODIS AOD and considerable overestimations in the AE. On the EOF analysis it was observed that a good correlation between MODIS & AERONET AOD are observed on the correlation matrices in all the data. Lower correlation is only observed at Ilorin AERONET wavelength at 470nm (ILA470) with Ilorin 660nm (ILM660).On the total variance explained table for MODIS and AERONET AOD, it was observed that out of the 6 components put into the EOF, only one component was extracted with a very high percentage of 81.57% For MODIS and AERONET AE,two components were observed with a percentage of 83.95% These show that the level of similarities is very high for MODIS and AERONET AOD,and little variation was observed for MODIS and AERONET AE.
Keywords: Aerosol optical depth, Angstrom exponent, Empirical orthogonal function, AERONET nd MODIS Satellite data.

INTRODUCTION

The Moderate Resolution Imaging Spectroradiometer (MODIS) is an enhanced instrument which was first launched in December 1999 onboard the EOS-Terra satellite, then a second instrument was launched onboard EOS-Aqua in May 2002. Both satellites are sun-synchronous with Equatorial overpass at 10:30 AM for Terra and 1:30 PM for Aqua, local time. They measure angular dependence of radiance at multi-wavelengths ranging from UV to infrared. As they are able to provide spectral optical depth, and aerosol size information in the form of Angstrom exponent (Remer *et al.*, 2005).

MODIS also measures the properties of aerosols—tiny liquid or solid particles in the atmosphere. Aerosols enter the atmosphere from manmade sources like pollution and biomass burning and natural sources like dust storms, volcanic eruptions, and forest fires (Kaufman *et al.*, 2000).

Aerosol Robotic Network (AERONET) is a federated ground-based remote sensing network of well-calibrated sun photometers. It now includes more than 500 sites around the world, covering all major troposphere aerosol regimes Holben *et al.*, (1998; 2001). To validate the Aerosols retrieval parameter, ground-based measurement data are necessary. The aerosols optical properties retrieved using direct solar radiation from sun-photometers of the Aerosols Robotic Network (AERONET) are free from surface reflectance and cloud contamination .Therefore it is widely used to evaluate the efficiency of satellite based aerosols retrieval algorithm as well as to develop new algorithm (Misra *et al.*,2015).

The aerosol optical depth (AOD) is an important parameter for visibility degradation (due to atmospheric pollution), solar radiation extinction, climate effects, and tropospheric corrections in remote sensing (Dubovik et al., 2002).Angstrom (1929) proposed an empirical formula to approximate the spectral dependence of atmospheric extinction (scattering and absorption) caused by aerosols.

Angstrom Exponent (AE) is often used as a qualitative indicator of aerosol particle size distribution (Kedia *et al., 2014)*. It is also used to parameterize the relationship between aerosol size and dependence of optical depth on wavelength AE as defined by (Eck *et al.*, 1999).

$\alpha = -ln(\tau/\tau_1)/ln(\lambda/\lambda_1)$ (1)

where α is the AE parameter, τ and and τ_1 are aerosol optical depth at wavelength λ and λ_1 respectively. The fine mode fraction value (FMF) can vary from 0 (single coarse mode aerosols) to greater than 1 (single fine mode aerosols) and provide a quantitative information on the nature of the aerosols size distribution (Kedia et al., 2014). Aerosols which are small in size and more absorbing than the natural aerosols (Anthropogenic) contribute about 20-40% to the global aerosol optical depth τ, and are smaller in size and more absorbing than the natural aerosols. (Myhre *et al.,* 2009).

MATERIALS AND METHODS

MODIS C006 and AERONET AOD and AE DATA

In this paper MOD04 L2 aerosol optical properties data from level 2 collection 6 (C006) aerosol products were used. The product were obtained from The Multi-sensor Aerosols Sampling System (MAPSS) (http://giovanni.gsfc.nasa.gov/mapss/) from which the long term (2004-2015) daily data were obtained and Microsoft excel spread sheet was used to compute the monthly data.

MODIS AOD data at three wavelengths $\tau_{470,}$ τ_{550}, and τ_{660} were used to compare with AERONET AOD data at the same wavelengths The MODIS Angstrom exponent (AE) were also computed using the range of $\alpha_{470-550}$ $\alpha_{470-660\,and}$ $\alpha_{550-660}$ to compare with the AERONET AE at the same range. The dataset were divided into two groups based on their seasonal variation as used in some literatures (Anuforom *et al.*, 2010; Chin *et al.*, 2009) they are: (1) dry season (2) summer to analyze their seasonal variability.

Although there are more than 500 AERONET stations. Here only one station was used to represent two aerosol type. The location of the station selected in the study is shown in Figure 1 and the summary of the locations, time period, longitude and latitude, region and aerosol type are listed in Table 1.

Figure 1. Locations of the AERONET station selected in the study.(Source: http://aeronet.gsfc.nasa.gov/cgi-bin/site_info)

Table 1 AERONET STATION SELECTED IN THE STUDY

S/NO	COUNTRY	AERONET STATION	LATITUDE	LONGITUDE	AEROSOL TYPE	DATA-PERIOD	REGION
1	NIGERIA	ILORIN	8.32	4.34	BB+DUST	2004-2015	WEST AFRICA

Empirical Orthogonal Function (EOF)

Empirical orthogonal function (EOF) analysis or principal component analysis (PCA) have become standard statistical techniques in the geophysical sciences of meteorology and oceanography particularly in the area of climate research (Peixoto and Oort, 1992; von Storch and Zwiers, 1999).

It is a method of statistical analysis that is used to reduce any complicated data set into a finite and small number of new variables.

It uses correlation between variable to discover a smaller number of new variables called components that can give significant information about the data. To determine the correlation matrix, the data is converted into the $N \times M$ matrix X.where N is the number of observations which comprised both MODIS and AERONET data. The analyses was performed in two steps. The first uses AOD for both MODIS and AERONET and the second AE for both MODIS and AERONET and M is the number of months .If the data matrices are put in the forms:

$$X = M \begin{array}{c} N \\ \left[\quad\quad \right] \end{array} \text{ where i=1, M:j=1, N} \quad (2)$$

$$X^T = N \begin{array}{c} M \\ \left[\quad\quad \right] \end{array} \text{ where i=1, N:j=1 M} \quad (3)$$

The two possible correlations matrices which comprises $XX^T$and X^TX are called dispersions matrices the first as

$S_1 = XX^T$ which is an $M \times M$ matrix

The second as

$S_2 = X^TX$ which is an $N \times N$ matrix

The EOFs are found by computing the eigenvalues and eigenvectors of a spatially weighted anomaly correlation matrix of the dispersion relation. The derived eigenvalues provide a measure of the percentage variance explained by each mode. SPSS software version 20 (IBM SPSS statistics) was used for the analysis.

RESULTS AND DISCUSSION

Ilorin Aerosol Optical depth (AOD) AndAngstrom exponent (AE)

Here the result of the station will be discussed. The behavior of such station will be displayed graphically with their statistical analysis (EOF).The Ilorin station sits in the Sahel, a region affected by both biomass burning from South Africa and dust from the Sahara. As a result, the aerosol properties over this region are more complicated, and lead to difficulties in MODIS retrieval.

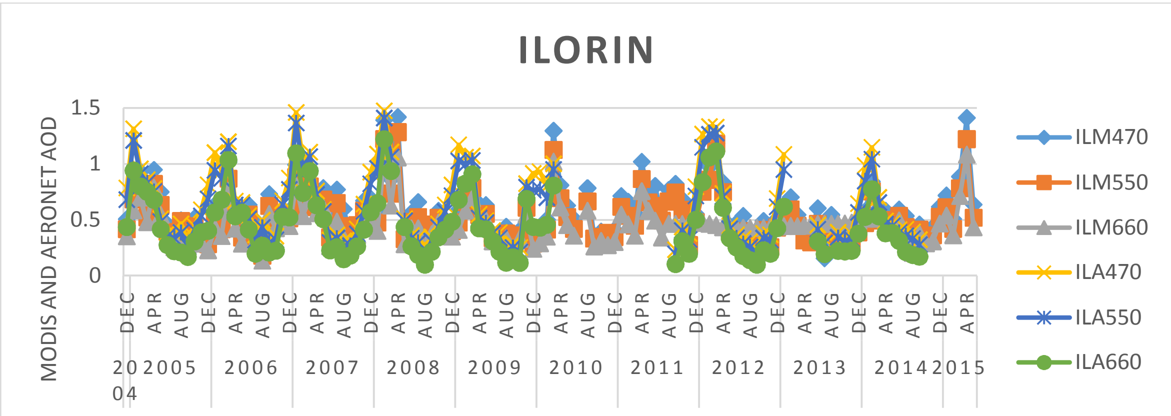

Figure 2 Plots of MODIS AOD and AERONET AOD for Ilorin for Years Dec 2004 to May 2015

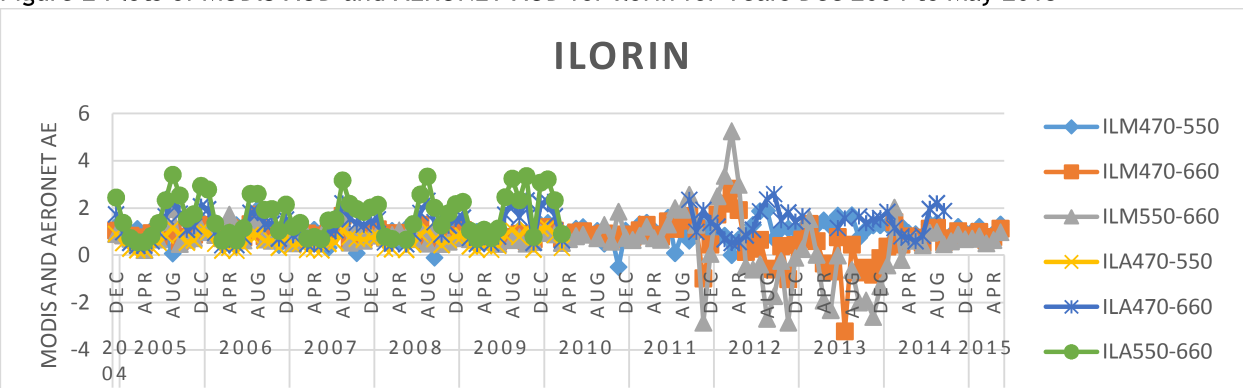

Figure 3 Plots of MODIS and AERONET AE for Ilorin for Years Dec 2004 to May 2015

Figure 2 shows that seasonal variation of AOD peaks during the dry season in Dec and reaches minimum during summer August 2008 and Figure 3 show that there is an overestimation of MODIS AE over AERONET AE.

Table 2 KMO AND BARTLETT"S test of Ilorin MODIS AND AERONET AOD

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.688
Bartlett's Test of Sphericity	Approx. Chi-Square	1682.745
	df	15.000
	Sig.	0.000

Table 2 show the KMO test with a value of 0.688 which is > 0.5 and a significance is 0.000 all to three places of decimal. The usual interpretation is that if KMO is < 0.5 no good interpretation can be obtained. Hence this show that the data is suitable and adequate for the test or the analysis.

Table 3 Correlation matrix of Ilorin MODIS and AERONET AOD

		ILM470	ILM550	ILM660	ILA470	ILA550	ILA660
Correlation	ILM470	1	0.990	0.851	0.674	0.714	0.788
	ILM550	0.990	1	0.824	0.658	0.700	0.780
	ILM660	0.851	0.824	1	0.531	0.571	0.653
	ILA470	0.674	0.658	0.531	1	0.996	0.946
	ILA550	0.714	0.700	0.571	0.996	1	0.972
	ILA660	0.788	0.78	0.653	0.946	0.972	1

This matrix is positive definite
a. Determinant = 6.37E-009.

Table 3 shows the correlation matrix which is typically used to do an eyeball test and get a picture for which variable is strongly associated with which variable. The matrix shows the fraction of the variance of each variable that can be explained by all of the other variables. It show good correlation between all MODIS and AERONET data.

Table 4 Total varienced explained of Ilorin MODIS and AERONET AOD

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.89	81.57	81.57	4.89	81.57	81.57
2	0.86	14.37	95.93			
3	0.20	3.30	99.23			
4	0.04	0.64	99.87			
5	0.01	0.13	100.00			
6	0.00	0.00	100.00			

Table 4.is the total explained variance of the model. And is defined as the sum of the squared loading factor for each factor. It also summarizes the total variance explained by the EOF solution and gives an indication about the number of useful factors available. This table has two parts, The first part whose title is initial eigen values gives the variance explained in by all the possible components. There are a total of 6 components, which is the same as the number of variable entered into the EOF. The first column under initial Eigen value gives the Eigen values for all the possible factors in decreasing order which is now followed by variance and cumulative variance. A number greater than one is extracted by SPSS. In this analysis one factor was extracted The second part, titled Extraction Sums of squared loadings gives the information for the factor extracted and the word "Extraction" here refers to the fact that these values are calculated after factor extraction. The "Total Variance Explained" table shows how much of the total variance of the observed variables is explained by each of the EOF components.

The first EOF component, by definition is the one that explain the largest part of the total variance (eigen value) of 4.89 this amount to 81.57% of the total variance. The “cumulative%” column of the table tells us how much of the total variance that can be accounted for by the first components together in this test, the analysis extracts only one factor of a very high percentage of about 81.57% of the total variance.

Table 5 Component matrix MODIS and AERONET AOD

Component	
	1
ILA660	0.952
ILM470	0.925
ILA550	0.919
ILM550	0.914
ILA470	0.891
ILM660	0.812

Table 4 is the components matrix which is the key to interpreting the factor extracted earlier. The factor loading that is shown in this table is the correlation coefficient between the variable and the factor. It can be seen that there is high significance, and good correlation at all observations. Lower correlation is only seen at ILM660 this shows that there is significance relationship between MODIS and AERONET data.

Table 6 Correlation matrix of Ilorin MODIS and AERONET AE

		ILM470-550	ILM470-660	ILM550-660	ILA470-550	ILA470-660	ILA550-660
Correlation	ILM470-550	1	0.68	0.017	0.178	0.166	0.163
	ILM470-660	0.68	1	0.745	0.365	0.362	0.361
	ILM550-660	0.017	0.745	1	0.336	0.343	0.344
	ILA470-550	0.178	0.365	0.336	1	0.997	0.995
	ILA470-660	0.166	0.362	0.343	0.997	1	1
	ILA550-660	0.163	0.361	0.344	0.995	1	1

Determinant =0 .000

This matrix is not positive definite

Table 6 is the correlation matrix of MODIS and AERONET AE It could be seen that poor correlation is seen in all the MODIS and AERONET AE data which may be probably due to low data accuracy.

Table 7 Total varienced explained of Ilorin MODIS and AERONET AE

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.53	58.88	58.88	3.53	58.88	58.88
2	1.50	25.08	83.95	1.50	25.08	83.95
3	0.96	15.96	99.91			
4	0.01	0.09	100.00			
5	0.00	0.00	100.00			
6	0.00	0.00	100.00			

Table 7 show that out of the 6 component put into the EOF only two were extracted

Table 8 Component matrix of Ilorin MODIS and AERONET AE.

	Component	
	1	2
ILA470-660	0.934	-0.349
ILA470-550	0.933	-0.343
ILA550-660	0.933	-0.350
ILM550-660	0.577	0.407
ILM470-660	0.670	0.738
ILM470-550	0.370	0.658

Table 8 is the component matrix of Ilorin MODIS AND AERONET AE it could be seen that at component 1 all data are statistically significant. But component 2 shows that only the MODIS data are statistically significant but the AERONET data are statistically insignificant.

CONCLUSION

In this paper, The MODIS C006 aerosol AOD and AE products were assessed and comparing the data with AERONET AOD and AE observations. The results show that the overall agreement between MODIS and AERONET AOD and MODIS and AERONET AE are fairly good.

On the graphical representation, it could be seen that the seasonal variation of AOD peaks during the dry season and reaches minimum during summer (figure 1).An overestimation was observed in the MODIS AE over AERONET AE.in figure 2

From EOF result, On the correlation matrix tables, for MODIS and AERONET AOD the type of the matrix is a non-definite matrix, with determinant of 0.0000 while for the MODIS and AERONET AE it is a positive definite with determinant of 6.37E-009.

On the total variance explained table, for MODIS and AERONET AOD the data was explained by one eigenvalue of 4.89 and together explained 81.57% of the relationships. For MODIS and AERONET AE, the data were explained by two eigen values of 3.53 and 1.50 and together explained 83.95% of the relationship.

On the component matrices, for MODIS and AERONET AOD, there is high significance, and good correlation at all observations. Lower correlation is only seen at ILM660 this shows that there is significance relationship between MODIS and AERONET data. While for MODIS and AERONET AE component 1, all data are statistically significant. But component 2 shows that only the MODIS data are statistically significant but the AERONET data are statistically insignificant. This shows there is similarities in MODIS and AERONET observation and little similarities in MODIS and AERONET AE observation.

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