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Znanstveni časopis *Hrvatski meteorološki časopis* nastavak je znanstvenog časopisa *Rasprave* koji redovito izlazi od 1982. godine do kada je časopis bio stručni pod nazivom *Rasprave i prikazi* (osnovan 1957.). U časopisu se objavljuju znanstveni i stručni radovi iz područja meteorologije i srodnih znanosti. Objavom rada u Hrvatskom meteorološkom časopisu autori se slažu da se rad objavi na internetskim portalima znanstvenih časopisa, uz poštivanje autorskih prava.

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COMPARATIVE ASSESSMENT OF GROUND AND SATELLITE AEROSOL OBSERVATIONS OVER LAGOS-NIGERIA

Usporedna ocjena mjerenja aerosola satelitom i sa zemaljskih postaja u Lagosu, Nigerija

MOSES ETERIGHO EMETERE[1,3] and MOHAMMAD VALIPOUR[2]

[1]Department of Physics, Covenant University Canaan land, P.M.B 1023, Otta, Nigeria
[2]Young Researchers and Elite Club, Kermanshah Branch,
Islamic Azad University, Kermanshah, Iran
[3]Department of Mechanical Engineering Science, University of Johannesburg,
Auckland Park Kingsway, Johannesburg, South Africa

emetere@yahoo.com

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Abstract: The performance of ground and satellite measuring sensors or devices in the West Africa climate system is worrisome. These challenges had resulted in the loss of large volume of useful data on notable database e.g. Aerosol Robotic Network (AERONET), Multi-angle Imaging SpectroRadiometer (MISR), Modern-Era Retrospective Analysis for Research and Applications (MERRA) e.t.c. With only about 47% of data available to scientists, it is evident that accurate nowcast or forecast can no longer be guaranteed. The frequent failures of ground measuring devices over West Africa are more systemic than error due to device fabrication. The optical state over Lagos-Nigeria was investigated using the aerosol model. Fourteen years aerosol dataset from MISR and two years aerosol dataset from AERONET were used for the study. The optical state over Lagos is significant due to the massive human population. Lagos is located within the latitude of 6.465 °N and longitude of 3.406 °E. The regression analysis and Mann-Kendall (MK) test show no significant trend and considerable relationship between satellite and ground data. The standard deviations of the optical state via satellite and ground observations are 0.131 and 0.233, respectively. The average optical state predictability of the satellite and ground observation was 14.2% and 53.1%, respectively. The atmospheric constants in Lagos are: $a_1 = 1.175$, $a_2 = 0.8227$, $n_1 = 0.2926$, $n_2 = 0.3573$, and $\alpha = \beta = \pi/2$.

Key words: atmospheric constant, dispersion model, satellite observation, ground observation, aerosols, Lagos

Sažetak: Učinkovitost mjernih instrumenata i senzora ili uređaja na tlu u klimatskom sustavu Zapadne Afrike je zabrinjavajuća. Velika količina korisnih podataka u bazama podataka je zbog toga izgubljena, npr. u robotskoj mreži mjerenja aerosola (AERONET), kod Višekutnog Spektralnog Radiometra (MISR), u mreži (MERRA) itd. Samo oko 47 % setova podataka je raspoloživo znanstvenicima te je očito da točne kratkoročne prognoze više ne zadovoljavaju kriterije zadane točnosti. Pogreške mjernih instrumenata su češće nego pogreške zbog kvarova instrumenata. Optičko stanje atmosfere iznad Lagosa u Nigeriji istraživano je upotrebom modela aerosola. U ovoj studiji upotrijebili smo četrnaest-godišnji niz podataka MIRS-a i dvo-godišnji niz podataka AERONET-a. Optičko stanje atmosfere iznad Lagosa pod utjecajem je velikog broja stanovnika. Lagos je smješten između 6,465 °N i 3,406 °E. Regresijska analiza i Mann-Kendall (MK) test pokazali su da ne postoji značajan trend ni veza između satelitskih i zemaljskih podataka. Standardna odstupanja optičkog stanja putem satelitskih i zemaljskih opažanja su 0,131 i 0,233.. Prosječna predvidljivost optičkog stanja satelitskih mjerenja je 14,2 %, a zemaljskih opažanja 53,1 %. Atmosferske konstante u Lagosu su: $a_1 = 1.175$, $a_2 = 0.8227$, $n_1 = 0.2926$, $n_2 = 0.3573$, i $\alpha = \beta = \pi/2$.

Ključne riječi: atmosferska konstanta, model disperzije, satelitska mjerenja, prizemna motrenja, aerosol, Lagos

1. INTRODUCTION

About 15% of the atmospheric aerosols of the previous year is retained over the West Africa troposphere per year (Emetere et al., 2015a). This process leads to the thickening of the aerosol layer in the atmosphere depending on the aerosol sources e.g. atmosphere-aviation pollution, earth-anthropogenic sources, etc. (Emetere, 2017). Primarily, the aerosol layer scatters or absorbs light from the sun. Beyond its absorbing or scattering tendency, it has the ability to create several refractive indices for light and signals (Emetere et al., 2015b). This research is an important concept in satellite communication industry, aviation industry and meteorological measurements. The presence of multiple refractive indices affects the functionality of ground measuring devices and satellite sensors via signal attenuation (Emetere et al., 2015c).

The adequate monitoring of the optical state of Lagos is important because it influences atmospheric parameters like rainfall, solar radiation and thermal comfort (Emetere et al., 2015a, 2015b, 2015c). In this paper, we propose a technique to aid measuring instruments for higher performance. The challenges facing the functionality of measuring instruments are more of systemic error than design error (Emetere, 2016). This may be the main reason for the poor satellite and ground data sets. The tropospheric aerosols loading over Lagos is somewhat different from other locations in West Africa (Emetere et al., 2015a). Its sources of pollution can be categorized as large scale. They include: industrial, anthropogenic, aviation, domestic, bush burning, construction work, agriculture waste, wind transported pollution from neighboring locations, etc. Lagos is the commercial hub of the most populous nation in Africa–Nigeria. Unfortunately, the aerosols loading over Lagos is not known at the moment. The available measuring sources of aerosol data over Lagos are Multi-Angle Imaging SpectroRadiometer (MISR) and Aerosol Robotic Network (AERONET). The MISR and AERONET have proven aerosol retrieving algorithm (Li et al., 2015). Hence, we proposed in this study that the atmospheric or calibration constant over Lagos must be revised for maximum functionality. These constants are inserted into the compact flash card (CF-Card) of the measuring instruments. The CF-Card contains computational programme or codes which includes the calibration constants. The primary function of the calibration constant is to transform/convert signals (from the sensor) to real units. The real unit is in form of data set. It is retrieved and logged onto a control processing unit (CPU) or a designated website for further use.

The dynamics for the estimation of calibration constant for the Raman lidar system over different locations strongly agrees with the objective of this research (Avdikos, 2015). The calibration campaign of the Raman lidar system was reported by Cornacchia et al. (2004) for May to June 2002. The stability of the calibration constant was investigated by Mona et al. (2007) for May 2002 to June 2006 and the uncertainties on the radiosondes were calculated to be over 5%. However, for longer period, we propose that the uncertainties would definitely increase with respect to unpredictable aerosols dispersion in West Africa (Madonna et al., 2011). A typical need for the documentation of the atmospheric constants over a geographical region can be seen in the radiosonde temperature biases noticed on a wide variation between the temperature of device sensor and its surrounding air (Sun et al., 2013).

To correct this major flaw, radiosonde manufacturers have developed algorithm using limited data. Some meteorological agencies have developed algorithms which have been recommended to radiosonde manufacturers (Sun et al., 2013). For example, Assessment of Standard Operating Procedures for Ozone sondes panel (ASOPOS) recommends the use of a constant for radiosonde RS41 to analyze vertical profile (Viasala, 2014). The atmospheric constant in some regions have been documented for industrial use (Schotland et al., 1986; Welton et al., 2002). For example, the use of the Canadian general climate model (GCMII) outside Canada requires tuning constants of 0.20 and 3.1 for Mace Head (Ireland), 0.26 for Ireland, and 1.4 for Heimaey, Iceland. Arai and Liang (2011) recommended the maintenance of calibration constant of the spectrometer over an area to enhance an efficient Aerosol Optical Depth (AOD) retrieval. Aside using atmospheric field dataset, radiometric calibration constant can be obtained using standard laboratory lamps (Kiedron et al., 1999). The change in atmospheric constant over a geographical location is due to the turbulent aerosol layer in the troposphere which was detected by Wilson et al. (2014) using radar and balloons. Hence, the atmospheric or calibration constant needs to be reviewed more frequently to update the configurations on the compact flash.

In this study we investigate the reasons for the poor data set noticed in both satellite and ground observations. We proposed that the calibration constant over Lagos needs to be documented for maximum quality of ground measurements.

2. METHODOLOGY

To obtain the atmospheric or calibration constant over a geographical location, a long-term satellite or ground observations of aerosol are essential. Fourteen years of satellite dataset from Multi-angle Imaging SpectroRadiometer (MISR) and two years of ground dataset from Aerosol Robotic Network (AERONET) was used for this research. The MISR operates at various directions i.e. nine different angles (70.5°, 60°, 45.6°, 26.1°, 0°, 26.1°, 45.6°, 60°, 20.5°) and gathers data in four different spectral bands of the solar spectrum (blue, green, red, and near-infrared). The blue band is at wavelength 443 nm, the green band is at wavelength 555 nm, the red band wavelength 670 nm and the infrared band is at wavelength 865 nm. MISR acquires images at two different levels of spatial resolution i.e. local and global mode. It gathers data at the local mode of 275 meter pixel size and 1.1 km at the global mode. Typically, the blue band is used to analyze data in coastal and aerosol studies. The green band is used in Bathymetric mapping and estimating peak vegetation. The red band analyze the variable vegetation slopes and the infrared band analyze the biomass content and shorelines (Emetere, 2016). The first step is to test the validity or evaluate indices of the satellite and ground observations to know its level of reliance.

Three parameters can be obtained from the MISR dataset: atmospheric constants, tuning constants and phase differences. These parameters are obtained from the Equation 1. Since MISR has nine directions, the pseudorange domain errors from nominal signal deformation are inevitable. Hence, the following procedural steps were adopted to solve the problem:

- we introduce the phase difference parameter to the dispersion model (Emetere et al., 2015a),
- we assume that there are two distinct aerosol layers per time.

Hence, the extended equation from Emetere et al. (2015a) is written as:

$$\psi(\lambda) = {a_1}^2 cos\left(\frac{n_1\pi\tau(\lambda)}{k_y} + \alpha\right) cos\left(\frac{n_1\pi\tau(\lambda)}{k_z} + \alpha\right) + \\ + {a_2}^2 cos\left(\frac{n_2\pi\tau(\lambda)}{k_y} + \beta\right) cos\left(\frac{n_2\pi\tau(\lambda)}{k_z} + \beta\right) \qquad (1)$$

Here α and β are the phase differences, n_1 and n_2 are the tuning constants, a_1 and a_2 are numerical constants, k_y and k_z are the eddy diffusivities in the direction of the y- and z- axes [m^2s^{-1}] and $\pi\tau(\lambda)$ is the aerosol size distribution factor.

Equation 1 was inserted into the Matlab curve fitting tool, to obtain the atmospheric or calibration constants, tuning constants and phase differences from the MISR dataset. The inserted equation fits into the dataset, thereby resolving numerically the constants highlighted in Equation 1. This method was adopted by Holzbecher (2012).

2.1. Evaluation indices

In this study, R^2 index was selected for comparison of the satellite and ground data as follows:

$$R^2 = \frac{\sum_{i=1}^{n}((X_i - \bar{X})(Y_i - \bar{Y}))^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2} \qquad (2)$$

Where, X_i and Y_i are the i^{th} observed and estimated values, respectively; $\bar{Y}$ and $\bar{X}$ are the average of X_i and Y_i, and n is the total number of data.

In addition, trend evaluation was done using regression analysis and Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975; Gilbert, 1987). The related equations for calculating the MK test, statistic S, and the standardized test statistic Z are as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j\text{-}x_i) \qquad (3)$$

$$sign\ x_j\text{-}x_i = \begin{cases} 1 & if\ (x_j - x_i) > 0 \\ 0 & if\ (x_j - x_i) = 0 \\ -1 & if\ (x_j - x_i) < 0 \end{cases} \qquad (4)$$

$$VAR(S) = \frac{1}{18}\left[n(n\text{-}1)(2n+5)\ - \right.$$
$$\left. -\ \sum_{p=1}^{g} t_p(t_p\text{-}1)(2t_p+5)\right] \qquad (5)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ \ S > 0 \\ 0 & if\ \ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ \ S <\neq 0 \end{cases} \qquad (6)$$

where x_i and x_j are the sequential data values of the time series in the years i and j, n is the length of the time series, t_p is the number of ties for the p^{th} value, and g is the number of tied values. Positive values of Z indicate increasing trends, while negative Z values indicate decreasing trends in the time series. The MK test examines necessary conditions to reject the null hypothesis (H_0) and accept the alternative hypothesis (H_a), where H_0 is non-monotonic trend and H_a is monotonic trend. When $|Z|>Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is the critical value of Z from the standard normal table.

3. RESULTS AND DISCUSSION

The ground and satellite dataset are complementary to each other – especially as it relates to AOD (Fig. 1). It can be seen on Figure 1a, that in the year 2012 ground data is missing only for November, while satellite data are missing for the period from June to September. It can be concluded that the satellite measurement of AOD may be inactive during raining season (Emetere, 2016). A large difference can be observed between the ground and satellite dataset for April 2012. In the year 2013 the ground dataset showed high aerosol optical depth, while the satellite data pretty low (Fig.1b). This difference sometimes occurs especially looking at the West Africa climate system (Emetere et al., 2018).

The main advantage of satellite observation over the ground-based observations is its tendency to provide more spatially representative measurements of AOD. Ground-based observations have the advantages of high accuracy if properly maintained. Also, it enables the study of local variability effects by tuning processes during ground truthing. However, the main challenge of not totally relying on either the satellite or ground observations is, in this paper, more visible by the regression test results. Climate changes affect operational satellites and recalibration of ground-based instru-

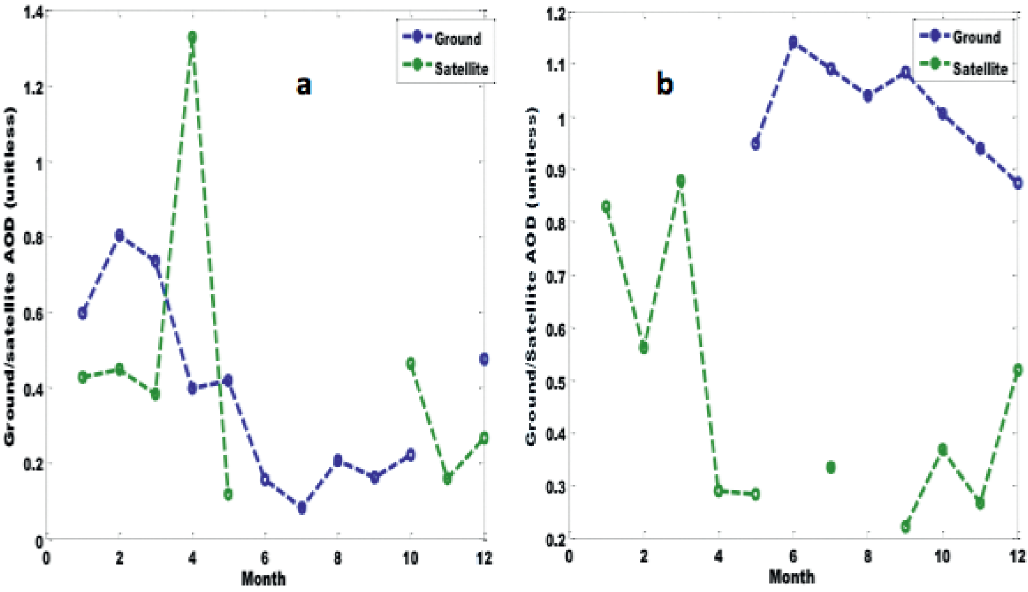

Figure 1. Ground and satellite observations of AOD over Lagos in the years 2012 (a) and 2013 (b).

Slika 1. Prizemna i satelitska mjerenja optičke debljine atmosfere (AOD) iznad Lagosa u 2012. (a) i 2013. (b) godini.

Table 1. Statistical parameters of ground and satellite AOD data sets for Lagos, for the years 2012 and 2013.

Tablica 1. Statistički parametri prizemnih i satelitskih skupova podataka optičke debljine atmosfere (AOD) iznad Lagosa za 2012. i 2013. godinu.

Statistical Parameter	**2012**		**2013**	
	Ground	**Satellite**	**Ground**	**Satellite**
Standard error	0.03194	0.074879	0.049783	0.06908
95% confidence interval	0.075539	0.169377	0.10957	0.15391
Variance	0.008162	0.056069	0.02974	0.052492
Standard deviation	0.0903041	0.236789	0.17245	0.229112
Coefficient of variation	0.089	0.5213	0.19466	0.54109
Skew	-0.205	1.03	0.504	0.904
Kurtosis	-1	-0.298	-0.975	-0.434
Kolmogorov - Smirnov stat	0.15	0.245	0.233	0.265

ments (Fioletov et al., 2002). As shown in all Figures in this section, features of AOD are more poorly pronounced with respect to satellite observation (Mikhalev et al., 2003). Statistical parameters shown in Table 1 illustrated the level of reliance on the satellite data set over West Africa. Bojanowski et al. (2014) highlighted the several sources of uncertainties when validating satellite observation. The uncertainties include: different viewing perspective, different spatial footprint and different sensitivity of a satellite. These uncertainties were investigated by comparatively validating the reliance on satellite and ground observations over the West African atmosphere.

From the statistical result, the ground data set for Lagos is more reliable than the satellite dataset. The ground data for 2012 has a low standard error and standard deviation. It is more convenient to align this kind of data than using any aerosol dispersion model. A comparative study of the ground and satellite data set reveals an abnormal variance in April. The satellite data set for April 2012 and 2013 is 1.35 and 0.3, hence, the abnormalities noticed in April show the dual impact of wind recirculation and atmospheric aerosols retention over Lagos. The ground dataset for April 2012 and 2013 is 0.4 and 0.96 respectively. This result affirms the impact of the wind recirculation over Lagos. The sensitivity of satellite and ground data set to capture the AOD over Lagos could be obtained from the skew analysis, that is, the measure of the asymmetry of the AOD probability distribution. The negative and positive skew analysis for 2012 and 2013, respectively, shows that the atmospheric condition over Lagos is dynamic. The nowcast can be inferred from the coefficient of variation, that is, normalized dispersion of probability distribution. The dynamism of the AOD over Lagos shows that the difference between the ground and satellite observation in 2012 and 2013 are 83% and 64%, respectively. A close observation of 2012 and 2013 may prompt an early conclusion that the atmospheric dynamism increases and may likely extend for some years. For example, the Kolmogorov-

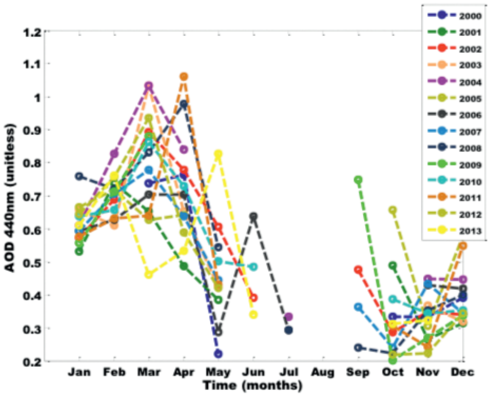

Figure 2. Annual course of AOD for Lagos, for the period 2000–2013.

Slika 2. Godišnji hod optičke debljine atmosfere (AOD) za Lagos, za razdoblje 2000.–2013.

Smirnov stat showed that higher AOD continuity distribution occurred in 2013.

The AOD variation in Lagos (Fig. 2) is unstable partly due to massive moisture updraft due to its location. However, AOD data retrieval in Lagos (Fig. 3) is relatively stable compared to Abuja (Emetere et al., 2016). This may be due to stratospheric aerosols which emanates from the oceanic recirculation (Hasebe and Noguchi, 2015). May 2001 was clearly out of the proposed model. This signifies an extra atmospheric activity in May 2001. The reason may not be easily adduced because data before the event are not available on the NASA –MISR portal. Interestingly, the month of May from 2001–2013 was in conformity with the proposed model. June and August 2005 was not in conformity with the proposed model. We proposed that the anthropogenic activities and the wind recirculation activities increased due to the combination of both the tropospheric and stratospheric aerosols (Hasebe and Noguchi, 2015). In general, the AOD trend for fourteen years follows a positive parabolic curve. The minimum value of the curve can be found at the presumed raining season. Hence, it could be adduced that aerosols in Lagos are more of carbonated and dust aerosols which can be reduced by rainfall.

The numerical results obtained on the Matlab were within 95% confidence bounds. The properties of the „goodness of fit“ for all the curves in Figure 3 have Sum of Squares Due to Error (SSE) of 0.006216. SSE measures the total deviation of the response values from the graphical fit. The R^2 is given as 0.9468. R^2 measures how successful curve fits in explaining the variation of the aerosol optical depth (AOD) data. From the data, it is shown that the proposed model, that is Equation 1, is able to explain 94.68% of the total variation in the Multi-angle Imaging SpectroRadiometer (MISR) dataset. Summarily, the constants obtained from the numerical output have high accuracy, and as such, it can be relied upon.

The dispersion model used in Equation 1 has shown a perfect assimilation of the MISR aerosol optical depth dataset by the trending and determination of the AOD values of at least five months per year. For example, year 2002 and 2006 had five months AOD in line with the proposed model; year 2001, 2005, 2008 and 2009 had six months AOD in line with the proposed model; year 2007, 2010, 2012 and 2013 had seven months AOD in line with the proposed model; only the year 2011 had eight months AOD in line with the proposed model; year 2004, 2003 and 2013 had nine months AOD in line with the proposed model. The above results affirm a high efficiency of the proposed model to describe the optical state of Lagos, Nigeria. In addition, the proposed model can be used to forecast rainfall, wind, thermal comfort and solar radiation patterns. The optical state can be used to calculate the link budget in communication. Figure 3 shows that the perfect optical state of the thirteen years MISR dataset in Lagos occurred in February and November. The near perfect optical state occurred in May and October, hence, the optical state is the critical point where the atmospheric aerosols have either a positive or negative trend. The importance of the optical state over a geographical region is basically to trigger aerosol mixing state (Srivastatva and Ramachandran, 2013; Wang et al., 2010).

The non-retrieval of the AOD in June and July over Lagos may be due to interferences of the moisture content (Adebiyi et al., 2015), cloud scavenging (Dani et al., 2003), precipitable water content (Vijayakumar and Devara, 2013) and high rain drop rate (Boucher and Quaas, 2013). The proposed model showed that the range of the AOD expected in June and July would range from 0.4 to 1.0. The model also predicted the possibility of a sudden AOD drop and rise in December and January, respectively. The significance of this possibility had been discussed by Emetere et al. (2015b). Hence, the optical state in Lagos is critical in January and December for the purpose of good planning of terrestrial radio links over geographical locations (Emetere et al., 2015), aviation projection (Peyrille et al., 2007) and disease propagation arising from unpredictable thermal comfort (Ahmed et al., 2014). It has been established that the radio frequencies above 30 MHz are affected by refractive index variations in the lower atmosphere. Hence, this study suggests a complementary technique to strengthen the International Telecommunication Union (ITU) model.

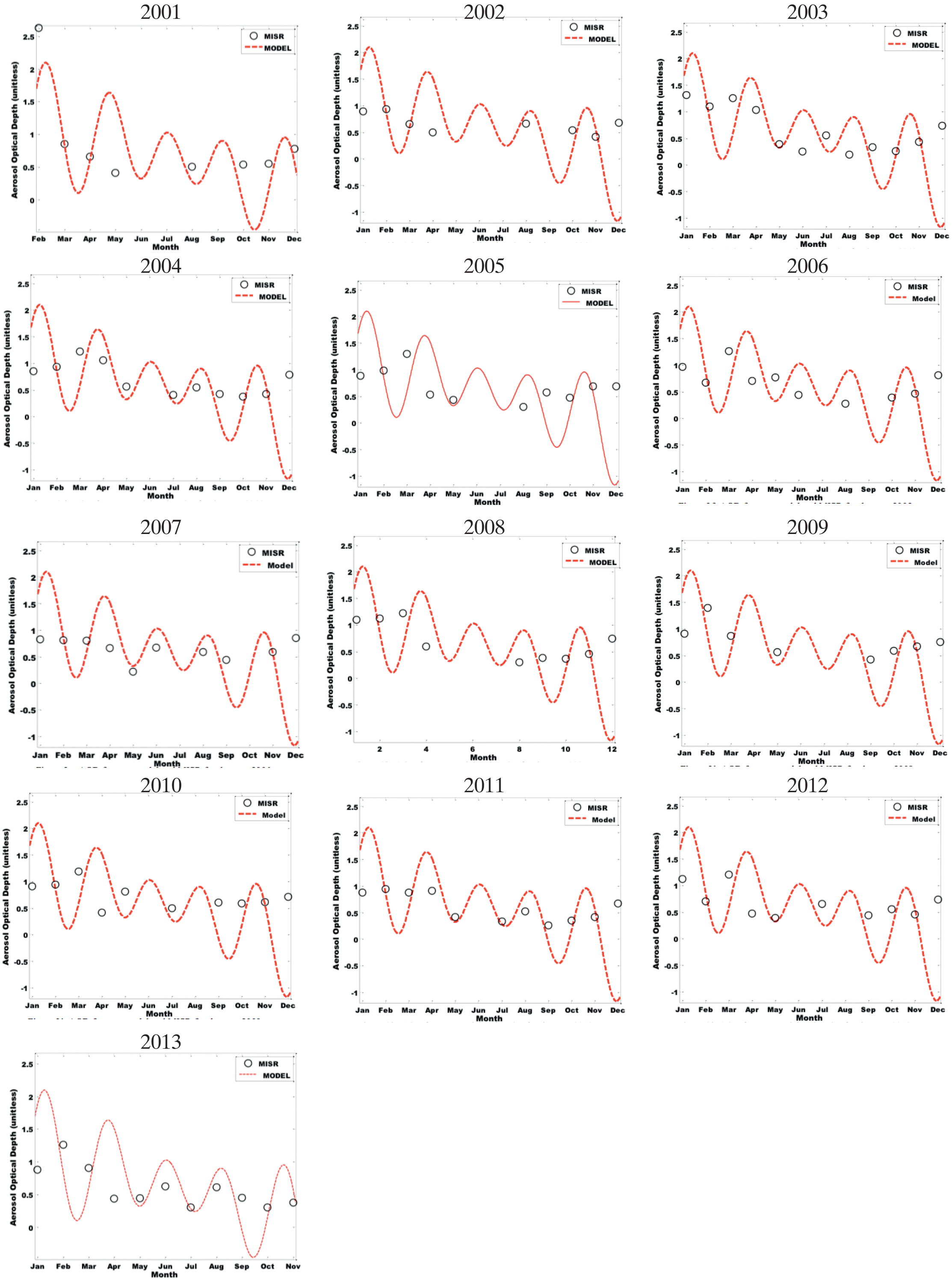

Figure 3. AOD for new model and MISR for years 2001 to 2013.

Slika 3. Optička debljina atmosfere (AOD) dobivena mjerenjima MISR i novim modelom za godine od 2001. do 2013.

Table 2. Atmospheric constants, tuning constants and phase difference for Lagos.

Tablica 2. Atmosferske konstante, konstante podešavanja i fazna razlika za Lagos.

Location	a_1	a_2	n_1	n_2	α	β
Lagos	1.175	0.8227	0.2926	0.3573	π/2	π/2

The atmospheric/calibration constants, tuning constants and phase differences for Lagos was calculated using Equation 1 and the values are given in Table 2.

The parameters in Table 2 are: atmospheric constants (a_1 and a_2) which moderates the transmitted or received signals in accordance to the actual aerosol loading over a geographical area; phase difference (α and β) is the difference in degrees or time between two or more signals having the same frequency and referenced to the same point in time. This parameter guides the installation of ground stations dedicated to examining atmospheric profiles. Also, it may apply to satellite sensor positioning for maximum data retrieval and provides accurate low multipath measurements when the common-mode time variations are adequately calibrated. Tuning constants n_1 and n_2 moderates the signaling angular positions. For instance, if the Canadian general climate model (GCMII) is adopted in Lagos without reconfiguring the compact flash card, its optical state, as well as its data retrieval would be very poor because its constants differ from the constants given in Table 2.

It is important to note that this paper has significant interest to the ITU model because it suggests notable alterations

$$N = \frac{77.6P\varpi}{T} + 3.73 \times 10^5 \frac{e}{T^2} = \\ = N_{dry} + N_{wet}(N - units) \tag{7}$$

where e is the water vapour pressure, P is the atmospheric pressure (hPa), ϖ is the aerosol retention and T is the absolute temperature (K). The mathematical relationship between relative humidity and water vapour pressure is expressed in the following equation:

$$e = \frac{RH}{100} a\varpi exp\left[\frac{bT}{T+c}\right] \tag{8}$$

Here T is the temperature in °C and the coefficients a, b and c have the following values: a = 6.1121, b = 17.502 and c = 240.97. The implication of this research upon the understanding of the results from Leck and Svensson (2015) is that the determination of coefficients a, b and c are influenced by the optical state over a geographical location. The study proposes an inclusion of the attenuation due to moving aerosols layer into the ITU model which is significant for tropical region.

Finally, the authors attempted to find the relationship between the satellite and ground dataset. This section explains why the proposed model was perfect, i.e. considering the reliability of the satellite and ground measurement. However, Figure 4 shows that there is no considerable relationship between these two kind of data.

Figure 4 indicates that it is not reliable to estimate satellite information by using recorded data on ground due to poor correlation obtained for these data. One of the reasons for this result can be found using trend analysis of both observed and estimated data (Fig. 5 and Fig. 6).

According to Figures 5 and 6 there is no significant trend in the satellite and ground dataset. It is notable that similar results were observed for other wavelengths (i.e. 555, 670 and 865 nm). Therefore, these anomalies (Fig. 5 and Fig. 6) approve the earlier hypothesis that the satellite and ground observations may not be relied upon without a periodic re-estimation of the atmospheric constants (Fig. 4).

The only two observed trends belong to ground information. There is a significant downward trend in February data (-9.2%, Fig. 6). There is a significant upward trend in June (3.2%). So, more focus on the conditions of these two months may give useful information to justify the obtained significant monotonic

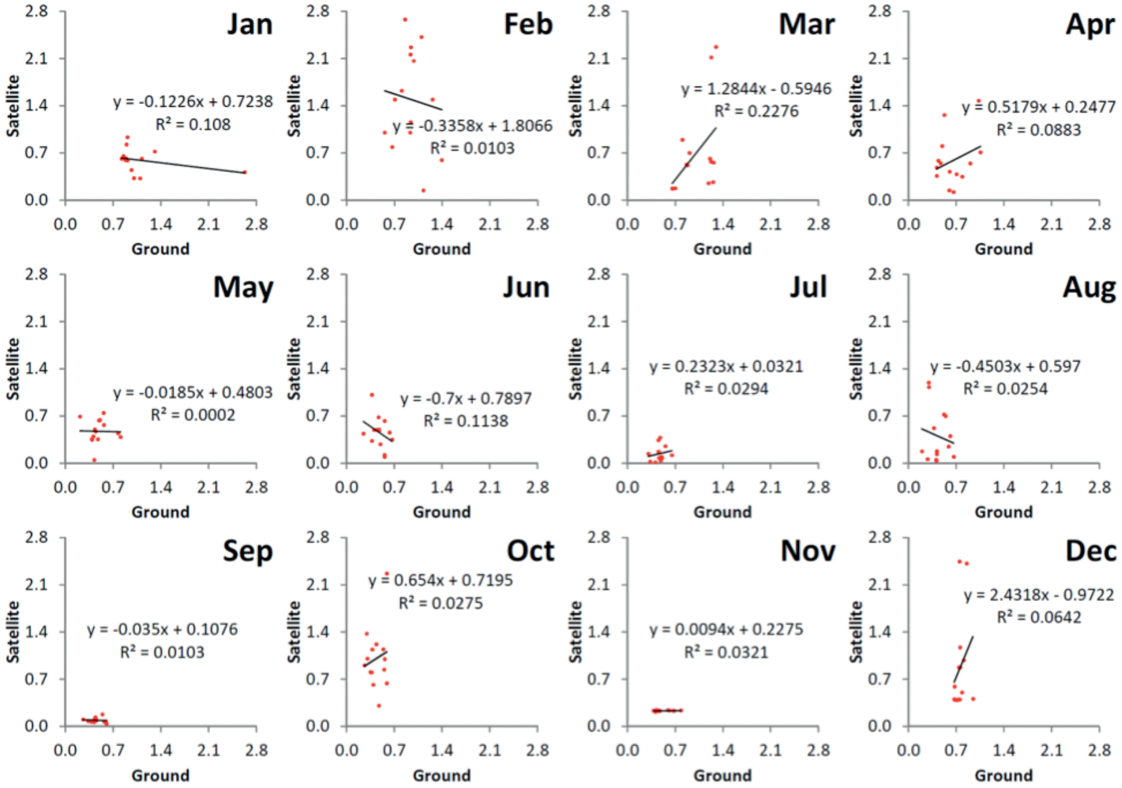

Figure 4. Regression analysis to assess the relationship between ground and satellite data (wavelength 443 nm).

Slika 4. Regresijska analiza veze između prizemnih i satelitskih podataka (valna duljina 443 nm).

trends. Figure 6 also shows that there is a decreasing non-significant trend from December to May and an increasing non-significant trend from June to October (except September). It should be noted that more investigations on satellite and ground observations is required i.e. considering the role of climate change.

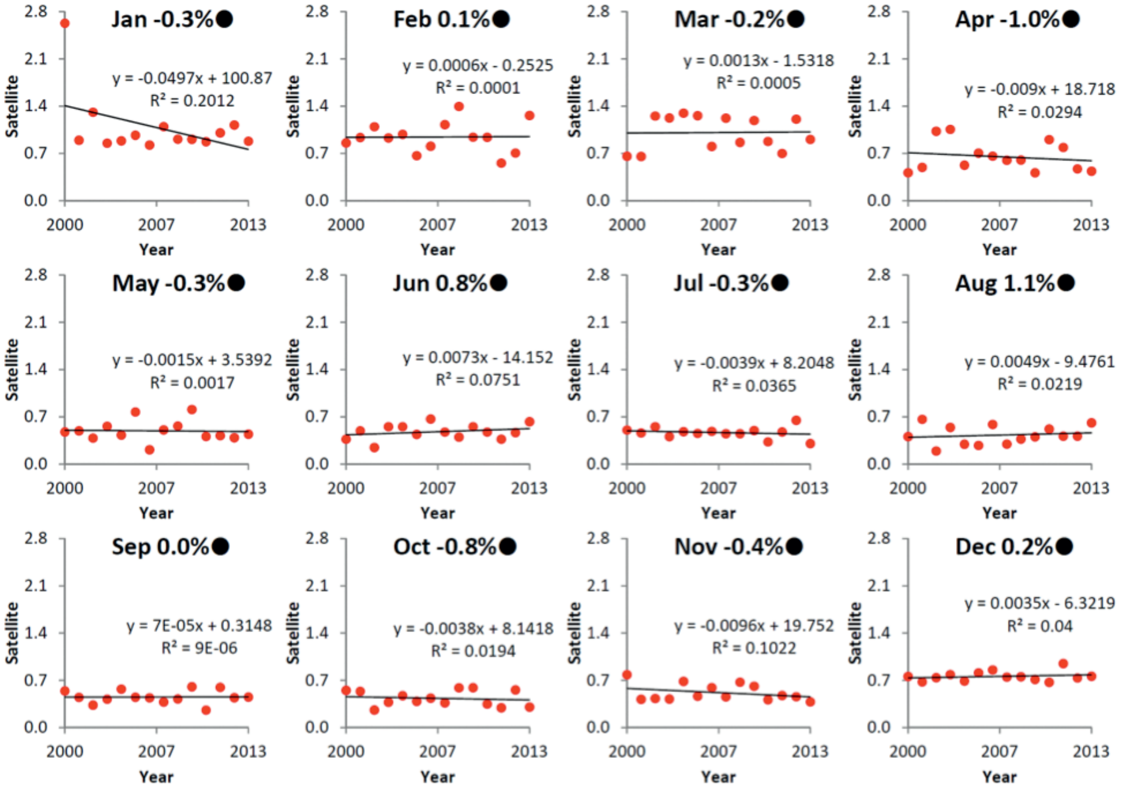

Figure 5. Trend analysis of satellite data (wavelength 443 nm), black circles indicate no significant trend and the values indicate the rates of variations by MK test.

Slika 5. Analiza trenda satelitskih podataka (valna duljina 443 nm), crni krugovi znače da nema značajnog trenda, a vrijednosti predstavljaju iznos varijacije MK testa.

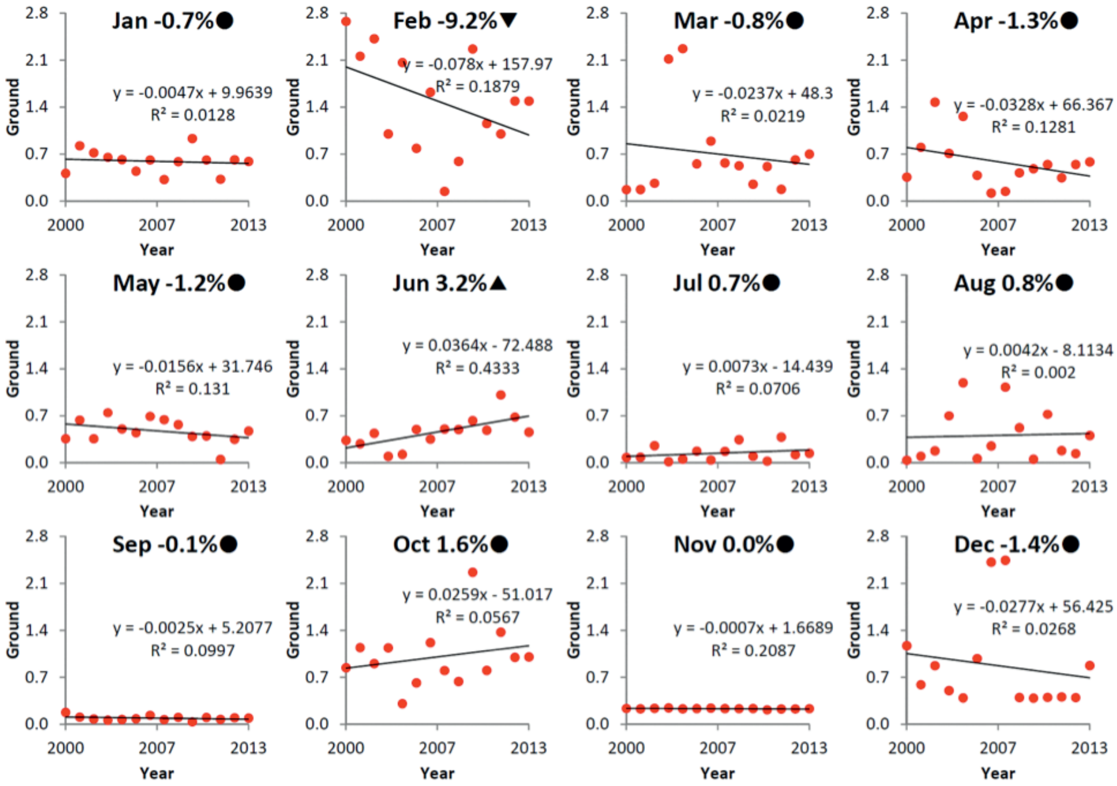

Figure 6. Trend analysis of ground data, black circles indicate no significant trend, triangular indicate significant trend (at the confidence level 90%) and the values indicate the rates of variations by MK test.

Slika 6. Analiza trenda prizemnih podataka, crni krugovi znače da nema značajnog trenda, a trokuti označavaju značajan trend (razina pouzdanosti 90 %), vrijednosti predstavljaju iznos varijacije MK testa.

4. CONCLUSION

The proposed model was successfully applied to determine the calibration constant over Lagos. The reliability of the fourteen years satellite (MISR) dataset and eighteen months ground (AERONET) were validated using the regression analysis and Mann-Kendall test. There was a poor correlation between the satellite and ground data set over Lagos-Nigeria. We used the instrumentality of the modified dispersion equation to obtain the atmospheric constants via the Matlab curve fitting tool. The curve fitting tool showed that the proposed model could predict a minimum of five months and maximum of nine months within any year in Lagos. These results further affirm the authenticity of the atmospheric constants over the troposphere of Lagos. The atmospheric constants over Lagos-Nigeria are: $a_1 = 1.175$, $a_2 = 0.8227$, $n_1 = 0.2926$, $n_2 = 0.3573$, and $\alpha = \beta = \pi/2$. Hence, the objective of the paper, that is, to document the calibration constants (which include the atmospheric constants, tuning constants and phase difference) over Lagos was successfully achieved. This shows that radiosonde and other measuring instrument could achieve over eighty percent data retrieval on a daily basis. We suggest the inclusion of aerosol retention factor in the ITU model. Hence, the documentation of atmospheric constant over Lagos is a novel concept which affects satellite communication industry, aviation industry, meteorological stations and disease control agencies.

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REFERENCES

Abdel-Ghany, A.M., I.M. Al-Helal and M.R. Shady, 2014: Evaluation of human thermal comfort and heat stress in an outdoor urban setting in summer under arid climatic conditions. *Environment Protection Engineering*, **40**(3), 139–150.

Adebiyi, A.A., Z. Paquita and J.A. Steven, 2015: The convolution of dynamics and moisture with the presence of shortwave absorbing aerosols over the southeast atlantic. *Journal of Climate*, **28**, 1997–2024.

Arai, K. and X.M. Liang, 2011: Comparative calibration method between two different wavelengths with aureole observations at relatively long wavelength. *Int. J. Appl. Sci.,* **2**, 93–101.

Avdikos, G., 2015: Powerful Raman lidar systems for atmospheric analysis and high-energy physics experiments. *EPJ Web of Conferences*, **89**, 04003.

Bojanowski, J.S., R. Stöckli, T. Anke and K. Heike, 2014: The impact of time difference between satellite overpass and ground observation on cloud cover performance statistics. *Remote Sensing*, **6**, 12866–12884.

Boucher, O. and J. Quaas, 2013: Water vapour affects both rain and aerosol optical depth. *Nature Geosciences*, **6**, 4–5.

Cornacchia, C., et al, 2004: The IMAA Raman lidar system for water vapour measurements. *Reviewed and revised papers presented at the 22nd International Laser Radar Conference (ILRC22)*, Matera, Italy, **ESA SP-561**, 107–110.

Dani, K.K., R.S. Maheskumar and P.C.S. Devara, 2003: Study of total column atmospheric aerosol optical depth, ozone and precipitable water content over Bay of Bengal during BOBMEX-99. *Journal of Earth System Science,* **112** (2), 205–221.

Emetere, M.E., 2016: Generation of atmospheric constants over some locations in West Africa: A Theoretical Aid for Measuring Instruments Design. *International Journal of Engineering Research in Africa*, **27**, 119–146.

Emetere, M.E., 2017: Investigations on aerosols transport over micro- and macro-scale settings of West Africa. *Environ. Eng. Res.,* **22**(1), 75–86.

Emetere, M.E., M.L. Akinyemi and U.E. Uno, 2015a: Computational analysis of aerosol dispersion trends from cement factory. *IEEE Proceedings of the International Conference on Space Science & Communication,* 288–291.

Emetere M.E., M.L. Akinyemi and O. Akinojo, 2015b: A novel technique for estimating aerosol optical thickness trends using meteorological parameters. *2015 PIAMSEE: AIP Conference Proceedings,* **1705** (1), 020037.

Emetere, M.E., O.A. Akinwumi, T.V. Omotosho and J.S. Mandeep, 2015c: A tropical model for analyzing radio refractivity: Selected locations in North Central Nigeria. *International Conference on Space Science and Communication (IconSpace),* 292–296., doi: 10.1109/IconSpace.2015.7283760.

Emetere, M.E., L. Marvel, M.L. Akinyemi and O. Akinojo, 2016: Theoretical aid for measuring instruments in Niamey-Niger. *Proceedings of the World Congress on Engineering*, London, U.K., **II**, 737–741.

Emetere, M.E., M.L. Akinyemi, M.E. Ojewumi and B.M. Muhammad, 2018: Exploring the challenges confronting the West Africa climate system. *International Journal of Engineering and Technology,* **7** (3), 1881–1887.

Fioletov, V.E. et al, 2002: Global and zonal total ozone variations estimated from ground-based and satellite measurements: 1964–2000. *Journal of Geophysical Research,* **107**(D22), 4647–4651.

Gilbert, R.O., 1987: Statistical methods for environmental pollution monitoring. John Wiley & Sons, 336 pp.

Hasebe, F. and T. Noguchi, 2015: A Lagrangian description on the troposphere-to-stratosphere transport changes associated with the stratospheric water drop around the year 2000. *Atmospheric Chemistry and Physics,* **15**, 28037–28068.

Holzbecher, E., 2012: Environmental modeling using MATLAB. Springer, Heidelberg, doi: 10.1007/978-3-642-22042-5.

Kendall, M.G., 1975: Rank correlation methods. 4th edition, Charles Griffin, London.

Kiedron, P.W., J.J. Michalsky, J.L. Berndt and L.C. Harrison, 1999: Comparison of spectral irradiance standards used to calibrate shortwave radiometers and spectroradiometers. *Appl. Opt.,* **38**, 2432–2439.

Leck, C. and E. Svensson, 2015: Importance of aerosol composition and mixing state for cloud droplet activation over the Arctic pack ice in summer. *Atmos. Chem. Phys.,* **15**, 2545–2568.

Li, S., R. Kahn, M. Chin, M.J. Garay and Y. Liu, 2015: Improving satellite-retrieved aerosol microphysical properties using GOCART data. *Atmos. Meas. Tech.,* **8**, 1157–1171.

Madonna, F. et al, 2011: CIAO: the CNR-IMAA advanced observatory for atmospheric research. *Atmos. Meas. Tech.,* **4**, 1191–1208.

Mann, H.B., 1945: Non-parametric tests against trend. *Econometrica*, **13**, 163–171.

Mikhalev, A.V., A.T. Mikhail, M.A. Chernigovskaya and A. Yu, 2003: Erythemal ultraviolet radiation as deduced from data of ground-based and satellite measurements. *Ninth Joint International Symposium on Atmospheric and Ocean Optics/Atmospheric Physics: Part II, Proceedings of SPIE,* **5027**, 256–258.

Mona, L. et al, 2007: Characterization of the variability of the humidity and cloud fields as observed from a cluster of ground-based lidar systems. *Q. J. Roy. Meteorol. Soc.,* **133**(S3), 257–271.

Peyrille, P., J.P. Lafore and J.L. Redelsperger, 2007: An idealized two-dimensional framework to study the West African monsoon. Part I: Validation and key controlling factors. *J. Atmos. Sci.,* **64**, 2765–2782.

Schotland, R.M. and T.K. Lea, 1986: Bias in a solar constant determination by the Langley method due to structured atmospheric aerosol. *Applied Optics,* **25**, 2486–2492.

Srivastatva, R. and S. Ramachandran, 2013: The mixing state of aerosols over the Indo-Gangetic Plain and its impact on radiative forcing. *Quat. J. of Royal Meteo. Soc.,* **139** (670), 137–151.

Sun, B., A. Reale, S. Schroeder, D.J. Seidel and B. Ballish, 2013: Toward improved corrections for radiation induced biases in radiosonde temperature observations. *J. Geophys. Res. Atmos.,* **118**, 4231–4243.

Vaisala, Oyj, 2014: User's guide, Ozone Sounding with Vaisala Radiosonde RS41.

Vijayakumar, K. and P.C.S. Devara, 2013: Study of aerosol optical depth, ozone, and precipitable water vapour content over Sinhagad, a high-altitude station in the Western Ghats. *International Journal of Remote Sensing,* **34** (2), 613–630.

Wang, J., M.J. Cubison, A.C. Aiken, J.L. Jimenez and D.R. Collins, 2010: The importance of aerosol mixing state and size-resolved composition on CCN concentration and the variation of the importance with atmospheric aging of aerosols. *Atmos. Chem. Phys.,* **10**, 7267–7283.

Welton, E.J. et al, 2002: Measurements of aerosol vertical profiles and optical properties during INDOEX 1999 using micropulse lidars. *Journal Geophysical Research,* **107** (D1), 8019.

Wilson, R., H. Luce, H. Hashiguchi, N. Nishi and Y. Yabuki, 2014: Energetics of persistent turbulent layers underneath mid-level clouds estimated from concurrent radar and radiosonde data. *J. Atmos. Sol.-Terr. Phy.,* **118** (A), 78–89.

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