INFERRING AEROSOL PROPERTIES AND RADIATIVE FORCING OVER GOBABEB, NAMIBIA USING GROUND BASED REMOTE SENSING

J.A. Adesina[1], S. J. Piketh[1], P. Formenti[2], G. Maggs-Kölling[3], B. N. Holben[4] and M. G. Sorokin[5]

[1]School of Geo- and Spatial Science, Unit for Env. Sc. and Management, North-West University, Potchefstroom
[2]Laboratoire Interuniversitaire des Systèmes Atmosphériques, UMR-CNRS 7583, Universités Paris-Est- Créteil and Paris Diderot, Institut Pierre Simon Laplace, Créteil, France
[3]Gobabeb Research and Training Centre, Walvis Bay, Namibia
[4]Laboratory for Terrestrial Physics, NASA Goddard Space Flight Center, Greenbelt, MD
[5]Science Systems and applications Inc. NASA Goddard Space Flight Center, Greenbelt, MD

Keywords: Gobabeb, Aerosol Optical Depth, Volume Size Distribution, Radiative Forcing

Email: joseph.adesina@nwu.ac.za

This study, based on twelve month data (December 2014 to November 2015)investigates the columnar optical properties of aerosol over Gobabeb, Namibia (23.56S, 15.04E, 405asl) using ground based remote sensing. An AERONET station was established at Gobabeb in August 2014 but started functioning consistently in November same year. Aerosol optical depth AOD_{500} has its maximum and minimum values in August (0.37±0.30) and June (0.06±0.02) respectively. The Angström parameter is mostly above unity and indicates the prevalence of fine particles for most part of the year with maximum and minimum in August (1.44±0.19) and December (0.57±0.19), respectively. The columnar water vapor was highest in March (2.09±0.58) and lowest in June (0.76±0.27). The volume size distribution shows the fine particles having a mean radius at 0.16 µm) and the coarse mode about 3 µm). Aerosol radiative forcing shows cooling effect at the atmosphere only in April and May but shows heating effect throughout the other months with a peak of 19.97 W m^{-2} in August.

A. INTRODUCTION

Aerosol study in the past four decades or more has yielded some positive results as their impacts are gradually being known based on modelling, in situ measurements from campaigns and long-term measurements from both ground and satellite-based instruments. Their optical, radiative and microphysical properties are not totally evasive as it used to be in many years gone by. The uncertainties on these properties mostly derive from the spatial and temporal variability of the aerosol load, as well as on the diversity of the mechanisms of formation and emission. As a consequence, aerosols from desert dust, biomass burning or oceanic origin behave differently from each other and differ in their impact on climate and health (Stocker et al., 2013). Especially in light of dynamic regional socio-economic change, the coastal stratocumulus cloud deck off of Namibia and Angola and the near coastal, South Atlantic Ocean is thought to have a potentially important radiative, biogeochemical and hydrological impact on the local, regional and possibly global climate. There is the need to build upon the success of a number of prior large-scale regional land-atmosphere experiments conducted in the region over the past decades: the Transport and Atmospheric Chemistry near the Equator-Atlantic (TRACE-A); the Southern African Fire-Atmosphere Research Initiative (SAFARI-92); the Southern African Atmospheric Research Initiative SAFARI-2000. These campaigns showed that: a) Southern Africa is an important region of the world in terms of global emissions to the atmosphere and a good natural laboratory to evaluate the earth (land and ocean), atmosphere interactions, and b) critical gaps remain in our understanding of the fate and impacts of the emissions on the functioning of the regional land-atmosphere-ocean systems. To fill these gaps, the regional international Sea-Earth-Air Linkages in southern Africa (SEALS-sA) programme has recently been initiated in order to promote coordinated field experiments and long-term monitoring along the west coast of southern Africa. In this framework, the Gobabeb Research and Training Center research station hosts an ongoing research program consisting in the long-term measurements meteorological parameters, aerosols and fog. In this paper we discuss the preliminary results of observations of the column aerosol optical properties provided by the AERONET sunphotometer located at the station.

B. SITE AND INSTRUMENTATION

a. Site

The Gobabeb Research and Training Center (GRTC; 23.6° S, 15.0° E, 405 m above sea level; http://www.gobabebtrc.org/) is located at Namib Desert in the southwestern African coast. This desert stretches nearly 2000 km from South Africa to Namibia. .

b. Instrumentation

The sun/sky sunphotometer (CE-318 CIMEL Inc, Paris, France) is a radiometer is capable of taking both direct sun and diffuse sky measurements (Holben et al., 1998). The instrument keeps track of the sun with the sensor head being within 1º of the sun approximately. Measurements are transmitted through METEOSAT geostationary satellite being received and monitored from NASA Goddard Space Flight Center in USA. The instrument takes direct sun measurements at eight spectral channels of 340, 380, 440, 500, 675, 870, 940 and 1020 nm with the 940 nm band use to measure columnar water vapor approximately every 15 minutes throughout the day. The diffuse radiance measurements in the solar almucantar or principal plane are taken at four spectral bands 440, 675, 870 and 1020 nm in the mornings and afternoon mostly at low solar elevation. From those measurement, the single scattering albedo, refractive index, volume size distribution etc. are retrieved using an inversion algorithm. More details regarding the error estimation, uncertainties, calibration protocols, etc. has been presented in (Dubovik et al., 2002; Dubovik and King, 2000). AERONET observations are available at three levels; level 1.0 corresponding to raw data, level 1.5 corresponding to cloud-screened observations and level 2.0 corresponding to quality assured data to which recent calibration has been applied. In this paper, we present preliminary analysis using level 1.5 as the level 2.0 is only available for data prior April 2015. However, the uncertainty for AOD retrieval under cloud screened condition for wavelengths greater than 440 nm is < ± 0.01 and for shorter wavelengths < ± 0.02 or less than ± 5% uncertainty in the retrieval of the sky radiance measurements. Errors of retrieving particles in the size range $(0.1 \leq r \leq 7\mu m)$ do not exceed 10% except for very small values. SSA have uncertainty of about 0.03 – 0.05 depending onaerosol loading and types.Real and imaginary parts have about 0.3 – 0.5 and ± 0.04 respectively (Alam et al., 2012; Dubovik et al., 2002).

C. RESULT AND DISCUSSION

a. Monthly Variability of AOD_{500}, CWV and $\alpha_{440-870}$

The Fig 1 (a-c) shows the median values of each of the quantity indicated by the red horizontal line. The median values for each month was used in this case as the data have outliers which makes the frequency distribution of the data to be skewed and in such a case the mean will not be a good representative of the measure of the central tendency of each month. The day to day variability of aerosol optical depth within the month was moderate from January to July and afterwards the daily variation became high from August to October indicating a wide range of anthropogenic activities within these period. The median value ranges from 0.054 in February to 0.27 in August. September equally has high value of 0.26. The August and September peak of AOD is common in Southern Africa and corresponds to the peak of the biomass burning season and to the transport from other regions, especially Zambia (Kumar et al., 2013; Queface et al., 2011). The aerosol loading over this location is generally low with frequency distribution of 77% for AOD of 0.1 and less.This location although receive very little rainfall, show high amount of water vapor present in the atmosphere at the beginning of the year and the latter part of the year but low in the middle months of the year. The minimum recorded was in June (0.74 cm) and maximum was in January (2.89 cm). Higher values of the water vapor content in January and April can be associated with relative humidity as rainfall is higher in the earlier part of the year (Feb – May), then August and October from the trend observed between 2002 - 2011 (Eckardt et al., 2013). The values were reasonably low in the drier winter month. The Angstrom parameter is a qualitative factor determining aerosol size. It indicates the relative abundance of the accumulation mode to the coarse mode with higher values greater than 0.75 representing the dominance of the accumulation mode and vice versa. It has median values much less than 1.0 only in February, November and December (0.74, 0.54, 0.54) respectively. These are months that have higher values of the coarse mode. The Namib Desert dust and marine aerosols seems to have more contributions to the total particulate matter during these months. The highest value was in September (1.48) followed by August (1.44). The frequency distribution showed that values greater1.0 is 55.5% meaning there was a general prevalence of fine particles over Gobabeb.

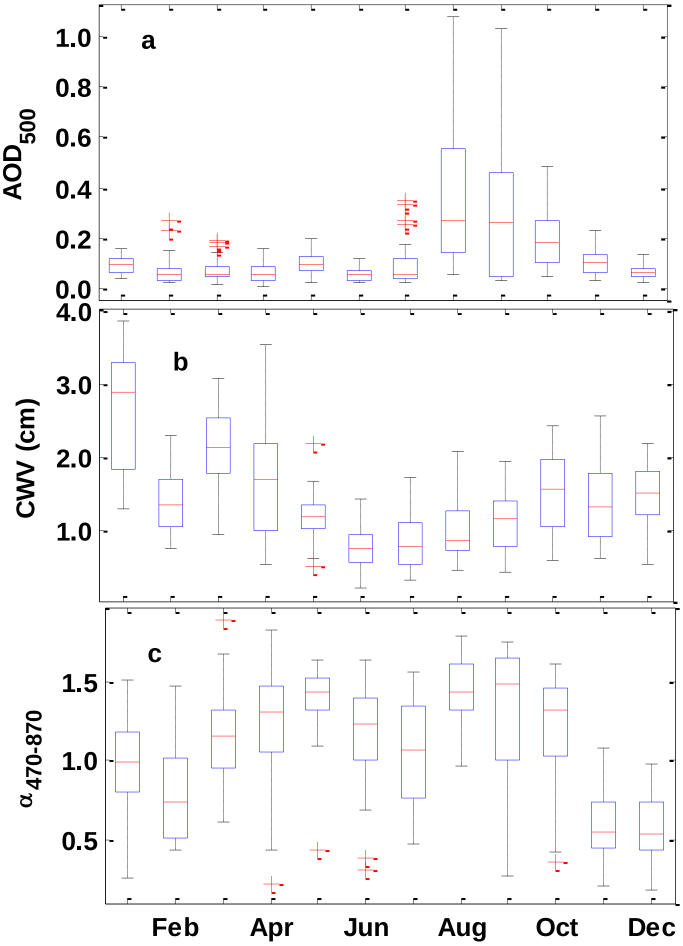

Fig 1 (a) Aerosol Optical depth at 500 nm (b) Columnar Water Vapor content and (c) Angstrôm parameter where the red line show the median value of each month, the vertical hinges represent data points from the lower to the upper quartile (i.e., 25th and 75th percentiles) and the whiskers represent data points from the 5th to 95th percentiles for the period December 2014 to November 2015 over Gobabeb.

b. Volume size Distribution and effective radius

The volume size distribution (VSD) account for the mixture of different types of aerosol present and advected into a location which are conditioned on scavenging processes and meteorological influences (Ali et al., 2014). In the AERONET retrievals the volume size distribution is represented in a lognormal form as

$$\frac{dV(r)}{d\ln r}=\sum_{i=1}^{n}\frac{C_i}{\sqrt{2\pi\sigma_i}}exp\left[\frac{-(\ln r-\ln R_i)^2}{2\sigma_i^2}\right]$$

Where C_i is the particle volume concentration, R_i is the median or geometric mean radius, σ_i is the variance or width of each mode, r is the particle radius, and n is the number of lognormal aerosol modes. In the Fig 2, the VSD shows a bimodal lognormal distribution which vary according to seasons with the spring season having the highest distribution for both accumulation and coarse modes. The winter has its highest distribution in the accumulation mode while the autumn and summer have their highest distribution in the coarse mode. The accumulation mode has its peak at a radius of about 0.16µm and the coarse mode range between 3 µm.

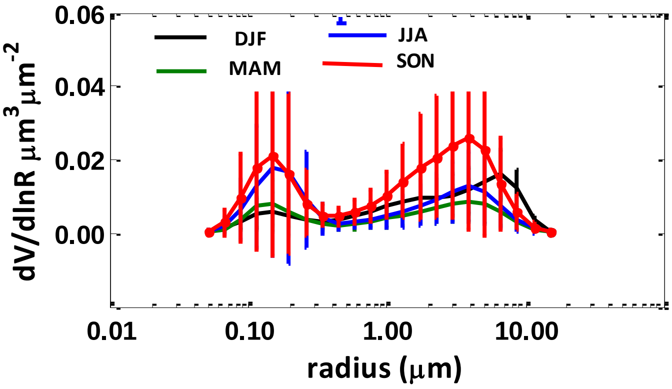

Fig. 2. AERONET retrieved volume size distribution in different seasons along with the standard deviations

c. Single Scattering Albedo

The single scattering albedo (SSA) is an important property in understanding aerosol radiative forcing and relates the ratio of scattering to extinction coefficient. It depends on the aerosol refractive index (that is on the composition) as well as the volume size distribution of the aerosol (Dubovik and King, 2000). SSA presents a distinct spectral behavior depending on the type of aerosol; increase with wavelength will indicate that aerosols absorbs more in the UV part of the spectrum. Such aerosols are large in size representing UV-absorbing compounds such as iron oxides from desert dusts while decrease with wavelength is mostly characteristic of fine aerosols which absorbs at shorter wavelengths. Such small size particles are associated with black carbon from biomass or urban/industrial aerosol (Dubovik et al., 2002). The seasonal plot of the SSA is shown in Fig 3. In summer (DJF), there is a slight increase from the shorter to the longer wavelength having values of 0.881, 0.883, 0.885 and 0.890 at (440, 675, 870 and 1020 nm). This indicates that particle of larger sizes predominates this season. These particles can be of desert origin or formed from hygroscopic growth of aerosols. In autumn, the spectral line decreased from 0.914 to 0.905 but later increased to 0.906 and further increased to 0.910 at the aforementioned wavelengths. This implies that the season is not particularly dominated by either fine or coarse particles as aerosols of different sizes make comparable contribution to the columnar aerosol loading. In winter, the spectral line has a constant decrease with wavelength, it means a higher absorption at shorter wavelength. This relates more to the predominance of biomass or urban/industrial aerosols with values of 0.837, 0.823, 0.808 and 0.799 respectively. Just like in the autumn the spectral line first increased in the lower but later decreased in the longer wavelength having values of 0.871, 0.878, 0.872 and 0.870 respectively. Previous studies in southern Africa showed that at Skukuza the range of SSA at visible wavelengths (440 – 675 nm) is between 0.91 and 0.89 while for Mongu its 0.87 and 0.83 respectively (Queface et al., 2011) but for Gobabeb it ranges between 0.88 and 0.87.

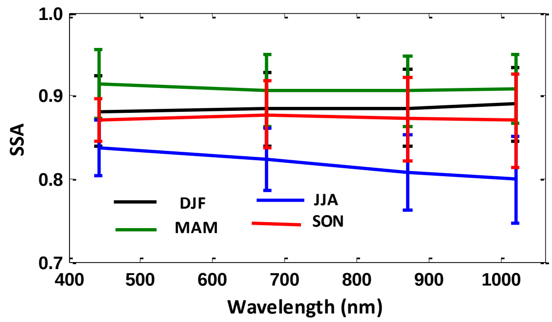

Fig. 3. Seasonal AERONET retrieved single scattering albedo at four different wavelengths along with the standard deviations

d. Refractive Index

The refractive index is made of the real n(λ) and the imaginary part k(λ). It reflects the ability of aerosol to scatter and absorb incoming radiation. The complex refractive indices for aerosol particles depends on the chemical composition. High values of the real part indicates scattering while high values of the complex part indicates absorption. In Fig 4, the seasonal real and imaginary parts of the refractive index for Gobabeb is shown. Comparing the real and the imaginary parts, it can be observed that the imaginary part exhibits larger dependence than the real part.

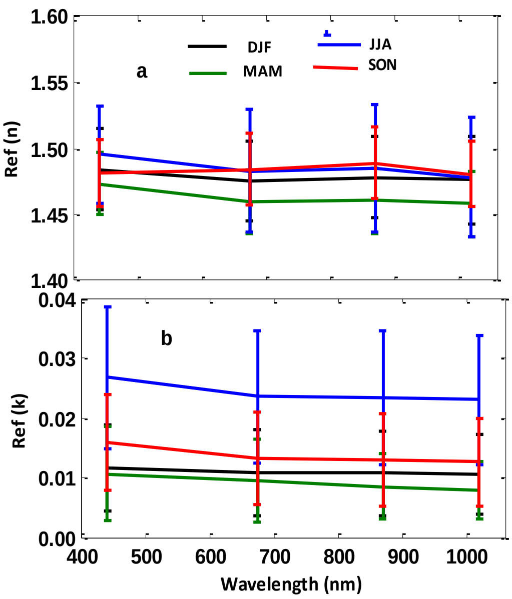

Fig. 4. Seasonal AERONET retrieved refractive index (a) Real (b) imaginary at four different wavelengths along with the standard deviations

The real part ranges between 1.47 and 1.49 in the shortest wavelength for all seasons but the imaginary part show higher absorption for winter (0.027) season followed by the spring (0.016). These seasons contain more of absorbing aerosols than the other seasons as indicated previously concerning the biomass season

e. Aerosol Radiative Forcing

Aerosol radiative forcing is defined as the difference between the downward (top of the atmosphere) and the upward (surface) fluxes of the short wave radiation with and without aerosols. This quantity is made available through the AERONET inversion code (calculated in the solar spectrum (0.2 – 4.0 µm)) and the assumptions has been extensively discussed in earlier works (Dubovik and King, 2000; Dubovik et al., 2006; García et al., 2011). García et al. (2011) further suggested that the value recorded for the surface forcing by AERONET is overestimated and needed to be corrected by (1-SA) where SA is the surface albedo. In this paper we have employed this method to make correction to the surface forcing. Table 1 shows the monthly radiative forcing over Gobabeb. The radiative forcing at the top of the atmosphere (TOA) which ranges from – 0.49Wm^{-2} in April to - 13.13 Wm^{-2} in August. The surface forcing – 0.04 Wm^{-2} in January to 6.83 Wm^{-2} was in August. The resultant effect on the atmosphere was lowest in November 0.34 Wm^{-2} and highest in August 19.97 Wm^{-2} resulting in warming effect but has cooling effect in April and May with values of -0.87 Wm^{-2}and -1.16 Wm^{-2} and heating effect for the rest of the months with highest in August (19.97 Wm^{-2}) and lowest in November (0.34 Wm^{-2}). The high value recorded during biomass burning episode is not unexpected.as biomass burning is associated with high absorbing aerosol.

Table 1: Monthly mean of aerosol radiative forcing over Gobabeb for December 2014 to November 2015

Month	TOA (wm^{-2})	Surface (Wm$^{-2)}$	Atmosphere (Wm^{-2})
Jan	-1.42	-0.05	1.37
Feb	-0.85	-0.78	0.08
Mar	-1.78	0.06	1.84
Apr	-8.70	1.52	10.22
May	-1.52	-2.68	-1.16
Jun	-1.78	0.06	1.84
Jul	-4.48	1.95	6.42
Aug	-13.13	6.84	19.97
Sep	-8.70	1.52	10.22
Oct	-3.99	-2.41	1.58
Nov	-2.05	-1.71	0.34
Dec	-12.41	1.31	13.72

D. CONCLUSION

Gobabeb like some other Southern African locations experiences high aerosol loading during the biomass season having its maximum AOD in August. The Angström parameter was above 1.0 for most part of the year indicating the prevalence of fine mode particles particularly when AOD was high. The radiative forcing at the atmosphere has a warming effect for most part of the year.

ACKNOWLEGDMENTS

Funding to this research is contributed by the Groupement de Recherche International "Atmospheric Research in Southern Africa and the Indian Ocean" (ARSAIO, CNRS/NRF) and the PHC PROTEA (contract n. 863243K) of the NRF and the French Ministries of National Education, of Research and of Foreign Affairs and International Development.

REFERENCES

Alam, K., Trautmann, T., Blaschke, T.andMajid, H. (2012). Aerosol optical and radiative properties during summer and winter seasons over Lahore and Karachi. *Atmospheric Environment, 50*, 234e245.

Ali, M., Tariq, S., Mahmood, K., Daud, A.andBatool, A. (2014). A study of aerosol properties over Lahore (Pakistan) by using AERONET data. *Asia-Pacific Journal of Atmospheric Sciences, 50*(2), 153-162.

Dubovik, O., Holben, B., Eck, T., Smirnov, A., Kaufman, Y., King, M., Tanre, D.andSlutsker, I. (2002). Climatology of aerosol absorption and optical properties in key worldwide locations. *J. Atmos. Sci, 59*, 590-608.

Dubovik, O.andKing, M. D. (2000). A flexible inversion algorithm for retrieval of aerosol optical properties from Sun and sky radiance measurements. *Journal of Geophysical Research, 105*(D16), 20673-20696.

Dubovik, O., Sinyuk, A., Lapyonok, T., Holben, B. N., Mishchenko, M., Yang, P., Eck, T. F., Volten, H., Muñoz, O.andVeihelmann, B. (2006). Application of spheroid models to account for aerosol particle nonsphericity in remote sensing of desert dust. *Journal of Geophysical Research: Atmospheres*, *111*(D11).

Eckardt, F., Soderberg, K., Coop, L., Muller, A., Vickery, K., Grandin, R., Jack, C., Kapalanga, T.andHenschel, J. (2013). The nature of moisture at Gobabeb, in the central Namib Desert. *Journal of arid environments, 93*, 7-19.

García, O., Díaz, J., Expósito, F., Díaz, A., Dubovik, O., Derimian, Y., Dubuisson, P.andRoger, J.-C. (2011). Shortwave radiative forcing and efficiency of key aerosol types using AERONET data. *Atmospheric Chemistry and Physics Discussions, 11*(12), 32647-32684.

Holben, B., Eck, T., Slutsker, I., Tanre, D., Buis, J., Setzer, A., Vermote, E., Reagan, J., Kaufman, Y.andNakajima, T. (1998). AERONET—A federated instrument network and data archive for aerosol characterization. *Remote sensing of environment*, *66*(1), 1-16.

Kumar, K. R., Sivakumar, V., Reddy, R., Gopal, K. R.andAdesina, A. J. (2013). Inferring wavelength dependence of AOD and Ångström exponent over a sub-tropical station in South Africa using AERONET data: Influence of meteorology, long-range transport and curvature effect. *Science of the Total Environment*, *461*, 397-408.

Queface, A. J., Piketh, S. J., Eck, T. F., Tsay, S.-C.andMavume, A. F. (2011). Climatology of aerosol optical properties in Southern Africa. *Atmospheric Environment*, *45*(17), 2910-2921.

Stocker, T., Qin, D., Plattner, G., Tignor, M., Allen, S., Boschung, J., Nauels, A., Xia, Y., Bex, B.andMidgley, B. (2013). IPCC, 2013: climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.