EPJ Web of Conferences **119**, 08003 (2016) DOI: 10.1051/epjconf/201611908003
ILRC 27

STUDY OF AFRICAN DUST WITH MULTI-WAVELENGTH RAMAN LIDAR DURING "SHADOW" CAMPAIGN IN SENEGAL

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ABSTRACT

West Africa and the adjacent oceanic regions are very important locations for studying dust properties and their influence on weather and climate. The SHADOW (Study of SaHAran Dust Over West Africa) campaign is performing a multi-scale and multi-laboratory study of aerosol properties and dynamics using a set of in situ and remote sensing instruments at an observation site located at IRD (Institute for Research and Development) Center, Mbour, Senegal (14^0N, 17^0W). In this paper, we present the results of lidar measurements performed during the first phase of SHADOW which occurred in March-April, 2015. The multiwavelength Mie-Raman lidar acquired $3\beta+2\alpha+1\delta$ measurements during this period. This set of measurements has permitted particle intensive properties such as extinction and backscattering Ångström exponents (BAE) for 355/532 nm wavelengths corresponding lidar ratios and depolarization ratio at 532 nm to be determined. The backscattering Ångström exponent during the dust episodes decreased to ~-0.7, while the extinction Ångström exponent though being negative, was greater than -0.2. Low values of BAE can likely be explained by an increase in the imaginary part of the dust refractive index at 355 nm compared to 532 nm.

1. INTRODUCTION

Africa is one of the major sources of atmospheric dust and numerous campaigns were organized to study the dust properties near the origin source [1,2,3]. The SHADOW (Study of SaHAran Dust Over West Africa) campaign is performing a multi-scale and multi-laboratory study of aerosol properties and dynamics using a set of in situ and remote sensing instrumentation (multi-wavelength Raman LIDAR, Wind-LIDAR,, nephelometer, aethalometer, sun/lunar photometer, airborne sunphotometer, optical particle counter) in the framework of the CaPPA (Chemical and Physical Processed in The Atmosphere) project (http://www.labex-cappa.fr/). The site is located at IRD (Institue for Research and Development) Center, Mbour, Senegal (14^0N, 17^0W). The objective of the experiment is to report the optical, chemical and physical properties of the aerosols as well as the source apportionment in a location where aerosol loading can be very large and aerosol type depends on the season. Two enhanced observing periods of 7 weeks are considered: March-April 2015 when dust originating from the Sahara/Sahel region is dominant and December 2015-January 2016 when dust and carbonaceous aerosols resulting from fire activities are in variable proportion and transported at different altitudes. Other types of aerosols can also be present such as sulfates from nearby urban areas or maritime aerosols depending on the air mass flow. The mixed state of these various chemical components results in different radiative properties of the aerosols.

We hereinafter focus our study on multiwavelength Mie-Raman lidar measurements performed during the first phase of the SHADOW campaign for the period 8 March - 24 April. During this period approximately 40 day- and night-time measurement sessions were performed and numerous strong dust episodes were observed.

2. LIDAR SYSTEM DESCRIPTION

The results presented were obtained with LILAS multi-wavelength Mie-Raman lidar based on a tripled Nd:YAG Spectra Physics INDI laser with a 20 Hz repetition rate. The laser output power at λ=355 nm is about 2 W. The backscattered light is collected by a 40-cm aperture Newton telescope operated at 47 dg to horizon. The system is capable of detecting three backscattered signals at the laser wavelengths and two Raman signals, thus three backscattering and two extinction coefficients (so called $3\beta+2\alpha$ set) can be calculated. The outputs of the detectors are recorded at 7.5 m range resolution using Licel transient recorders that incorporate both analog and photon-counting electronics. The full geometrical overlap of the laser beam and the telescope FOV is achieved at ~1500 m range, which determines the lower limit of the full set of our $3\beta+2\alpha$ measurements due to the difficulty of calculating aerosol extinction in the overlap region. To improve the system operational capabilities, we detected rotational Raman scattering at 530 nm instead traditionally used vibrational nitrogen backscatter at 608 nm. [4]. For each profile 4000 laser pulses were accumulated so the temporal resolution of the measurements was about 3 minutes. The measurements were performed both in day and night time. The system has also capability for depolarization measurements at 355 nm and 532 nm wavelengths.

3. DUST PARTICLE PROPERTIES DERIVED FROM RAMAN LIDAR OBSERVATIONS

The vertical distribution of particle intensive properties is strongly influenced by the origin of the air masses which during the SHADOW measurement period were arriving either from ocean or continental regions. In this section, we present the results of three measurements sessions on 13 and 29 March which were characterized by different types of air masses.

13 March

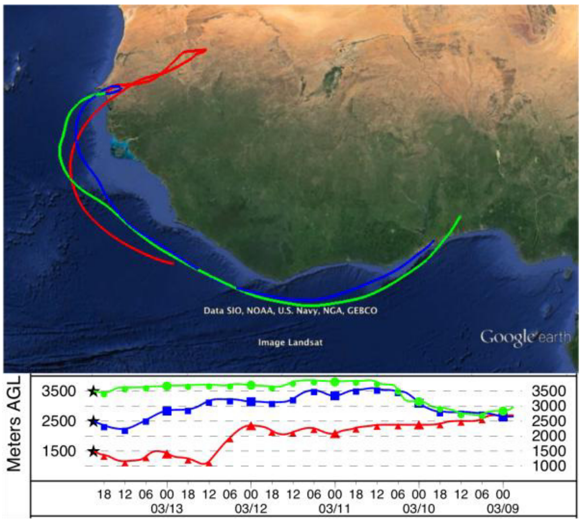

Fig.1. Five-day backward trajectories for the air mass in Mbour at altitudes 1500 m, 2500 m, 3500 m, on 13 March 2015 at 21:00 UTC.

As follows from fig.1, on 13 March the air masses at all heights were transported mainly over the ocean, but the back trajectory for 1500 m presents a “loop” over continent, so the corresponding air masses may contain more dust compared to other heights. Fig.2 shows the vertical profiles of $3\beta+2\alpha$ measurements together with lidar ratios LR_{355}, LR_{532}, depolarization ratio δ_{532}, and Angstrom exponents $A^{\alpha}_{355/532}$, $A^{\beta}_{355/532}$ on 13 March 2015. The aerosol layer extended up to 3500 m but the extinction coefficient α was relatively small; at both 355 and 532 nm wavelengths it did not exceed 0.16 km^{-1}. The particle depolarization ratio at 532 nm was approximately 31±4.5% inside the dust layer (up to ~2750 m) and decreased to less than 15% at 3250 m. Likewise, the $A^{\alpha}_{355/532}$ and $A^{\beta}_{355/532}$ are close to zero up to 2750 m, but above that height both EAE and BAE start to increase indicating the presence of smaller particles. The lidar ratios LR_{355} and LR_{532} are approximately 53±8 sr inside the dust layer. Above 2750 m uncertainties are larger but the mean values of LR do not seem to change above the 2750 m height.

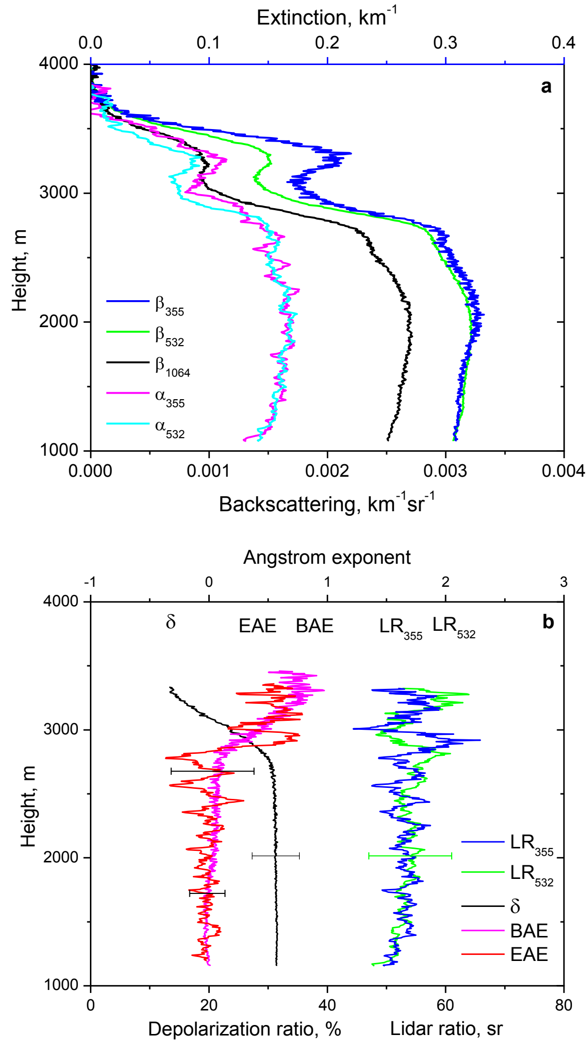

Fig.2. Vertical profiles of (a) backscattering and extinction coefficients and (b) lidar ratios, depolarization ratio, backscattering and extinction Angstrom exponents at 355/532 nm measured on 13 March 2015 for period 20:30-21:30 UTC.

29 March

The backtrajectories from the night of 29-30 March indicating a strong dust case are shown in Fig.3. The air masses at low altitude were transported over the continent and were strongly loaded with dust. Fig.4 presents the height profiles of the same particle parameters as in fig.2 but for 29 March. The extinction coefficient inside the dust layer (below 1500 m) is greater than 0.6 km^{-1} for both wavelengths. The backscattering coefficient at 355 nm inside the dust layer is lower than β_{532} which is consistent with the lidar ratio at 355 nm being larger than that at 532 nm with values as large as 65 sr.

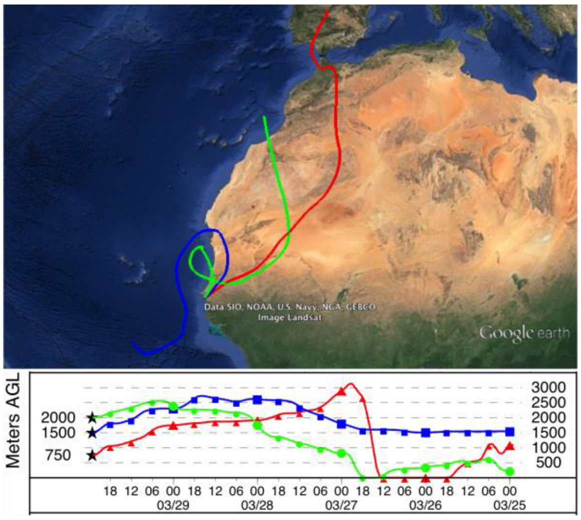

Fig.3. Five-day backward trajectories for the air mass in Mbour at altitudes 750 m, 1500 m, 2000 m on 29 March 2015 at 23:00 UTC.

The $A^{\beta}_{355/532}$ (BAE) is negative with a minimum value of less than -0.8, while EAE is still close to 0 as was observed on 13 March. The negative values of BAE observed on 29 March can be the result of the spectral dependence of the imaginary part of the dust refractive index (RI). It is well known that the imaginary part of RI of dust increases in the UV spectral region compared to that at 532 nm wavelength [3]. The ground based measurements performed during the SAMUM campaign demonstrated that the imaginary part of the dust RI could vary from m_I=0.005 at 532 nm to m_I=0.02 at 355 nm [3]. Such a strong enhancement of m_I may lead to a decrease of the backscattering coefficient [5].

To estimate the impact of the m_I enhancement at 355 nm on the values of EAE and BAE at 355/532 nm wavelengths, numerical simulations were performed. Extinction and backscattering Ångström exponents were calculated using the model of randomly oriented spheroids as described in [5] for a bimodal particle size distribution:

$$\frac{dn(r)}{d\ln(r)} = \sum_{i=f,c} \frac{N_i}{(2\pi)^{1/2}\ln\sigma_i} \exp\left[-\frac{(\ln r - \ln r_i)^2}{2(\ln\sigma_i)^2}\right]. \qquad (1)$$

where $N_{f,c}$ is particle number density in the fine (*f*) and the coarse (*c*) mode. Each mode is represented by a lognormal distribution with modal radius $r_{f,c}$ and dispersion $\ln\sigma_{f,c}$. For the fine mode the values r_f=0.1 μm, $\ln\sigma_f$=0.4 were used. For the coarse mode r_c=1.0 μm and three values $\ln\sigma_c$=0.4, 0.5, 0.6 were considered.

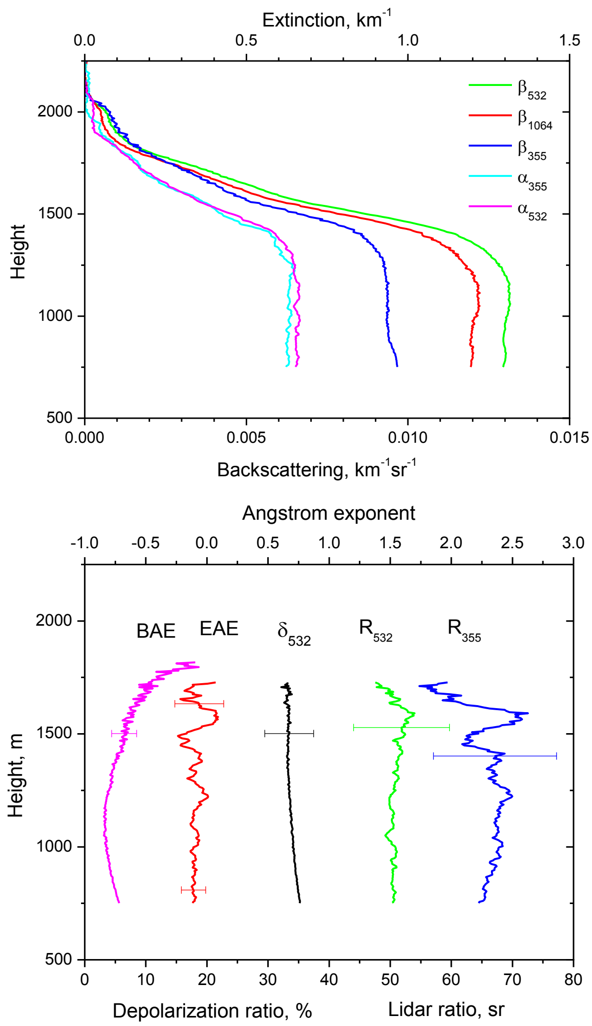

Fig.4. Vertical profiles of (a) backscattering and extinction coefficients and (b) lidar ratios, depolarization ratio, backscattering and extinction Angstrom exponents measured on 29 March 2015 for period 22:00-23:30 UTC.

Three size distributions used in computations are shown as insert in fig.5. The ratio N_c/N_f in all cases was 0.01, and the real part of CRI was 1.55 for all wavelengths. The imaginary part was fixed at 0.005 for 532 nm while it varied within the 0.005 – 0.05 range at 355 nm. Values of EAE and BAE as a function of m_I at 355 nm are given by fig.5. The EAE shows no significant sensitivity to changes in m_I, but BAE decreases rapidly with an increase of m_I at 355 nm. Although the present sensitivity study is limited, it illustrates the importance of accounting for the spectral dependence of $m_I(\lambda)$ in the analyses such as this.

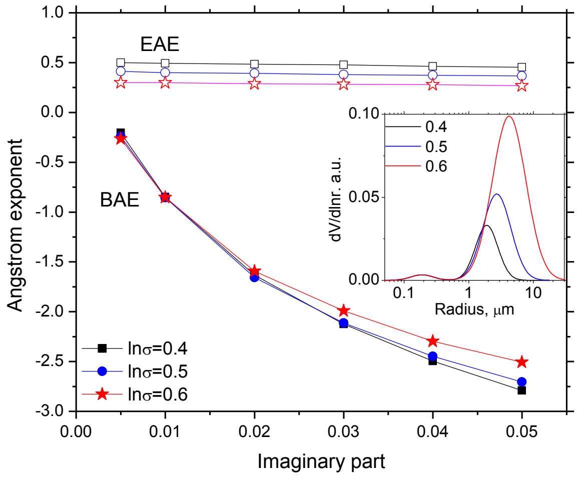

Fig.5. Extinction and backscattering Angstrom exponent for 355/532nm wavelengths as a function of the imaginary part of the refractive index at 355 nm. The CRI at 532 nm was kept m=1.55-i.005. Computations were performed using the model of randomly oriented spheroids for three bimodal PSDs shown in the insert.

CONCLUSION

The lidar measurements performed in March-April 2015 during the first phase of the SHADOW campaign in Senegal has provided a significant amount of information about dust particle parameters. The use of rotational Raman scattering in the LILAS for 532 nm observations improved the α_{532} measurements and, as a result, the calculation of lidar ratio and extinction Angstrom exponent were improved as well. The mean values of lidar ratios of pure dust were about 53±8 sr for both 532 nm and 355 nm wavelengths, which agrees with the values observed during SAMUM 1 (Morocco) and SAMUM 2 (Cape Verde) campaigns [3]. The mean value of particle depolarization ratio at 532 nm was 30±4.5%, however during strong dust episodes this ratio increased up to 35±5%, which is also in agreement with the results of SAMUM campaigns. The backscattering Angstrom exponent at 355/532 nm wavelengths during the dust episodes decreased to ~-0.7, while the EAE values, though being negative, were higher than -0.2. Low values of BAE may be a result of enhanced dust absorption at 355 nm.

Acknowledgments: Authors thank labex CaPPA for supporting this campaign and are very grateful to IRD-Dakar (Institut de Recherche pour le Développement) and specially A. Diallo and T. Ndiaye for their welcome and efficient support.

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