LIDAR RATIOS OF DUST OVER WEST AFRICA MEASURED DURING "SHADOW" CAMPAIGN

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ABSTRACT

The lidar ratios of Saharan dust at 355 and 532 nm (LR_{355} and LR_{532}) measured over West Africa during SHADOW field campaign are analyzed. Results demonstrate that even for pure dust, the lidar ratio may present strong height dependence. The possible reasons of height dependence of lidar ratios during strong dust events are considered.

1 INTRODUCTION

Atmospheric dust provides significant impact on the Earth system and this impact still remains highly uncertain. The Sahara desert is the largest source region of mineral dust, so quantification of the Saharan dust optical and microphysical properties is an important contribution to the study of the Earth radiative balance. In modeling the direct aerosol effect, the vertical profiles of the extinction coefficient belong to the basic inputs. When the extinction profiles are derived from the measurements of elastic backscatter lidar, the lidar ratio (extinction to backscattering ratio) is a key parameter in data inversion. The great advantage of Raman and HSRL lidars is in their ability to provide independent measurements of aerosol backscattering and extinction coefficients. The numerous lidar stations regular profile the properties of the Saharan dust layers during their transport to Europe and North America.

The properties of dust particles are modified during transport in atmosphere, so it is important to study the dust properties in the region of origin. Such observations were performed during SAMUM-1,2 experiments in 2006, 2008 (in Morocco and Capo Verde respectively), as well as during SHADOW campaign in Senegal in 2015-2016 in Senegal [1-5]. However, the dust is a mixture of various minerals whose relative abundance depends on dust origin, so even near the source of origin the dust properties may present significant variations. Atmospheric dust in Africa can also contain the products of biomass burning and the local pollutions. As a result, the comparison of lidar ratios observed during different campaigns my look controversy. The averaged values of LR observed during SAMUM-2 campaign, are LR_{355}=52.7±10.2 and LR_{532}=54.2±9.6 [3]. Corresponding averaged value of depolarization ratio at 532 nm is 31%, indicating that heavy dust episodes were predominant. In contrast to SAMUM, where lidar ratios at 355 and 532 nm were close, SHADOW measurements demonstrate that in many dust episodes the lidar ratio at 355 nm (LR_{355}) significantly exceeded LR_{532}, which was related by Veselovskii et al. [2] to increase of the imaginary part of the refractive index in UV. In our presentation we analyze vertical variation of the lidar ratios and consider relationship between LR_{355} and LR_{532} for different dust episodes.

2 EXPERIMENTAL SETUP AND RESULTS OF THE MEASUREMENTS

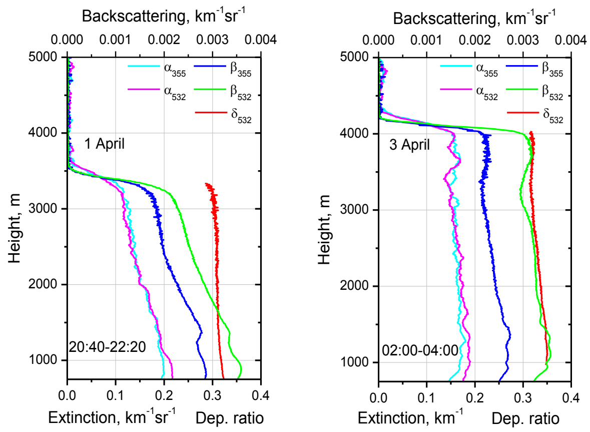

Figure 1. Vertical profiles of aerosol backscattering and extinction coefficients at 355 nm and 532 nm together with particle depolarization ratio δ_{532} for 1 April (20:40-22:20 UTC) and 3 April (02:00-04:00 UTC).

The instrumentation site is located at Mbour, Senegal. The observations were performed during March-April 2015 and December 2015-January 2016. Detailed information regarding the SHADOW campaign and the instruments is presented in [2]. The LILAS lidar is based on a tripled Nd:YAG laser with a 20 Hz repetition rate, and pulse energy of 90/100/100 mJ at 355/532/1064 nm. The aperture of the receiving telescope is 400 mm. The lidar allows evaluation of three particle backscattering (355 nm, 532 nm, 1064 nm) and two extinction coefficients (355 nm, 532 nm). To improve the system performance at 532 nm, the rotational Raman channel was used instead of the vibrational one.

2.1. Dust episode on 1-4 April 2015

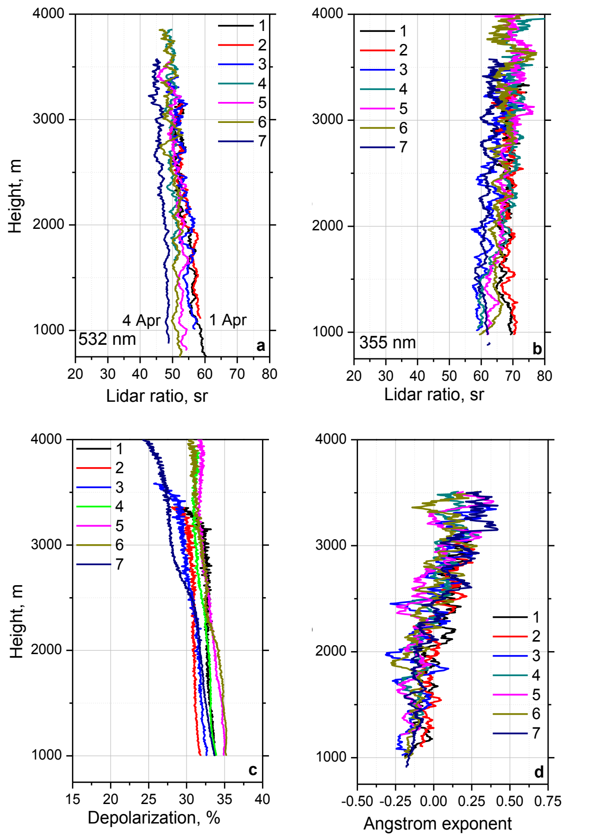

Figure 2. Vertical profiles of (a,b) the lidar ratios at 355 nm and 352 nm, (c) the particle depolarization ratio δ_{532} and (d) extinction Angstrom exponent at 355-532 nm for seven temporal intervals during 1-4 April period.

For period 1-4 April 2015 a strong dust episode occurred. Fig.1. shows vertical profiles of aerosol backscattering β and extinction α coefficients at 355 nm and 532 nm together with particle depolarization ratio δ_{532}, obtained during two measurements sessions on the nights 1-2 and 2-3 April. For both sessions δ_{532} exceeds 30%, and depolarization presents small decrease with height. The values α_{355} and α_{532} are close, while β_{355} exceeds β_{532}, which can be related to increase of the imaginary part m_I of the refractive index of dust at 355 nm, as discussed in [2].

Fig.2 shows profiles of lidar ratios at 355 nm and 532 nm for seven temporal intervals during 1-4 April sessions. At 1000 m height the LR_{532} decreases from 60 sr on 1 April to 50 sr by 4 April. Moreover, for all days lidar ratios at 532 nm decrease with height, reaching the value of 45 sr at 3500 m on 4 April. LR_{355} varies from 60 to 70 sr at 1000 m and, in contrast with LR_{532}, it rises with height, reaching 70 sr at 4000 m. The depolarization ratios for all sessions are above 30% and only on 4 April δ_{532} is below 30% near the top of dust layer. We should recall, that accuracy of calibration of depolarization measurements is about 15%, so day-to-day variations of depolarization can be partly due to uncertainty of calibration procedure. The Angstrom exponent is slightly negative (-0.15±0.1) at low heights, but it starts rising above 2000 m, indicating that particles become smaller.

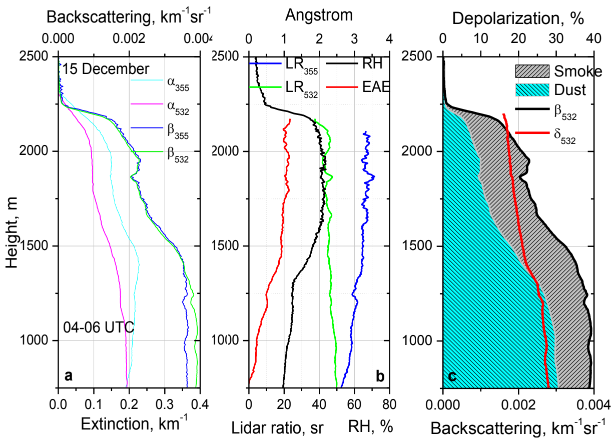

Figure 3. Vertical profiles of (a) extinction and backscattering coefficients at 355 and 532 nm, (b) lidar ratios, Angstrom exponent and relative humidity, (c) particle depolarization and decomposition of β_{532} for dust and smoke contributions.

One of possible explanations of observed height dependence of the particle intensive parameters is that at high altitudes the dust particles are mixed with another type of aerosol. The MERRA-2 aerosol transport model predicts, that for period considered the particles of organic carbon (main component of biomass burning aerosol) may occur above 2000 m [4]. Organic carbon (OC) is characterized by increased absorption in UV, which could explain the increase of LR_{355}. Presence of small OC particles could also explain the increase of the Angstrom exponent. However, for explanation of LR_{532} decrease with height we should assume that LR_{532} of OC is low. This may look unexpected, because lidar measurements usually provide high values of LR_{532} for the smoke (above 60 sr). We should keep in mind however, that our measurements were performed at condition of low relative humidity (below 30%).

2.2. Dust-smoke episodes

To analyze the values of lidar ratio of OC and their dependence on the relative humidity (RH), we have considered several smoke episodes during the campaign. The maximal value of RH in these episodes varied from 30% to 90%. The results obtained on 15 December 2015 are shown in Fig.3. The figure presents the lidar ratios at 355 and 532 nm together with profile of RH, calculated from lidar derived water vapor mixing ratio and radio sonde measured temperature. Maximal value of RH is below 40%. The LR_{532} and LR_{355} are close at 1000 m, but LR_{532} decreases with height from 50 sr to 40 sr, while LR_{355}, in opposite, increases up to 70 sr.

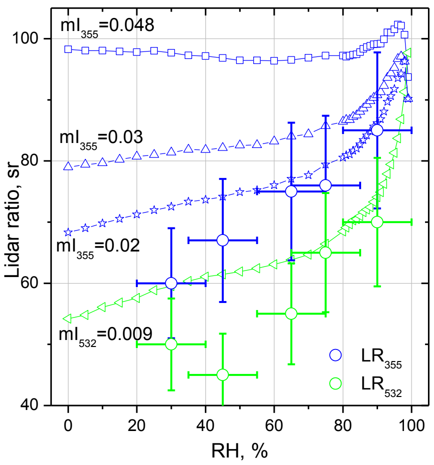

Figure 4. Lidar ratios LR_{355} and LR_{532} for five dust – smoke episodes (open symbols) together with simulated values (line + symbols). In simulation, three values of imaginary part of dry particles at 355 nm are considered: m_I =0.048, 0.03, and 0.02.

Assuming, that depolarization ratio of dust and smoke are known (35% and 7% correspondingly) the backscattering β_{532} can be decomposed for dust and smoke contributions [5], as shown in Fig.3c. The contribution of smoke to β_{532} becomes predominant above 2000 m, and corresponding value of LR_{532} is about 40 sr. For other dust - smoke episodes characterized by higher RH, the values of LR_{532} and LR_{355} are higher. Fig.4 shows dependence of lidar ratios on RH for five smoke episodes. Results are given for altitudes corresponding maxima of RH, where smoke contribution is predominant. The same figure shows the results of simulation, using parameters of OC from MERRA-2 model [4]. In simulation we considered three values of the imaginary part of dry particles at 355 nm: m_I =0.048, 0.03, 0.02. For 532 nm only one value m_I =0.009 was used. We should keep in mind, however, that smoke particles in different episodes may have different composition, so their properties depend not only on RH. For RH>70% the measured lidar ratios are in reasonable agreement with modeling (for mI_{355}=0.02), however for low RH the observed lidar ratios are smaller than modeled ones for both wavelengths.

2.3. Dust episode on 10-24 April 2015

Strong dust episode occurred also for period 10-24 April. Fig.5 shows extinction coefficients and lidar ratios at 355 and 532 nm for two sessions on 15-16 and 23-24 April. The depolarization ratio for both days is about 30%, so particles can be considered as a pure dust. Still, in contrast with 1-4 April episode, LR_{355} and LR_{532} are close, which can be an indication that absorption in UV is lower. To analyze the difference in dust origin, Fig.6 presents the back trajectories for 2 April (00:00 UTC) and 24 April (01:00 UTC). In first case, air mass arrives from North – East of Sahara. For second case, the origin of air mass above 1000 m is shifted more to the South. Close values of lidar ratios at 355 an 532 nm were observed for all sessions during this dust episode. It is possible, that difference between LR_{355} and LR_{532} for considered dust episodes is related to different mineralogy in the regions of dust origin.

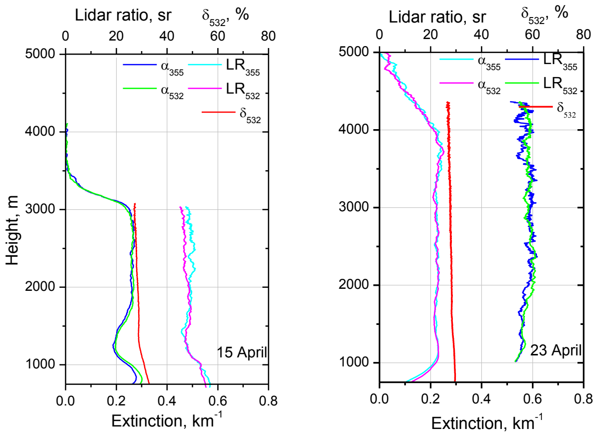

Figure 5. Vertical profiles of extinction coefficients and lidar ratios at 355 and 532 nm together with δ_{532} for the nights 15-16 and 23-24 April 2015.

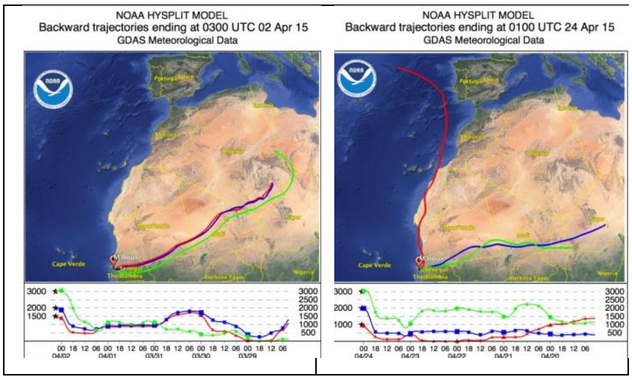

Fig.6. Back trajectory analysis for 2 April (00:00) and 24 April (01:00).

3 CONCLUSIONS

Presented results demonstrate that lidar ratio at 532 nm during dust episodes may decrease with height, which can be due to two reasons: presence of smoke near the top of the dust layer and height variation of the dust properties (in particular height variation of the imaginary part). Analysis of smoke episodes show that the lidar ratio of smoke depends on RH and varies from 40 to 70 sr at 532 nm. This confirms that smoke can contribute to the decrease of observed LR_{532} at condition of low humidity.

Observations demonstrate also that for some dust events the lidar ratios at 355 nm and 532 nm coincide, while for other episodes LR_{355} significantly exceeds LR_{532}. Such difference, in principle, can be the result if different mineralogy at the region of dust origin.

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