SAHARAN DUST AND BIOMASS BURNING AEROSOL CHARACTERIZATION: AIRBORNE HIGH SPECTRAL RESOLUTION LIDAR OBSERVATIONS OVER THE CAPE VERDE ISLANDS DURING SAMUM 2008

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ABSTRACT

Aerosol optical properties and their spatial distribution have been measured by airborne high spectral resolution lidar (HSRL) over the Cape Verde Islands during the Saharan Mineral Dust Experiment (SAMUM) 2008. The HSRL was operated aboard the Falcon research aircraft of the German Aerospace Center (DLR) together with an extensive set of aerosol *in–situ* probing instruments, two radiometers and a dropsonde system.

In contrast to the first SAMUM field campaign in Morocco during May/June 2006, where almost only pure Saharan dust was observed, three prominent aerosol types could be distinguished by means of their lidar– and aerosol depolarization–ratio during almost all flight missions over the Cape Verde Islands. Saharan dust plumes were observed to cover the lowermost 2 km above sea level (ASL) and partially mix with the marine boundary layer. Biomass burning aerosol layers which were advected from the central part of Africa reached up to 6 km ASL and contributed a fractional aerosol optical thickness (AOT) as high as 0.3 to the total AOT of the atmospheric column.

In this paper we present first results of mineral dust and biomass burning aerosol characterization during SAMUM 2008.

1. INTRODUCTION

The impact of aerosols on the Earth's radiation budget is still a highly uncertain quantity in global climate modeling [1]. Uncertainties associated with the aerosols' spatial distribution, their optical, and microphysical properties result in doubtful estimates of magnitude and sign of their radiative effects. Both, biomass burning aerosol and mineral dust are major constituents of the atmospheric aerosol in terms of mass loading and AOT [2] and are identified to exert a significant direct radiative forcing. During January and February 2008 the SAMUM 2 field experiment was carried out at Santiago / Cape Verde to investigate the radiative properties of aged Saharan dust and biomass burning aerosol originating from the central parts of Africa, respectively. Height resolved profiles of aerosol extinction are required for determining the direct radiative effects. Because of their high spatial and temporal resolution, lidar instruments are particularly suitable for remote sounding of the atmospheric aerosol.

In contrast to a conventional backscatter lidar, a high spectral resolution lidar is designed to spectrally separate the narrow bandwidth aerosol return from the strongly Doppler–broadened molecular backscatter spectrum [3; 4; 5]. Like in the Raman lidar technique [6] the decrease of molecular backscatter is used to directly determine aerosol extinction. Thus, no assumptions about the extinction–to–backscatter ratio the so–called lidar ratio are required. Because the lidar ratio is a prerequisite to derive extinction profiles from a normal backscatter lidar, the HSRL measurements are particularly important in the cases of biomass burning aerosol and pure Saharan dust where direct measurements are rare.

2. INSTRUMENTATION AND METHODS

For the HSRL measurements the narrow–bandwidth detector, which was already successfully deployed during SAMUM 2006 [7], was applied to the new DLR multi-wavelength H_2O DIAL *WALES*. The layout and performance of this new system will be presented in a separate paper within this issue. A high power, single longitudinal mode and frequency stabilized Nd:YAG laser in master oscillator / power amplifier configuration is used as the laser transmitter. Frequency doubling is done using a KTP crystal.

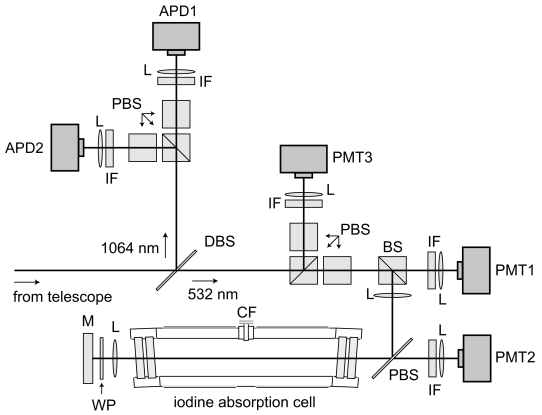

Figure 1: Part of the receiver used for aerosol detection at 1064 and 532 nm

The part of the lidar receiver used for aerosol detection is shown in figure 1. To spectrally separate the backscat-

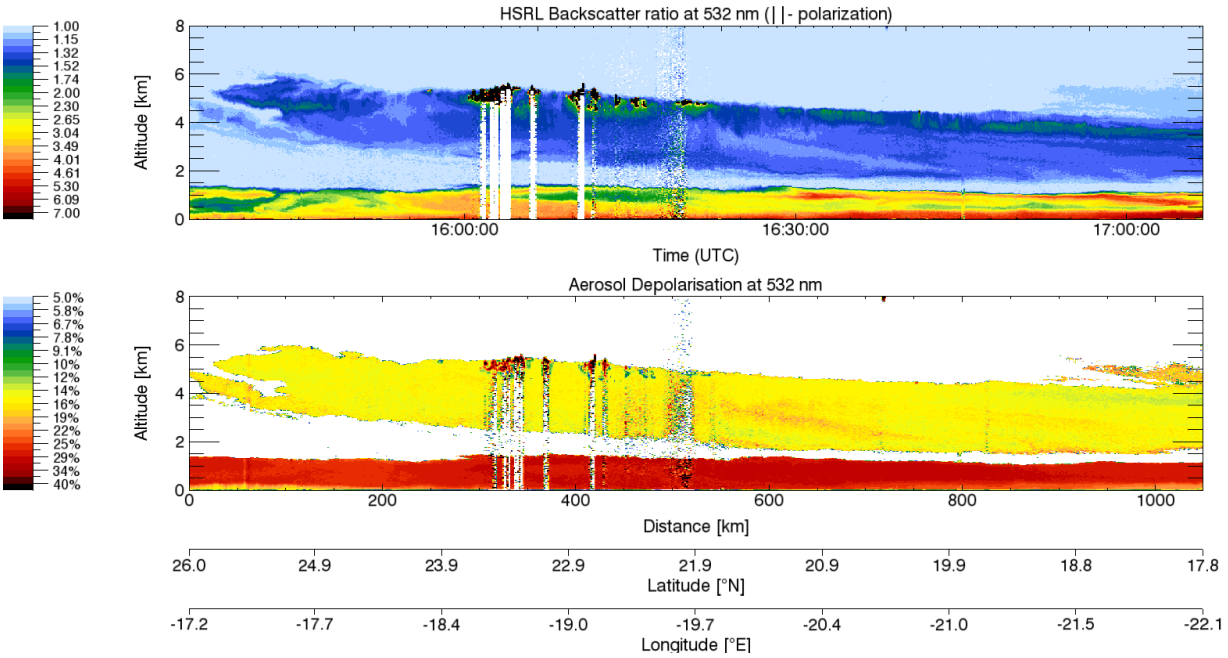

Figure 2: Cross section of the HSRL backscatter ratio (upper panel) and the aerosol depolarization ratio (lower panel) at 532 nm measured on the flight from Tenerife to the Cape Verde Islands on 19 January 2008. Flightaltitude was 10.8 km ASL. The upper aerosol layer ranging from 2–6 km ASL is advected from central parts of Africa, the lower aerosol layer originates from northern Africa.

tered signals at 1064 and 532 nm a dichroic beamsplitter is used. A 190 mm iodine vapor cell within the molecular channel at 532 nm is used in dual–pass configuration to suppresses the aerosol backscatter. The attenuation of aerosol backscatter within the iodine filter is better than 10^4. For polarization sensitive detection the receiver module is equipped with an additional cross–polarized channel at the two wavelengths respectively. The atmospheric backscatter is detected with avalanche photodiodes in case of 1064 nm and with photomultipliers at 532 nm. Vertical resolution of the measured profiles is 15 m for all backscatter and depolarization data. Because the aerosol extinction coefficient is derived from the measured AOT profile by numerical differentiation, vertical resolution is decreased (210 m – 420 m) in cases of extinction and lidar ratio profiles, to yield an adequate noise level. Relative systematic errors of the backscatter measurements are typically 4% to 8% within aerosol layers of approximately 0.3 AOT and statistical errors are negligible. In case of the extinction measurements relative systematic errors are usually less than 5%, so that statistical errors of typically 5% to 20% are dominant. Relative systematic errors of the depolarization measurements are primarily due to mechanical accuracy of the calibration measurement and results in a relative error of the aerosol depolarization ratio of 8% to 16%.

During the time of the field experiment the DLR Falcon research aircraft was stationed at Praia and conducted a total of 9 flight missions. The flight strategies included both, remote sounding by HSRL at high flight altitude to measure the overall column extinction profile, and *in–situ* probing at flight levels where aerosol structures have been detected by lidar before.

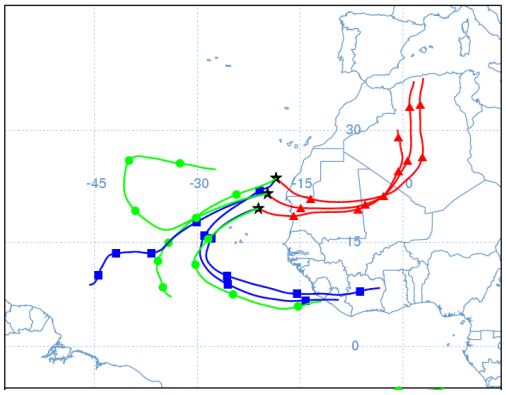

Figure 3: HYSPLIT 100 hours backward trajectories for 19 Jan. 2008 calculated using GDAS data. Trajectories arrive at 800 m (red), 4000 m (blue), and 4500 m (green) respectively.

3. RESULTS

During SAMUM 2008 biomass burning aerosol and Saharan dust plumes were detected in separated as well as in mixed structures. The fractional AOT of the biomass burning aerosol layers varied from 0.05–0.45. Maximum fractional AOT values of the Saharan dust layers were about 0.9 in cases of strong dust transports off the west

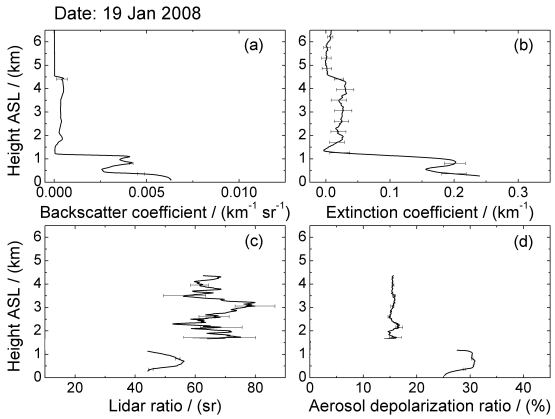

Figure 4: Lidar profiles of the aerosol backscatter coefficient (a), extinction coefficient (b), lidar ratio (c) and aerosol depolarization ratio (d) measured on 19 Jan. at 16:40 UTC. The error bars indicate the 3σ statistical error. Temporal average is 345 s, vertical resolution is 15m (a,d) and 275 m (b,c) respectively.

African coast. In the following two case studies will be presented showing the ability of the HSRL to differentiate these different aerosol types by means of their lidar– and depolarization ratio.

3.1. Separated layers

Fig. 2 shows an example of two well separated aerosol layers detected on the flight from Tenerife to Cape Verde Islands on 19 January 2008. As can be seen in the aerosol depolarization ratio diagram, two prominent aerosol types can be distinguished. The upper layer showing relatively low depolarization values of 15–19% ranges from 2–6 km ASL. The strongly depolarizing (30%) lower aerosol layer extends from sea surface up to 1.5 km ASL. The analysis of the water vapor DIAL measurement (not shown here) reveals an extraordinary dry air mass between the two aerosol layers. Fig. 3 shows backward trajectories arriving at 1000 m (red), 2000 m (blue), and 3500 m ASL (green), respectively, indicating that the lower aerosol layer was advected from Algeria and the upper one from central parts of Africa. The analysis shows 100 hours backward trajectories calculated using the Hybrid Single–Particle Lagrangian Integrated Trajectory (HYSPLIT) model [8] for three coordinates along the Falcon flight track. By means of MODIS (Moderate Resolution Imaging Spectroradiometer) global fire maps, several fire positions could be identified along the trajectories arriving at 4–4.5 km ASL. Thus, the upper aerosol layer is attributed to biomass burning aerosol. Fig. 4 shows a 345 s average of the backscatter and extinction coefficient, the corresponding lidar ratio and the aerosol depolarization ratio. The average was taken around 16:40 UTC, the error bars indicate the 3–σ statistical error. The profiles show lidar ratio values of 50 sr and depolarization ratio values of 30% for the lower aerosol layer. These values haven been measured for Saharan dust during SAMUM 2006 [9]. The upper layer indicates significantly higher lidar ratios ranging from 60–80 sr.

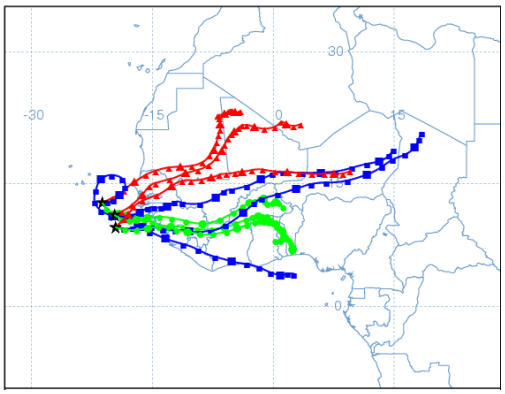

Figure 6: HYSPLIT 150 hours backward trajectories for 4 Feb. 2008 calculated using GDAS data. Trajectories arrive at 1000 m (red), 2000 m (blue), and 3500 m (green) respectively.

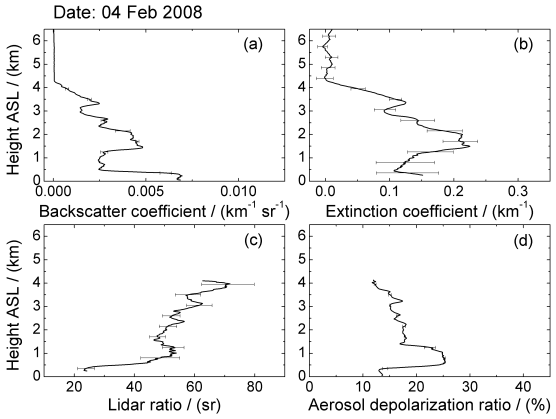

Figure 7: Lidar profiles of the aerosol backscatter coefficient (a), extinction coefficient (b), lidar ratio (c) and aerosol depolarization ratio (d) measured on 4 Feb. at 16:33 UTC. The error bars indicate the 3σ statistical error. Temporal average is 106 s, vertical resolution is 15m (a,d) and 250 m (b,c) respectively.

3.2. Mixed layers

Fig. 5 shows an example of a more complex aerosol structure observed during the measurement flight directed south–east of the Cape Verde Islands on 4 February 2008. Again, the depolarization cross section reveals a strongly depolarizing aerosol layer close to the sea surface and an upper layer with comparatively low depolarization values. However, in this case maximum depolarization values are decreased to about 25 % indicating a mixing process. Additionally, the trajectories (Fig. 6) show a less pronounced difference in the air mass advection. Fig. 7

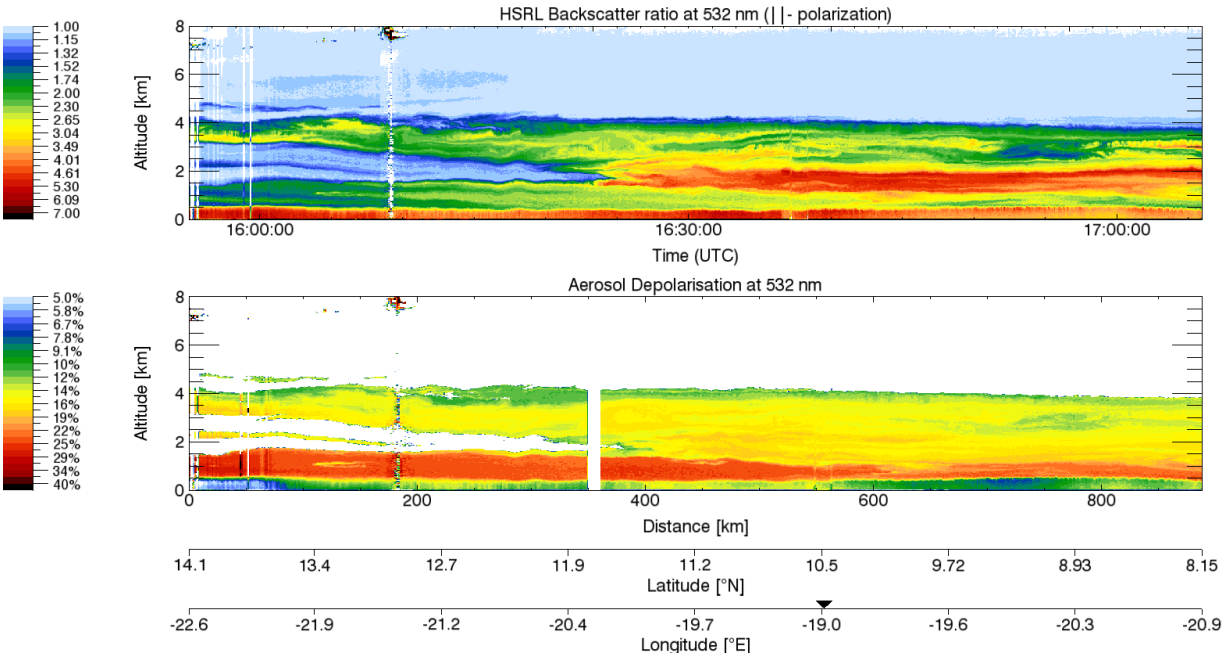

Figure 5: Cross section of the HSRL backscatter ratio (upper panel) and the aerosol depolarization ratio (lower panel) at 532 nm measured on the flight from the Cape Verde Islands towards south–east on 4 February 2008. Flightaltitude was 9.6 km ASL. The strongly depolarizing aerosol layer is advected from northern parts of Africa, the low depolarizing aerosol layer originates from central Africa. In both panels the marine boundary layer can be seen to reach up to 500 m ASL. Arrows on the Longitude/Latitude axis indicate changes in the flight direction of the aircraft.

(c) shows a gradual increase of the lidar ratio from 50–70 sr within the mixed layer. The decrease of the lidar ratio below 0.7 km ASL is due to the marine boundary layer.

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