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AN AIRBORNE HIGH SPECTRAL RESOLUTION LIDAR BASED ON AN IODINE ABSORPTION FILTER

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1. INTRODUCTION

Aerosols directly influence the fluxes of solar and terrestrial radiation within the atmosphere by absorption and scattering of light. The quantification of this effect accounts for accurate determination of the aerosol's optical properties. With conventional backscatter lidars climatically relevant aerosol properties like aerosol extinction can only be derived by inverting the lidar signal (Klett 1981, 1985) under the assumption of a a priori known lidar ratio, which generally is a highly variable quantity. For mineral dust, which is one of the major constituents of the tropospheric aerosol, lidar ratios ranging from 50 - 80 sr have been measured (Mattis et al. 2002). Uncertainties in the lidar ratio will consequently lead to large errors in the retrieved optical properties. A well calibrated high spectral resolution lidar, HSRL, allows the direct determination of optical depth and extinction as described below. We have developed an airborne HSRL based on an iodine vapor absorption filter and a high power, frequency doubled Nd:YAG laser. The instrument was successfully employed during the Saharan Mineral Dust Experiment, SAMUM in May/June 2006 in Morocco to measure the optical properties of desert dust. With our measurements the Saharan dust can be characterized with regard to its lidar ratio, depolarization ratio and infrared-to-green backscatter ratio.

2. MEASUREMENT PRINCIPLE

Using a HSRL, the lidar signal is split in two parts and spectrally filtered in order to separate the Mie- from the Rayleigh spectral components (Shimizu et al. 1983, Shipley et al. 1983). Therefor the HSRL utilizes the different spectral broadening of light scattered by gaseous and solid atmospheric constituents respectively. The narrow-band optical filter in the molecular channel suppresses the unbroadened aerosol backscatter and transmits a certain part of the Doppler-broadened molecular backscatter spectrum. In contrast, the combined channel detects the intensity of the total backscatter. Using the measured or calculated atmospheric density profile the aerosol optical depth can directly be determined from the measured signal in the molecular channel. In both channels the signal is attenuated by the two-way transmission of the atmosphere so that the atmospheric transmission is canceled out by taking the ratio of both channels. Thereby aerosol backscatter coefficients can be determined without assuming a lidar ratio. Thus a HSRL overcomes the limitations of a conventional backscatter lidar and allows to directly measure the aerosol optical depth, extinction-corrected backscattering. The lidar ratio can be readily deduced from the measured quantities so that no doubtful assumptions have to be made.

3. INSTRUMENT SPECIFICATION

For the development of the HSRL an existing water vapor DIAL system with a single mode laser has been extended by a narrow bandwidth filter channel. The lidar transmitter consists of a high power Nd:YAG laser with a pulse energy of 220 mJ at 1064 nm and a repetition rate of 100 Hz. The system is laid-out as a master oscillator power amplifier (MOPA) configuration (Ehret et al. 2000). The host laser is injection seeded with a single mode cw-Nd:YAG laser. For HSRL operation the laser output at 532 nm was frequency stabilized to the center of the iodine absorption line used for narrow bandwidth filtering.

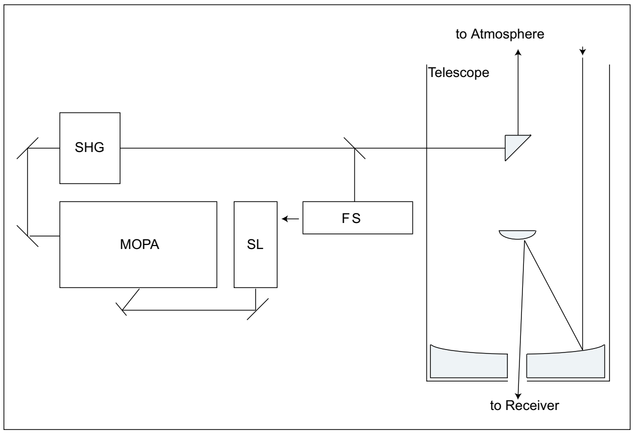

FIG. 1: Build up of the transmitter system. FS: frequency stabilization, MOPA: master oscillator power amplifier, SHG: second harmonic generator, SL: seed laser

The lidar transmitter is equipped with an optical parametric oscillator (OPO) to enable measurements of water vapor at 935 nm with the differential absorption technique (Poberaj et al. 2002). In this paper we focus on HSRL operation only so that water vapor measurements will not be dealt with. Fig. 1 shows the transmitter system schematically. The fundamental and frequency converted laser output is emitted into the atmosphere and backscatter is detected with a 350 mm Schmidt-Cassegrain telescope in

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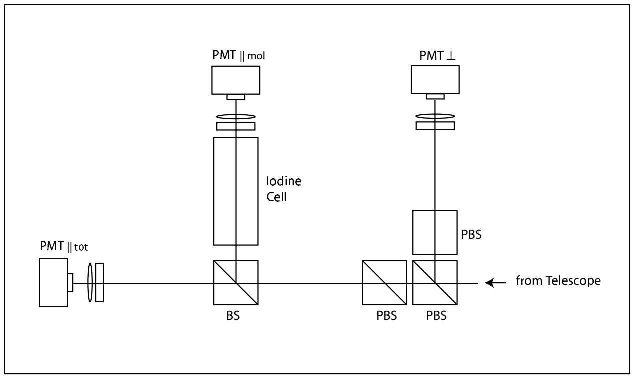

FIG. 2: Schematic of the receiver channel at 532nm. PBS: polarization beam splitter, BS: beamsplitter, PMT: photomultiplier

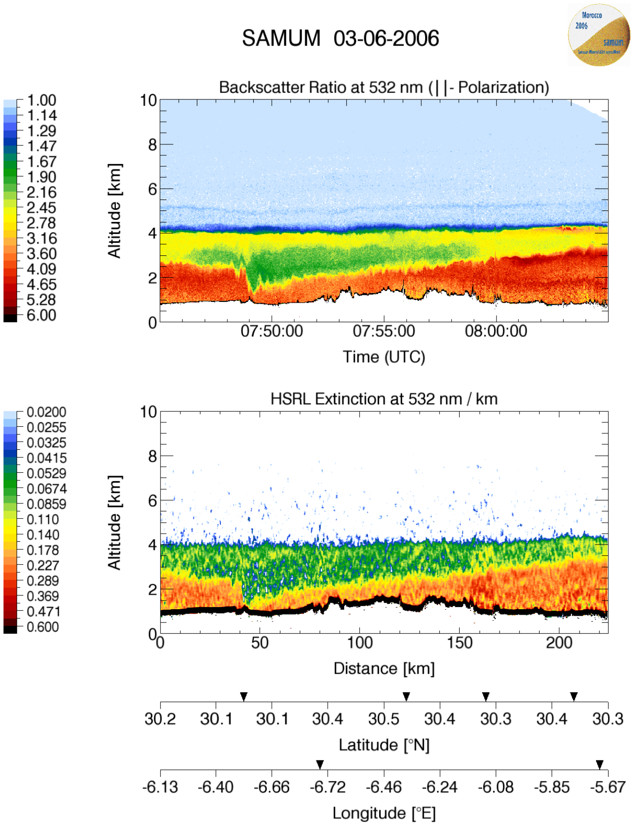

FIG. 3: Cross section of backscatter ratio and aerosol extinction at 532 nm during a measurement flight on June 3rd. 2006

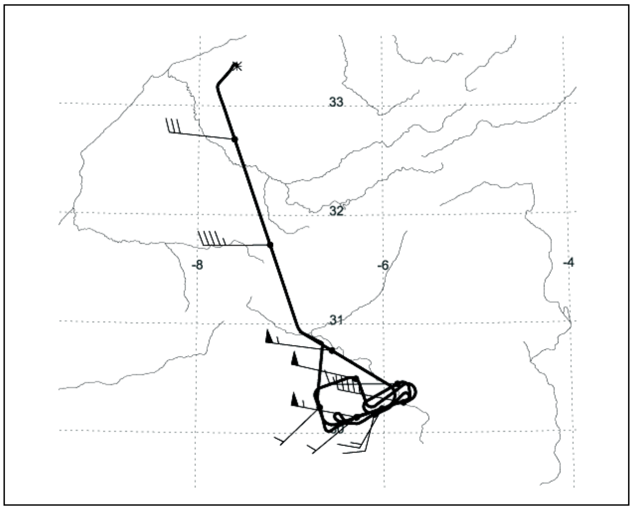

FIG. 4: Flight path of DLR Falcon research aircraft on June 3rd. 2006

monostatic configuration. In the receiver a dichroic mirror guides backscattered light at 532 nm into the HSRL channel which is schematically depicted in Fig. 2. With polarizing beamsplitter cubes depolarized atmospheric backscattering is separated from the parallel component of the lidar signal. A beamsplitter cube transmits a part of the parallel component onto a PMT which detects the intensity of the total backscatter spectrum after background suppression with a 1 nm interference filter. The other part of the parallel component is led through an iodine vapor absorption cell and detected with an other PMT. To assure constant absorption, the cell is heated and a cold finger within is temperature stabilized to a tenth of a degree centigrade. Typically, one third of the molecular backscatter intensity transmits the absorption cell. Depending on the properties of the used iodine absorption line the filter cell can be used either in one- or double pass configuration. Measurements were done using iodine absorption lines number 1113 and 1109 (as assigned in Gerstenkorn, 1978). For calibration purpose laser light is coupled into the receiver and the laser frequency is scanned over the molecular transition at regular intervals. Using the measured absorption line profile and the calculated pressure and temperature dependent Rayleigh-Brillouin spectrum, the HSRL calibration constants are calculated. The necessary pressure and temperature profiles are obtained from radiosondes which were launched from Ouarzazate ground station in coordination with each measurement flight. The system specifications are summarized in Table 3.

4. PRELIMINARY RESULTS FROM SAMUM PHASE 1

The Saharan Mineral Dust Experiment, SAMUM is a joint research project of several German institutes aiming at the characterization of Saharan dust referring to its optical, microphysical, chemical and radiative properties.

Pulsenergy at 1064 nm	220 mJ
Repetition rate	100 Hz
Linewidth at 1064 nm	$<$ 80 MHz
Laser divergence at 1064 nm	0.5 mrad
Pulsenergy at 532 nm	100 mJ
Frequency fluctuations at 532 nm	$< 8 \times 10^{-9}$
Spectral purity at 532 nm	99.99 %
Telescope diameter	350 mm
Background filter bandwidth	1 nm
Detector divergence	1 mrad
Detection mode	analog detection
Vertical resolution	15 m

Table 1: HSRL System Parameters

The first field phase of SAMUM took place in May/June 2006 in southern Morocco including ground stations in Ouarzazate (30.9 N, 6.9 W) and Zagora (30.1 N, 5.3 W) from where ground based measurements with active and passive remote sensing as well as in-situ instruments were conducted. Two research aircraft were engaged during the first SAMUM field phase. Equipped with the nadir-viewing HSRL and an extensive set of aerosol in-situ probing instruments the DLR - Falcon research aircraft performed airborne measurements of dust properties. During SAMUM field phase 1 the DLR Falcon aircraft was stationed in Casablanca from were science flights started either southwards to sound the atmosphere over the ground stations or northwards for measurements of long range transport of desert dust. Fig 3 shows exemplarily a cross section of backscatter ratio and aerosol extinction at 532 nm measured on June 3rd. 2006 south of the atlas mountain range. The corresponding flight path of the DLR Falcon aircraft is depicted in Fig. 4 starting in Casablanca and arriving in Ouarzazate.

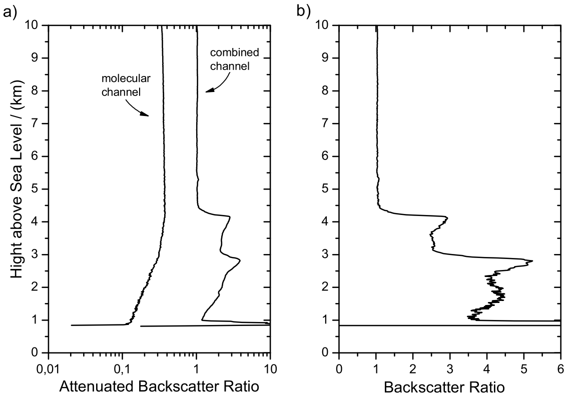

FIG. 5: a) Measured attenuated backscatter in the molecular and the combined channel. b) Extinction corrected backscatter ratio. 30s temporal average each.

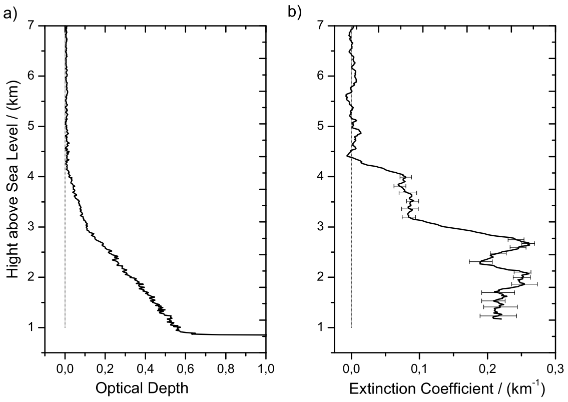

FIG. 6: a) Optical depth and b) Extinction coefficient. 30s temporal average each.

The backscatter and extinction data were measured during the box-shaped flight pattern at the most southern part of the flight path. As can be seen the well defined dust boundary is as high as 4.5 km above sea level and the dust layer is split in two parts with values for extinction ranging from 0.1 km^{-1} within the upper layer to 0.3 km^{-1} within the lower one. For scaling the lidar signals a backscatter ratio of 1.01 was assumed in the free troposphere between 8.5 km and 9 km height. From these data profiles of backscatter ratio, extinction, optical depth and lidar ratio are calculated. For all profiles the temporal average of data measured between 08:01:00 UTC and 08:01:30 UTC was used. Fig. 5a shows the comparison between the attenuated backscatter ratio in the combined and in the molecular channel. The combined channel indicates the two aerosol layers with boundaries at 4.5 km and 3 km as well as the ground signal at 1 km hight over sea level. The signal in the molecular channel increases slightly along with temperature in the free troposphere and than falls monotonously within the dust layer due to aerosol extinction. The signal decreases by a factor of 3.2 indicating a one-way transmission of the dust layer of 0.56 at a wavelength of 532 nm. Together with the system calibration the extinction-corrected backscatter ratio is calculated from the measured attenuated backscatter of the two channels (Fig. 5b).

Fig. 6a shows the optical depth as calculated from the attenuated backscatter of the two channels. The one-way optical depth amounts to 0.58 at the surface. The separation of the dust layer in two main parts results in two clearly distinguishable slopes in the optical depth profile. For calculation of the extinction profile the optical depth is differentiated with respect to hight using a Savitzky-Golay filter of 1st. order. The FWHM of the used filter kernel was 390 m. Fig. 6b shows the corresponding extinction profile with the error bars indicating the 3σ deviation of the data. Obviously, the distinct aerosol layering which can be observed in the backscatter ratio profile is represented in the extinction profile as well.

Further data examples of SAMUM including the aerosol characterization in terms of lidar ratio and depolarization as well as intercomparisons with other instruments will be part of our presentation.

5. CONCLUSION

We have developed an airborne high spectral resolution lidar based on an iodine vapor absorption filter and a high power, frequency doubled Nd:YAG laser. The instrument is capable to measure atmospheric backscatter and linear depolarization at 1064 nm and 532 nm, molecular backscatter within the HSRL channel at 532nm as well as water vapor absorption at 935 nm with the DIAL-technique. During SAMUM field phase 1 the system measured desert dust optical properties with stable and faultless performance aboard the DLR Falcon research aircraft.

6. ACKNOWLEDGMENTS

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