Optical properties of long-range transported Saharan dust over Southern Germany

Silke Gross[1], Volker Freudenthaler[1], Josef Gasteiger[1], Franziska Schnell[1], Theresa Hayek[1], Markus Eifried[1], Matthias Wiegner[1], and Peter Köpke[1]

[1]Meteorological Institute, Ludwig-Maximilians-Universität, Munich, Germany,

silke@meteo.physik-uni-muenchen.de

ABSTRACT

At the end of May 2008 one of the strongest Saharan Dust outbreaks ever reached Central Europe. It significantly influenced the aerosol load over Southern Germany for as long as one week. The optical properties of the aerosol particles as a function of time and height are derived from data of the lidar systems POLIS and MULIS of the Meteorological Institute of the Ludwig-Maximilians-Universität at Munich (Germany, 48.14N, 11.57E) and Maisach (Germany, 48.20N, 11.25E), respectively. Measurements include particle backscatter and extinction coefficient, the linear particle depolarization ratio and the extinction to backscatter ratio at 355 nm and at 532 nm. The data sets are supplemented with spectral optical depths derived from CIMEL sunphotometer measurements at Munich. The dust plume reached the measurement sites on May 26 with a southerly flow, lasting until June 2, only interrupted on May 30 and 31 by a front passage. The dust layer was located above the boundary layer (0.5 – 1 km above ground level) with an extent up to 4 – 6 km height. Preliminary analyses result in linear particle depolarization ratios of about 0.3 to 0.4 at 532 nm, which indicate dust. The extinction coefficient within this layer ranges from 0.05 km^{-1} to 0.2 km^{-1}, with maximum values of about 0.3 km^{-1}. This analysis agrees very well with observations of atypically high total aerosol optical depths of up to 1 derived from the sunphotometer. The Angström exponent during the episode mainly ranges from 0.1 – 0.5, demonstrating the dominating contribution of the dust particles.

1. INTRODUCTION

Mineral Dust is one of the major aerosol components of the atmosphere and is expected to considerably influence the earth's radiative budged (Tegen et al., 1996). This impact strongly depends on the spatial distribution and optical properties of the aerosols (Sokolik et al., 2001). The main source region of mineral dust is the Saharan desert. Dust particles, raised to high altitudes by strong convection, can be transported over long distances (Prospero and Carlson, 1972).

To improve the knowledge of mineral dust, observations were made during several field campaigns. Measurements of pure, not aged Saharan Dust were made in Morocco in May and June 2006 during the first field campaign of the SAharan Mineral dUst eperiMent (SAMUM) (Heintzenberg, 2009). During the second SAMUM field campaign at the Cape Verde islands in January and February 2008 transported dust as well as a mixing with other types of aerosols was observed. Long-range transported dust to northern Europe was studied in the framework of the European Aerosol Research Network (Earlinet) (Bösenberg et al., 2001b) (Ansmann et al., 2003, Mattis et al., 2003). As the transport of Saharan dust mainly takes place in the free troposphere (Prospero and Carlson, 1972), lidar measurement are most useful for monitoring, because they clearly separate the optical effect of the boundary layer aerosols and the lofted dust layer.

In this work we present lidar observations of optical properties of Saharan mineral dust at the Central European sites Munich (Germany, 48.14N, 11.57E) and Maisach (Germany, 48.20N, 11.25E) during a strong Saharan dust outbreak in May and June 2008.

2. MEASUREMENTS AND INSTRUMENTATION

Range-resolved measurements presented in this work were performed with the two lidar systems MULIS (MUltiwavelength LIdar System) (Freudenthaler et al., 2009) and POLIS (POrtable LIdar System) (Gross et al., 2008) of the Ludwig-Maximilians-Universität (LMU) München. Observations between May 27 and May 30 were made at the sites Maisach and Munich, respectively. From May 31 to June 02, 2008 both instruments were located in Maisach.

MULIS is a Raman and depolarisation lidar with elastic backscattered wavelengths of 355 nm, 532 nm, and 1064 nm, two N_2-Raman channels at 387 nm and 607 nm, and linear depolarisation channels for 532 nm cross and perpendicular polarisation. POLIS is a small, low power, two wavelength lidar with either one elastic channel at 355 nm and one Raman channel at 387 nm, or in the linear depolarization configuration with cross- and perpendicular polarisation channels at 355 nm. The required extinction-to-backscatter ratio for the Klett inversion (Klett, 1985) was taken from simultaneous MULIS measurements. The AERONET CIMEL (NASA) sun- and sky photometer of the LMU, located in Munich, provided measurements of direct spectral radiances at several wavelengths between 340 nm and 1550 nm, and scattered radiances from the almucantar geometry.

In this work, profiles of optical properties at the beginning and at the end of the dust episode, i.e. May, 27 and June, 2, will be presented.

3. MEASUREMENT SITUATION

High dust loaded air masses reached the measurement sites Munich and Maisach on May, 26 with a southerly flow.

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

A low pressure system over Western Europe together with a high pressure system over south easterly Europe in the first part of the event and north easterly Europe in the second part initiated the advection of warm dust loaded air masses from the Saharan dessert to Central Europe. The dust event lasted until June 2, only interrupted by a front passage on May, 30 and 31.

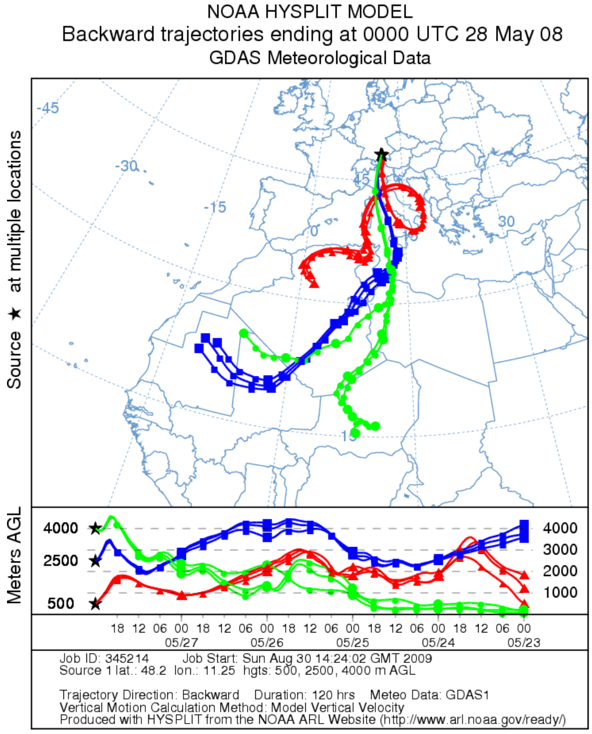

Figure1. *Calculated 5-day* HYSPLIT *backward trajectories of May 28, 2008 0000 UTC for the measurement sites Munich (48.14° N, 11.57° E) and Maisach (48.20° N and 11.25° E) for heights of 500 m, 2500 m and 4000 m above ground level.*

According to calculated HYSPLIT backward trajectories (see Figure 1 and Figure 2) the air masses observed in Munich and Maisach originated in the Saharan region between 10° N and 30° N and 15° E and 15° W. The dust plume travelled 3 - 4 days until it arrived at Southern Germany in a height up to 4 – 6 km above ground level (agl). The air masses which arrived in heights up to 5 km above ground level were located in the Saharan dessert regions below 3000 m agl. During the first part of the event they crossed north western Libya, the Mediterranean Sea, northern Italy and the Alps before arriving in Southern Europe. After the front passage on May 30 and 31, the high dust loaded air masses crossed north westerly Algeria, the western part of the Mediterranean Sea, South France and Switzerland.

The corresponding measurements with the AERONET CIMEL sun- and skyphotometer at Munich (Figure 3) provide the aerosol optical depth (AOD) and Angström exponent. During the dust period the Angström exponent (440 nm to 870 nm) with 0.1 to 0.5 was an indication for Saharan dust. Observations of total aerosol optical depth show atypically high values with the maximum up to 1.

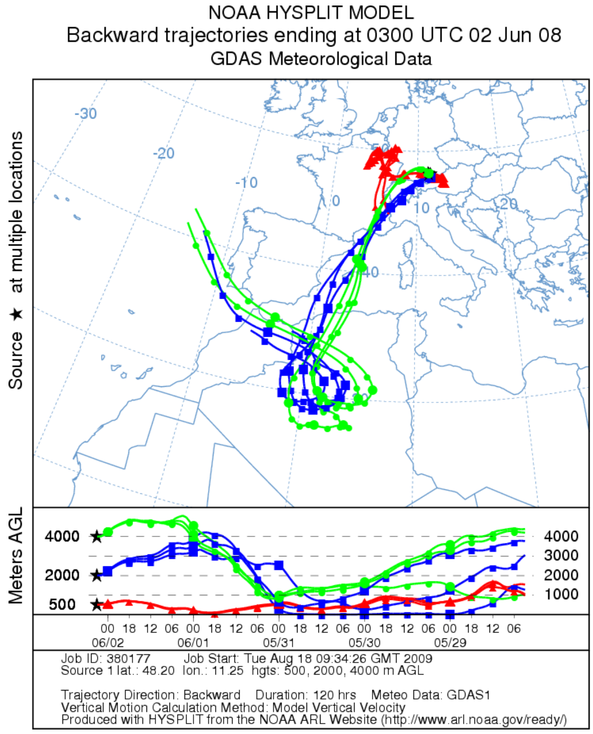

Figure2. *Same as Figure 1, except date (June 2, 2008 0300 UTC) and heights (500m, 2000m and 4000m)*

.

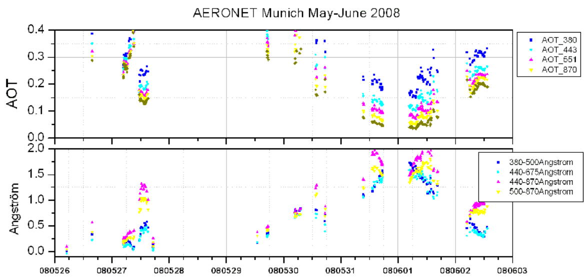

Figure3. *Level 1.5 Data of the Aerosol Optical Thickness (AOT) and Angström exponent from the AERONET CIMEL sun- and skyphotometer measurements in Munich for May and June, 2008. Source:* http://aeronet.gsfc.nasa.gov/cgi-bin/type_one_station_opera_v2_new

4. RESULTS AND DISCUSSION

Vertical profiles of the particle backscatter and extinction coefficient and of the lidar ratio measured during the outbreak are shown in Figure 4 and 5. The measurements were performed with MULIS at 355 nm and 532 nm at Maisach. The calculated lidar ratios at both wavelengths were used for the Klett inversion and depolarisation analyses of the daytime measurements as well as for simultaneous POLIS measurements.

Integration of the extinction coefficient of 0.05 km^{-1} up to 0.15 km^{-1} results in measured values of the AOD within the dust layer of 0.3 at 355 nm and 532 nm on May 27 to 0.19 at 355 nm and 0.16 at 532 nm on June 2, 2008. Considering the additional AOD of the boundary layer below, these values agree very well with correlative CIMEL sunphotometer measurements of the total optical depth of about 0.4 at 355 nm and 532 nm and 0.3 at 355 nm and 0.25 at 532 nm on May 27 and June 02, respectively. The calculated lidar ratios in the dust layer vary from 50 – 70 sr and show no significant wavelength dependency. In the first part of the dust episode, they seem to be slightly higher, but this difference is also not significant.

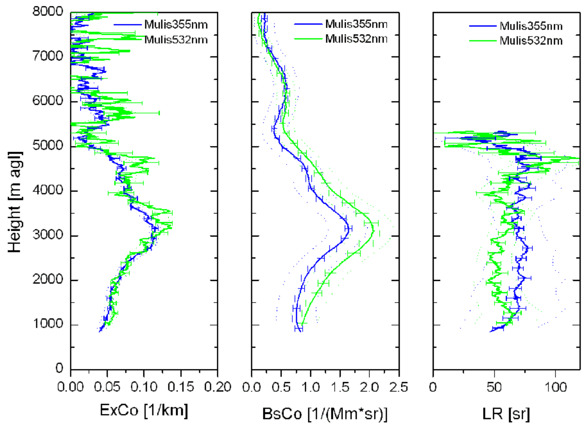

Figure 4. *Particle extinction coefficient (ExCo), particle backscatter coefficient (BsCo) and Lidar Ratio (LR) of Saharan dust above Maisach on May 27, 2008. The measurements are averaged between 2130 and 2230 UTC. Before calculating the scattering properties the signals profiles were smoothed with a window length of 652.5 m and 907.5 m at 355 nm and 532 nm, respectively. The measurement angle was 87°. The error bars indicate the statistical error, the doted lines the systematic errors.*

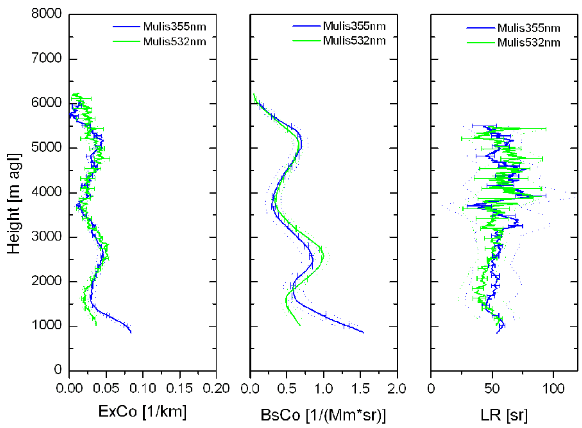

Figure 5. Same as Figure 4, but June 2, 2008. Measurements are averaged between 0000 and 0130 UTC.

The particle depolarization ratio (Freudenthaler et al., 2009) was measured with MULIS at 532 nm and with POLIS at 355 nm. Vertical profiles of preliminary results at 355 nm and 532 nm together with corresponding backscatter coefficients at 355 nm, 532 nm and 1064 nm calculated with the Klett inversion, using the lidar ratio from the Raman analyses (Figure 4 and Figure 5) for 355 nm and 532 nm and a constant lidar ratio of 55 sr for 1064 nm, are shown in Figures 6 and 7.

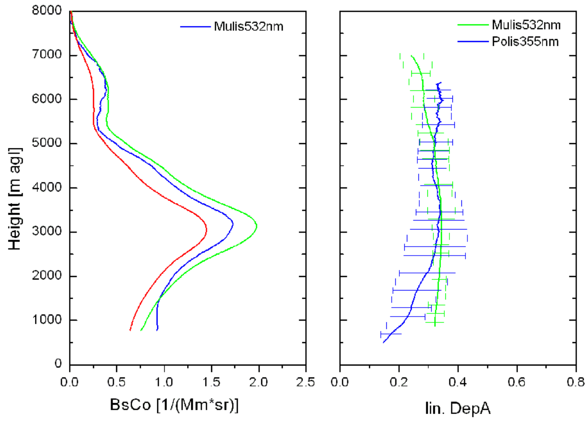

Figure 6. *Particle backscatter coefficient at 355 nm, 532 nm and 1064 nm calculated by Klett inversion and linear particle depolarisation ratio at 355 nm and 532 nm. The MULIS measurements of Maisach were averaged between 2130 and 2230 UTC. Due to missing simultaneous POLIS measurements, linear particle depolarisation ratio at 355 nm were analysed by averaged measurements between 1900 and 2030 UTC. The signal profiles were smoothed with a window length of 907.5 m. MULIS and POLIS measurements were performed in Maisach and Munich at the measurement angels 87° and 70°. The error bars indicate the systematic errors.*

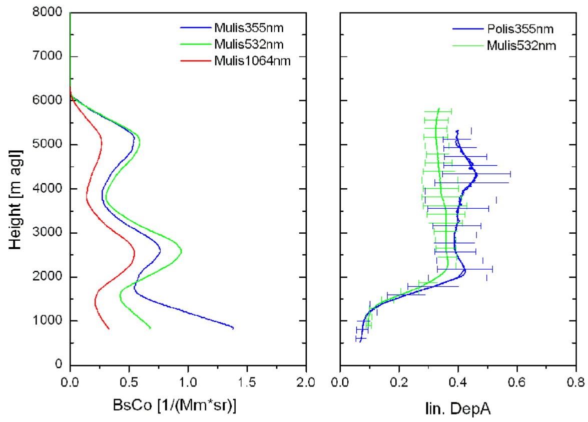

Figure 7. *Same as Figure 6 except time of observation (June 2, 2008, 0000 – 0130 UTC for MULIS and 0055 – 0255 UTC for POLIS).*

Unexpected large values of the mean linear particle depolarization ratio up to 0.4 at 355 nm were observed in the presumptive dust layers on both analysed days, while the values at 532 nm ranged between 0.3 and 0.35 (see Figure 5 and Figure 7). No significant wavelength dependency of the depolarization between 355 nm and 532 nm could be found, considering the large systematic errors especially at 355 nm.

5. SUMMARY AND OUTLOOK

We analysed optical properties of Saharan dust at 355 nm and 532 nm. Lidar ratios in the dust layer ranged from 50 – 70 sr at both wavelengths. Unexpectedly large values of the linear particle depolarization were found in the UV wavelength region. These high values may be caused by aging of the aerosols during the long-range transport and a possible mixing with other types of aerosols. Dust depolarization values during SAMUM1 and preliminary analysis of SAMUM2 data indicate differences of the wavelength dependency of the depolarization to the results presented here.

To get further information a detailed analysis of the measurements during this event with accurate error estimation is necessary. The findings have to be related to information from backward trajectories to be able to assess possible influences along the transport. Furthermore, results from in situ measurements of particle shape and size distribution combined with model calculations of the scattering properties can be compared.

ACKNOWLEDGMENTS

The SAMUM research group is funded by the Deutsche Forschungsgesellschaft (DFG) under grant number FOR 539.

We furthermore gratefully acknowledge the financial support for the improvement of the EARLINET infrastructure by the European Commission under grant RICA-025991, as well as the ESA financial support under the ESTEC Contract No. 21487/08/NL/HE and the ESRIN Contract No. 21769/08/I-OL.

REFERENCES

[1]Ansmann A., J. Bösenberg, A. Chaikovsky, A. Cameron, S. Eckhardt, R. Eixmann, V. Freudenthaler, P. Ginoux, L. Komguem, H. Linne, M. A. Lopez Marquez, V. Matthias, I. Mattis, V. Mitev, D. Müller, S. Music, S. Nickovic, J. Pelon, L. Aauvage, P. Sobolewsky, M.K. Srivastava, A. Stohl, O. Torres, G. Vaughan, U. Wandinger, M.Wiegner, 2003: Long-range transport of Saharan dust to northern Europe: The 11 – 16 October 2001 outbreak observed with EARLINET, *Journal of Geophysical Research*, **108**, pp. 4783-4795.

[2]Bösenberg J., et al., 2001b: EARLINET: A European Aerosol Researcch Lidar network, *Advances in Laser Remote Sensing*, pp. 155 – 158

[3]Freudenthaler V., M. Esselborn, M. Wiegner, B. Heese, M. Tesche, A. Ansmann, D. Mueller, D. Althausen, M. Wirth, A. Fix, G. Ehret, P. Knippertz, C. Toledano, J. Gasteiger, M. Garhammer, M. Seefeldner, 2009: Depolarization-ratio profiling at several wavelengths in pure Saharan dust during SAMUM 2006, *Tellus, Ser. B*, **61**, pp. 165-179.

[4]Gross S., V. Freudenthaler, C. Toledano, M. Wiegner, 2008: Mini-Lidar measurements of particle depolarization and raman-scettering of Saharan dust and biomass burning at 355 nm during SAMUM2, *Proc. of the International Laser Radar Conference, Boulder, USA*

[5]Heintzenberg J., 2009: The SAMUM-1 experiment over southern Morocco: Overview and introduction, *Tellus, Ser. B*, **61**, pp. 2 – 11

[6]Klett J. D., 1985: Lidar Inversion with Variable Backscatter/Extinction Ratios, *Appl. Opt.* **24**, pp 1638

[7]Mattis I., A. Ansmann, D. Mueller, U. Wandinger, D. Althausen, 2003: Dual-wavelength Raman lidar observations of the extinction-to-backscatter ratio of Saharan dust, *Geophysical Research Letters*, **29**, pp. 1306 – 1310

[8]Prospero J. M., T. N. Carlson, 1972: Vertical and areal distribution of Saharan dust over the western equatorial North Atlantic Ocean, *Journal of Jeophysical Research*, **77**, pp. 5255-5265

[9]Sokolik I. N., D. M. Winker, G. Bergametti, D. A. Gillette, G. carmichael, Y. J. Kaufman, L. Gomes, L. Schuetz, J. E. Penner, 2001: Introduction to special section: Outstanding problems in quantifying the radiative impacts of mineral dust, *Journal of Geophysical Research*, **106**, pp

[10]Tegen I., A. A. Lacis, I. Fung, 1996: The influence on climate forcing of mineral aerosol from disturbed soils, *Nature*, **308**, pp. 419 – 422

AERONET http://aeronet.gsfc.nasa.gov/

HYSPLIT http://www.ready.noaa.gov/ready/open/hysplit4.html