7th COPS Workshop
27-29 October 2008
Strasbourg, France

Observation of a Saharan dust outbreak on 1-2 August 2007: determination of size and microphysical particle parameters

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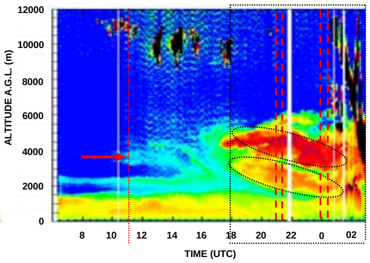
The Raman lidar system *BASIL* was operational in Achern (Supersite R, Lat: 48.64 °N, Long: 8.06 °E, Elev.: 140 m) in the frame of the Convective and Orographically-induced Precipitation Study. *BASIL* operated continuously over a period of approx. 36 hours from 06:22 UTC on 1 August to 18:28 UTC on 2 August 2007, to cover IOPs 13a-b. In this timeframe the signature of a severe Saharan dust outbreak episode was captured. Measurements reveal the presence of almost two separate aerosol layers: a lower layer located between 1.5 and 3.5 km and an upper layer extending between 3.0 and 6.0 km.

An inversion algorithm was used to retrieve particle size distribution parameters, i.e., mean and effective radius, number, surface area, and volume concentration, and complex refractive index, as well as the parameters of a bimodal particle size distribution, from the multi-wavelength lidar data of particle backscattering and extinction. The inversion method employs Tikhonov's inversion with regularization. Size distribution parameters are estimated as a function of altitude at different times during the dust outbreak event. Retrieval results reveal the dominance in the upper dust layer of a coarse mode with radii 3-4 μm. Number density and volume concentration are in the range 100-800 cm-3 and 5-40 μm3/cm3, respectively, while real and imaginary part of the complex refractive index are in the range 1.41-1.53 and 0.003-0.014, respectively.

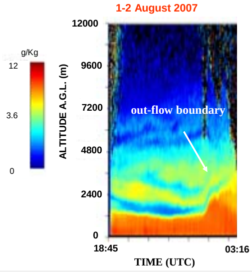
BASIL

Particle Backscatter Ratio at 1064 nm, 1-2 August 2007



Focus: two specific times when aerosol loading was higher
21:00-21:30 UTC on 1 August 2007
00:00-00:30 UTC on 2 August 2007 (red dashed lines in figure)

Water Vapour Mixing Ratio
1-2 August 2007



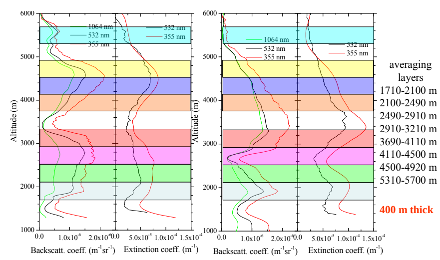
BASIL Raman Lidar

Measured parameters:

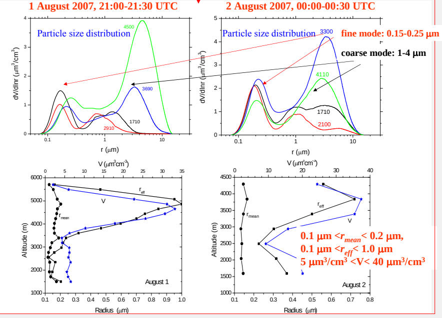
- particle backscattering coeff. @ 355, 532 and 1064 nm
- particle extinction coeff. @ 355 and 532 nm
- depolarization ratio @ 355 & 532 nm,
- atmospheric temperature
- water vapour mixing ratio
- relative humidity from simultaneous measurements of temperature and water vapor mixing ratio

Raman lidar measurements
(25 May – 30 August 2007)
More than 500 hours of measurement
distributed over 58 measurement days

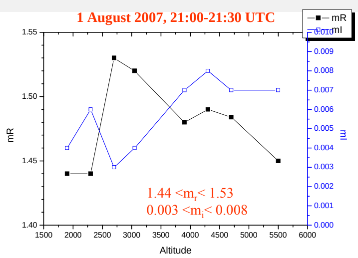
1 August 2007, 21:00-21:30 UTC — 2 August 2007, 00:00-00:30 UTC



1 August 2007, 21:00-21:30 UTC — 2 August 2007, 00:00-00:30 UTC



1 August 2007, 21:00-21:30 UTC



Method: Inversion with regularization, performed by generalized cross-validation.
In this retrieval, the combination of particle extinction and backscatter coefficients becomes especially important.
The number of backscatter coefficients in the retrieval procedure should exceed the number of extinction coefficients by a factor of 2–3.

Inversion algorithm

$3\beta + 2\alpha$ → Particle size distribution parameters:
Mean radius r_{mean}
Effective radius r_{eff}
Number concentration N
Surface concentration S
Volume concentration V
Complex refractive index m_r and m_i
Parameters of a bimodal size distribution

The retrieval scheme employs Tikhonov's inversion with regularization

Algorithm developed at the Physics Instrumentation Center

Veselovskii et al., Appl. Opt. **41**, 3685–3699, 2002.

New scheme: all layers are processed simultaneously

At any height altitude the measured optical quantities *gi* (backscattering or extinction) are related to the size distribution *f(r)* through the Fredholm integral equation:

$$\int_{r_{min}}^{r_{max}} K_i(m,\lambda,r) f(r) dr = g_i$$

In the solution of the inverse problem, particle size distribution *f(r)* is approximated by the superposition of base functions $B_j(r)$ as:

$$f(r) = \sum_{j=1}^{q} c_j(z) B_j(r)$$

where $c_j(z)$ are the weight coefficients.

Base functions have a triangular shape on a logarithmic-equidistant grid

The approximated values of the optical coefficients then are:

$$g_i = \sum_{j=1}^{q} A_{ij} c_j \rightarrow \mathbf{A}^l \mathbf{c}^l = \mathbf{g}^l$$

At any of *l* height layers in matrix-vector form

where the elements of weight matrix A_{ij} are calculated as:

$$A_{ij} = \int_{r_{min}}^{r_{max}} K_i(m,\lambda,r) B_j(r) dr.$$

Solved by means of inversion with regularization

$$\mathbf{C} = (\mathbf{A}^T\mathbf{A} + \gamma\mathbf{H})^{-1}\mathbf{A}^T\mathbf{G}$$

f(r) → Mean radius r_{mean}, Effective radius r_{eff}, Number concentration N, Surface concentration S, Volume concentration V

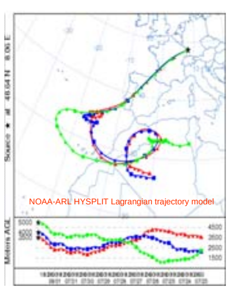
$$r_{eff} = \frac{\int_{r_{min}}^{r_{max}} r^3 f(r) dr}{\int_{r_{min}}^{r_{max}} r^2 f(r) dr} \qquad r_{mean} = \frac{\int_{r_{min}}^{r_{max}} r f(r) dr}{\int_{r_{min}}^{r_{max}} f(r) dr}$$

r_{min}=0.05 μm, r_{max}=15 μm
1.3 < m_r < 1.6
0 < m_i < 0.04

numerically integrating *f(r)* over the radius interval [r_{min}, r_{max}]

It is to be pointed out that dust particles are non-spherical, so the retrieval of particles parameters becomes challenging. In the present study we solved the inverse problem using Mie kernel functions for spherical particles and this may be source of significant uncertainties. In the next stage of the analysis process the phase functions of dust particles will be more appropriately accounted for by considering an ensemble of spheroids, as suggested in Dubovic et al. (2006). The application of the spheroids model will improve the accuracy of retrieved parameters.

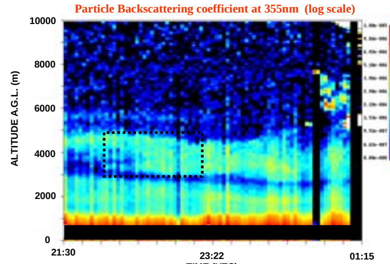
Backward trajectories ending at 00:00 UTC on 2 August 2007



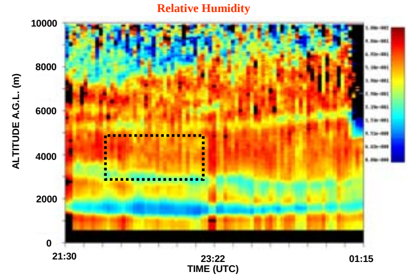
The air mass observed in Achern in the altitude region 3.5-5 km a.g.l. originates in the mixed layer over the Saharan desert

Dust particle hygroscopicity

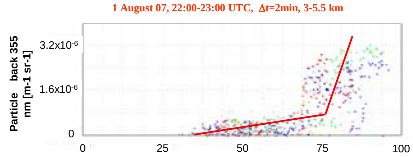
1-2 August 2007
Particle Backscattering coefficient at 355nm (log scale)



1-2 August 2007
Relative Humidity



Particle backscattering coeff. at 355 nm vs RH
1 August 07, 22:00-23:00 UTC, Δt=2min, 3-5.5 km



Back-trajectories show that airmasses originated in the Saharan desert transited for several days over the Atlantic Ocean → Aged dust particles presumably mixed with maritime aerosol during the advection to the meaurement site and partially coated with hygroscopic material

Substantial increase in particle backscattering when RH > 75 % → Swelling tendency of hygroscopic aerosol particles at large RH values → Trend compatible with partially soluble aerosol particles

Sub-micron fine mode: hygroscopic
Super-micron coarse mode: hygrofobic

References

Müller, D., U. Wandinger, D. Althausen, and M. Fiebig, 2001: Comprehensive particle characterization from three-wavelength Raman lidar observations: case study, Appl. Opt. **40,** pp. 4863–4869.

Veselovskii, .I., A. Kolgotin, V. Griaznov, D. Müller, U. Wandinger, and D. N. Whiteman, 2002: Inversion with regularization for the retrieval of tropospheric aerosol parameters from multiwavelength lidar sounding,Appl. Opt. **41,** 3685–3699

Dubovik, O., *et al.*, 2006: Application of spheroids models to account for aerosol particle nonsphericity in remote sensing of desert dust, J. Geophys.Res., **111**, doi:10.1029/2005JD00619.