Raman Lidar Retrievals

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Six-Wavelength Lidar

laser wavelengths:
355, 400, 532, 710, 800, 1064 nm

Raman wavelengths:
\( N_2 \) 387, 607 nm
\( H_2O \) 660 nm

Nd:YAG (A) -> dye (A)
Nd:YAG (B) -> dye (B)
beam combiner C
beam expander D
beam separator with detectors M

inside container -> outside container
## Retrieval of Physical Particle Parameters

### Input
- Backscatter coefficients at: 355, 400, 532, 710, 800, 1064 nm
- Extinction coefficients: 355, 532 nm
- Base functions
- MIE backscatter and extinction efficiencies

### Inversion with Regularization
- Independent of shape of particle size distribution
- No knowledge on refractive index necessary
- Works for wide range of particle parameters: $0.1 \, \mu m < r_{eff} < 1.5 \, \mu m$

### Output
- Approximation of volume concentration distribution
- Effective radius,
- Volume, surface-area, (number) concentration
- Complex refractive index
- Single-scattering albedo

Müller et al., 1999a: Microphysical particle parameters from extinction and backscatter lidar data by inversion with regularization: theory
Müller et al., 1999b: ...... : simulation
Müller et al., 2000 : ...... : experiment

*Applied Optics*
Aerosol layer from biomass burning in Canada

Particle backscatter coefficient at 532 nm

TIME, day of August 1998
TOMS aerosol index, North America, Aug 1-8 1998

ANALYTICAL 8-DAY BACKTRAJECTORIES
(1 AUG - 9 AUG 1998)

Andreas Stohl,
Technische Universität München
VALIDATION OF INVERSION RESULTS WITH AIR-BORNE IN-SITU MEASUREMENTS

9 AUG 1998, 22:00 - 24:00 UTC

3500-4000 m
inversion

3400-3900 m
in-situ
(r > 50 nm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>3500-4000 m inversion</th>
<th>3400-3900 m in-situ</th>
</tr>
</thead>
<tbody>
<tr>
<td>eff. radius (µm)</td>
<td>0.27 ± 0.04</td>
<td>0.25 ± 0.07</td>
</tr>
<tr>
<td>v (µm³/cm³)</td>
<td>13 ± 2</td>
<td>8 ± 5</td>
</tr>
<tr>
<td>s (µm²/cm³)</td>
<td>139 ± 7</td>
<td>95 ± 55</td>
</tr>
<tr>
<td>n (1/cm³)</td>
<td>291 ± 70</td>
<td>271 ± 74</td>
</tr>
<tr>
<td>real part</td>
<td>1.64 ± 0.09</td>
<td>1.56</td>
</tr>
<tr>
<td>imag. part</td>
<td>0.05 ± 0.02</td>
<td>0.07</td>
</tr>
<tr>
<td>single-scatt.</td>
<td>0.83 ± 0.06</td>
<td>0.79 ± 0.02</td>
</tr>
<tr>
<td>albedo (532nm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

532 nm
25 Mar 1999: Elevated Particle Layer
Long-Range Transport From India

BACKSCATTER COEFFICIENT (532 nm) - RES.: 15 m, 30 s
INDOEX, Maldives (4.2 N, 73.5 E), 25/03/99, 13:30 UTC

10 Day Backtrajectories
25 MARCH 1999: Physical Parameters

SINGLE-SCAT. ALBEDO (532nm)  REFRAC. INDEX, IMAG. PART  SURF.-AREA CONC. (μm² cm⁻³)
0.7  0.8  0.9  1.0  10⁻⁴  10⁻³  10⁻²  10⁻¹  10⁰  0  200  400  600  800

HEIGHT (m)

0.0  0.1  0.2  0.3  0.4

EFFECTIVE RADIUS (μm)

0.0  2.5  5.0  7.5  10.0

BACKSC. COEFF. (Mm⁻¹ sr⁻¹)

0.0  1.2  1.5  1.8  2.1  2.4

REFRAC. INDEX, REAL PART

0  20  40  60  80

VOLUME CONC. (μm³ cm⁻³)
DEPOLARIZATION RATIO, 532 nm, res. 60 m, 30 s
Raman Lidar, Leipzig (51.35 N, 12.43 E), 12-16 Oct 2001
Saharan Dust Outbreak
SeaWiFS, 13 October 2001
Particle size distribution from Sun photometer

From spheroidal particle model:
effective radius: 0.6–0.7 μm
refractive index (670 nm): real part 1.5–1.6, imaginary part 0.0014–0.0039
single-scattering albedo (670 nm): 0.93–0.96
Lidar ratio from measurement and model
Saharan Dust Outbreak, Oct. 2001
Horizontal Dust Load Over Europe
DREAM Model

10 Oct., 12 UTC

11 Oct., 12 UTC

12 Oct., 12 UTC

13 Oct., 12 UTC

14 Oct., 12 UTC

15 Oct., 12 UTC
Saharan Dust Outbreak, 14 Oct. 2001
Dust Load Over Leipzig (51.3° N, 12.4° E)
DREAM Model

At 1200 UTC

At 1800 UTC
Raman Lidar Measurements at Leipzig: September 1997 - September 2002

DATE

01.01.98 01.01.99 01.01.00 01.01.01 01.01.02

24:00 21:00 18:00 15:00 12:00

EMITTED FAILED UNIVERSAL TIME, h

sunrise sunset noon

1064 532 355

DAYS SINCE SEPTEMBER 1997, days

61 33 6 16

% of 896 possible routine measurements

Measurements

- regular
- additional
- failed because of:
  - precipitation
  - technical problems

\[ \Sigma : \]
Measurement Statistics
Raman Lidar, Leipzig

Dust-Layer Height

Extinction Coefficients (355nm, 532 nm)

Angström Exponent
EARLINET, Raman Lidar, Leipzig
Cluster-Mean Properties

Number of Cluster Members

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Number of Members</th>
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<tbody>
<tr>
<td>A</td>
<td>15</td>
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<tr>
<td>B</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>11</td>
</tr>
<tr>
<td>D</td>
<td>29</td>
</tr>
<tr>
<td>E</td>
<td>3</td>
</tr>
<tr>
<td>F</td>
<td>16</td>
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</table>

DUST LAYER HEIGHT, km

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Height (km)</th>
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<tbody>
<tr>
<td>A</td>
<td>0.0</td>
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<tr>
<td>B</td>
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<tr>
<td>C</td>
<td>2.0</td>
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<tr>
<td>D</td>
<td>3.0</td>
</tr>
<tr>
<td>E</td>
<td>4.0</td>
</tr>
<tr>
<td>F</td>
<td>5.0</td>
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</table>

EXT. COEF., Mm$^{-1}$

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Ext. Coef.</th>
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<tbody>
<tr>
<td>A</td>
<td>12</td>
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<tr>
<td>B</td>
<td>8</td>
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<tr>
<td>C</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>22</td>
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<tr>
<td>E</td>
<td>1</td>
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<tr>
<td>F</td>
<td>10</td>
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532 nm

ANGSTROM EXPONENT

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Angstrom Exponent</th>
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<tbody>
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<td>A</td>
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<tr>
<td>B</td>
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<tr>
<td>C</td>
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<td>D</td>
<td>21</td>
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<tr>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>8</td>
</tr>
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LATITUDE, degrees

LONGITUDE, degrees
<table>
<thead>
<tr>
<th>Project</th>
<th>Dates</th>
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</thead>
<tbody>
<tr>
<td>INDOEX</td>
<td>NE-Monsoon Feb/Mar 1999, Mar 2000</td>
</tr>
<tr>
<td></td>
<td>SW-Monsoon Jul/Oct 2000</td>
</tr>
<tr>
<td>ACE 2</td>
<td>Jun/Jul 1997</td>
</tr>
<tr>
<td>LACE 98</td>
<td>Jul/Aug 1998</td>
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<tr>
<td>German Lidar Network</td>
<td>1997-2000</td>
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<td>EARLINET</td>
<td>since 2000</td>
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