TROPOSPHERIC AEROSOL CHARACTERIZED BY A RAMAN LIDAR OVER SPITSBERGEN

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ABSTRACT

In this presentation the Koldewey Aerosol Raman Lidar (KARL) and first results of a new inversion technique applied on lidar data shall be introduced. KARL is located at the Koldewey Station in Ny Alesund, Spitsbergen at 78.9°N and 11.9°E and is managed by the Alfred-Wegener-Institute of Polar and Marine Research in Potsdam. Its purpose is to measure tropospheric aerosol and water vapour. Here we present the evaluation of an arctic haze event (increased aerosol loading over arctic regions in spring with optical densities of more than 0.1 in green light) recorded on March 1st 2002. Microphysical properties as the index of refraction and parameters of a log-normal size distribution are derived out of our lidar data successfully.

1. DESCRIPTION OF INSTRUMENT, DATA EVALUATION

KARL consists of a pulsed Nd:Yag laser operating at the wavelengths of 355nm, 532nm and 1064nm which has a power of 6W and 30Hz repetition rate. The divergence of the laser after passing a special expansion telescope is about 0.07mrad. The optical part of the system is formed by two parabolic telescope mirrors of 30cm and 11cm diameter. The large mirror sees the complete laser beam above 1800m altitude; the small mirror serves for measurements in the lowest troposphere which can be inclined towards the laser beam. This telescope can receive the full signal above 400m altitude.

Several wavelengths are registered by KARL: the three elastic backscattered, 532nm as well in a state of polarization perpendicular to the laser, and Raman-shifted lines of N2 at 387nm and 607nm as well as a water vapour line at 407nm. The small telescope collects the wavelengths of 532nm, 607nm and another Raman-shifted water line at 660nm, only.
The Transient recorders of the system are operating at a sampling rate of 20MHz, corresponding to a maximum height resolution of 7.5m. The most important channels are recorded twice, in a photocounting and in analog mode. Integrating the lidar signal for two hours under favourable night time conditions allows the evaluation of the weak Raman-shifted signals up to the tropopause in about 8km at Spitsbergen in late winter.

Data for this contribution was recorded during an haze event at March 1st, 2002 between 0 UT and 2 UT. Total optical depth, as confirmed by a star photometer, was 0.18 at 532nm and 0.24 at 355nm. These are considerably high values at our site, even in spring the optical depth in green light normally stays around 0.1.

To evaluate the data Ansmann's method [2] has been used for 532nm and 355nm. The feasibility of the evaluation was checked by comparison with the Klett evaluation of the elastic lidar profile [6,7]. The lidar ratio (ratio between aerosol contribution to extinction divided by aerosol contribution to backscattering), as derived by the Ansmann evaluation, was taken as an input for Klett's algorithm. The backscatter coefficient derived by Klett's method with this lidar ratio agreed very well with the one derived by Ansmann's method. Hence we do trust the evaluation of our Raman-shifted lidar profiles in spite of their lower SNR.
No Raman line appertaining to the infrared 1064nm channel is recorded with KARL. Therefore this wavelength has to be evaluated by a pure Klett algorithm.

2. INVERSIONS OF LIDAR DATA

The inversion code used here is based on the one proposed by Böckmann [3]. It was especially developed for a lidar system which offers 2 extinction coefficients (at 355nm and 532nm) and three backscatter coefficients (at 355nm, 532nm and 1064nm) and is based on Mie's theory of scattering. It consists of two parts: First of all an index of refraction (real and imaginary part) for all three involved wavelengths is estimated out of the five input parameters. This is done in an iterative process. After the determination of an average index of refraction a better choice for each single wavelength is calculated.

In a second step the inversion is performed. For numerical reasons not the number distribution function but the volume distribution function is inverted. This means that coefficients of this volume distribution function for a given basis is searched and the prior non-uniqueness is fixed by the constrain that the true solution should be the one with the smallest non-trivial norm, whereby the final expression contains a contribution of the regularisation and one of the coefficients of the volume distribution function. The mathematical concept behind this code has been described by Kirsche [5].

According to our experience the consideration of a dispersion relation leads to a smoother volume distribution function, especially in cases where no monotonic decrease of the extinction or backscatter coefficients with wavelength was registered.

3. OBSERVATIONS AND RESULTS

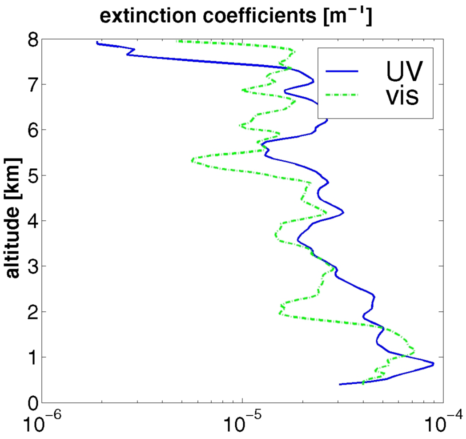
"Fig.1" shows backscatter and extinction coefficients as derived by KARL. The highest values are found in about 1000m altitude but the strong signal of the volume depolarisation there "Fig.2" prevents performing an inversion. Extinction and backscatter values generally increase with decreasing wavelength.

This is a sign that involved particles are very small compared to the lasers' wavelengths. Above about 1500m the value of volume depolarisation is very near to the background value of the clean Rayleigh atmosphere of 1.4%. Therefore aerosols cannot deviate from sphericity because the volume depolarisation is a very sensitive measurement for particles' shape.

The extinction and backscatter data at different height levels have been taken as input for the inversion code. For all altitudes between 1500m and 4800m the real part of the index of refraction seems to be around 1.49 for the three wavelengths used. The complex part of the index of refraction is around 10e-3. Thus our derived index matches to water soluble, dust-like, mineral or sulphate-rich aerosol [1]. A better containment was not possible. However, on other days at our site in Spitsbergen in spring, a high index of refraction indicates that some soot may be mixed into arctic haze.
We do not see any soot component in the data of March 1st, although aerosol load is considerable high and the lidar ratio reaches values as high as 70 in the visible "Fig.3". The results of the inversion are presented in "Tab. 1".

The real part of index of refraction, the particle density per cm^3 the effective radius of aerosol and the radius and width (sigma) of a corresponding log-normal distribution is given.

These parameters vary only smoothly with altitude. Therefore one homogeneous type of aerosol can be assumed at altitudes above 2000m with an index of refraction of some 1.49 and an effective radius of 2.5 microns. The aerosol load decreases almost monotonically with altitude, with the only exception being the height around 3.5km with its low values for extinction and backscatter coefficients.



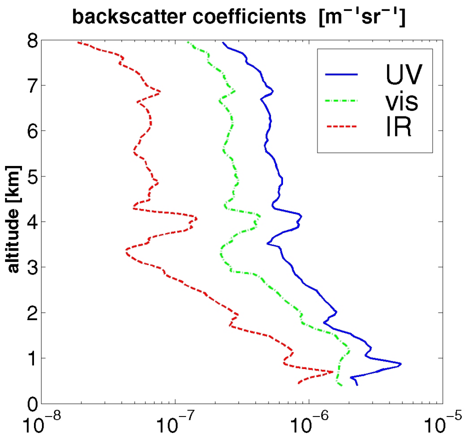


Fig. 1. Extinction (up) and backscatter coefficients (down).

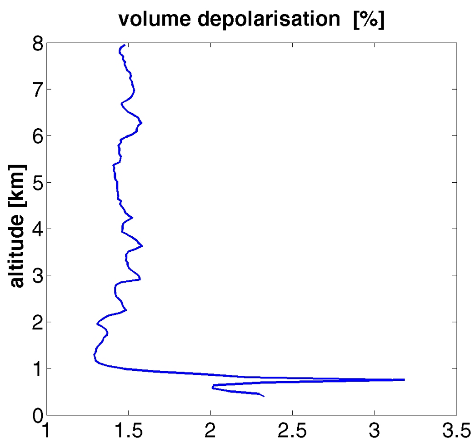


Fig. 2. Volume depolarisation

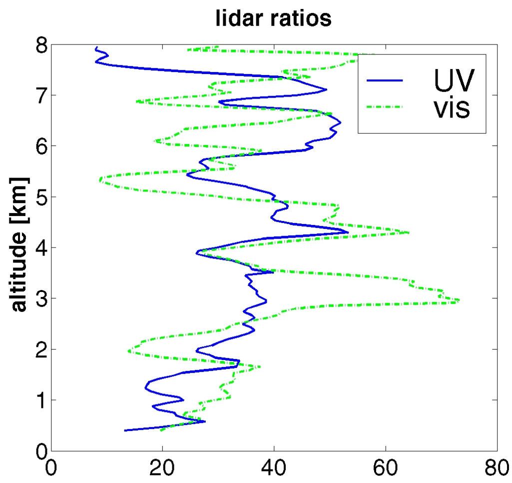


Fig 3. Lidar ratios

Table 1: Microphysical properties

Altitude km	n	particles per cm^3	Reff 10^{-7} m	Rmod 10^{-7} m	σ
4.7	1.50	80.6	2.57	1.377	1.648
4.0	1.50	91.6	2.33	1.365	1.588
3.5	1.47	72.1	2.49	1.682	1.594
3.0	1.49	79.9	2.99	1.428	1.723
2.8	1.48	97.5	2.77	1.336	1.717
2.6	1.47	118.0	2.56	1.283	1.692
2.4	1.49	166.8	2.05	1.234	1.568
2.0	1.48	172.4	2.14	1.224	1.606
1.5	1.46	49.2	4.62	3.080	1.496

n*: index of refraction*

The lowest layers of the troposphere are dominated by larger particles. As can be seen in the sharp spike of the volume depolarisation around 1000m altitude and the high values of the infrared backscattering the particles there should be large and aspherical, maybe even solid.

With the index of refraction of spherical aerosol, its effective radius and its number density known other microphysical quantities can be evaluated by Mie's theory of scattering.

Especially important as an input to climatological models are the single scattering albedo ω (defined as the ratio between scattering to extinction of the aerosol) and the asymmetry factor P (which gives the angular dependence of the preferred direction of scattering. Positive values mean that scattering in forward direction dominates).

The value of ω strongly depends on the imaginary part of the index of refraction. We estimate an insecurity of 30% in the determination of ω in a single inversion calculation.

Assuming the existence of a uniform type of aerosol between 2 and 4.7km altitude, however, a mean value of ω can be calculated to 0.844 (with standard deviation of 0.088).

The asymmetry factor appeared very uniform with height and had a mean value of 0.836 (deviation: 0.0078).

4. SUMMARY AND CONCLUSIONS

Observations derived by the Koldewey Aerosol Raman Lidar (KARL) have been presented here. Inversion of the three backscatter and two extinction coefficients derived by KARL yields information of the index of refraction and size distribution. An aerosol contamination up to at least 5km altitude is definitely seen. In other reports artic haze has been observed up to 3.5km altitude and only sporadically in thin layers above this height [4]. The uppermost layer of aerosol mainly determines its climatological impact according to Quijano [8]. Apart from a surface layer of large, aspheric particles, the aerosol in other heights is almost spherical and can be successfully inverted by Mie theory. An uniform index of refraction of 1.49 and an effective radius of about 2.5 micron have been derived.
Determination of a mean value of the single scattering albedo leads to 0.844. The combination of KARL measurements and the inversion technique allow to constrain input data for atmospheric models in the arctic.

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