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UV-DEPOLARIZATION LIDAR REMOTE SENSING EXPERIMENT ANALYSIS USING SCATTERING MATRIX FORMALISM

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ABSTRACT. In this paper, an optical remote sensing method is proposed to retrieve the number concentration of non spherical volcanic ash particles. An UV-polarization sensitive remote sensing experiment is interpreted in the frame of the scattering matrix formalism. It follows that UV-optical scattering and depolarization, when they are used together and in correlation with laboratory measurements on scattering matrix elements, are meaningful to retrieve information on volcanic ash particles such as shape or number concentration.

1. Introduction

Natural atmospheric aerosols, such as mineral dust or volcanic particles, present a wide range of sizes, shapes and chemical compositions. In this contribution, in complement to airborne measurement techniques, a ground-based optical remote sensing method is proposed to retrieve the number concentration N_{ns} vertical profile of non spherical particles. A main advantage of performing a remote sensing experiment is that aerosols scattering and polarization properties are measured under in situ conditions (temperature, relative humidity) with a non destructive technique whose sensitivity provides an unique interpretation of the particles physical properties such as size and shape. As explained by Mishchenko et al. [2], atmospheric aerosols's ability to depolarize laser light is mainly governed by the aerosols shape, which can thus be remotely gathered with a polarization-sensitive detector, by measuring the magnitude of the depolarization.

In this contribution, the studied particles are volcanic particles, released from the mid-April 2010 eruption of the Eyjafjallajökull volcano (63.63°N, 19.62°W, Iceland), which passed in the troposphere above Lyon Lidar experiment (45.76°N, 4.83°E, France) after advection over 2600 km. Section 2 is devoted to the UV-backscattering and depolarization experiment. The UV-spectral range has been chosen to be sensitive to particles in the size range of a few cents of nanometers. Very sensitive and precise measurements of the particle backscattering coefficient β_p and of the Lidar depolarization ratio $\delta_p = \beta_{p,\perp}/\beta_{p,\parallel}$ are proposed. For the sake of clarity, let us recall that β_p describes the amount of light scattered in the backward direction and is equal to $N_p \times (d\sigma/d\Omega)_p$, where N_p is the particles number concentration (in m^{-3}) and $(d\sigma/d\Omega)_p$ is the particle backscattering differential cross-section (in $m^2.sr^{-1}$), averaged over the particles size distribution. Observed δ_p-variations are interpreted in section 3 where the ash particles depolarization ratio is retrieved from

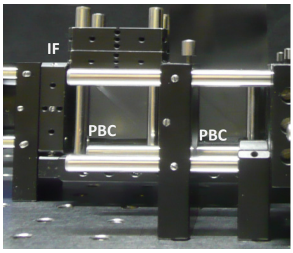

Figure 1. Photography of the novel home-built UV-polarization sensitive detector. Only the perpendicular channel is represented. PBC stands for polarizing beam-splitter cubes and IF for interference filter ($\Delta\lambda = 0.35$ nm).

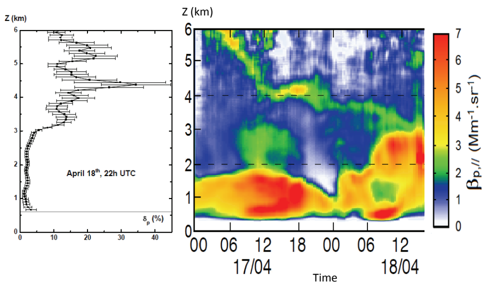

Figure 2. Vertical profile of the particle UV-depolarization ratio δ_p and time-altitude map of the parallel particle UV-backscattering coefficient $\beta_{p,\|}$ (color plot), showing the volcanic cloud in a filament tilting into the low troposphere.

O. Munoz et al.'s laboratory measurements [1] by applying scattering matrix formalism [2]. Within our error bars, our δ_p-values correlate with this study to distinguish non spherical ash particles from spherical small-sized particles. At altitude z, we then retrieve the non spherical ash particles backscattering coefficient β_{ns}, from which we evaluate the non spherical particles number concentration N_{ns}, by optical computing of ash particles scattering cross-sections, using O. Munoz et al. 's ash particles optical parameters [1].

2. UV-backscattering and depolarization

The Lidar laser source is a highly linear polarized Nd:YAG laser emitting at 355 nm. The UV-polarization sensitive detector is a novel home-built detector composed of two UV-polarizing beam-splitter cubes (see figure 1), to make the cross-talk between parallel ($P_{\|}$) and perpendicular ($P_{\perp}$) channels fully negligible. The detector optical properties have been tested at the laboratory where a dedicated test bench has been built to measure the detector transfer matrix elements. Backscattered photons from the atmosphere are collected with a 200 mm Newtonian telescope before entering the light detector, where after detection by a photomultiplier, photoelectrons are sampled with a 12-bits 40-MHz Licel AD-converter. The Lidar signals are then range-averaged to obtain a vertical resolution of 75 meters.

Vertical profiles of $\beta_{p,\|}$ (parallel particle UV-backscattering coefficient) and δ_p (particle UV-depolarization ratio) are displayed in figure 2. The time-altitude map of $\beta_{p,\|}$ is retrieved from Klett's algorithm by using a constant backscatter to extinction ratio of (55 $\pm$ 5) sr for volcanic particles, in agreement with recent measurements performed on the Eyjafjallajökull volcano [3]. δ_p is then evaluated from $\beta_{p,\|}$ and $\delta = P_\perp / P_\|$ by applying Winker and Osborn's method into the low troposphere [4]. The δ_p-calibration is performed under in-situ conditions by inserting a half-wave plate on the optical path [5]. The volcanic cloud is visible on figure 2-backscattering vertical profile where a thin filament tilts into the low troposphere, as confirmed by 7-days air mass back-trajectories and FLEXPART ash particles numerical dispersion model [6]. Within our error bars, the depolarization ratio vertical profile exhibits several volcanic layers, showing that, after long-range advection, volcanic particles were not homogeneously spread into the low troposphere and were still non spherical.

3. Results and discussion

Vertical profiles of $\beta_{p,\|}$ and δ_p are displayed in figure 3 on April 19^{th} at 18h30, after the filament has mixed into the planetary boundary layer. Below 3 km, the observed $\beta_{p,\|}$ enhancement can be related to spherical small-sized sulfate particles, strongly affected by hygroscopic growth, which lower the depolaration ratio δ_p. Above 3 km, within our error bars, a double-layer structure is visible on the δ_p-profile and a maximum value $\delta_p = (35 \pm 10)\%$ is reached in the free troposphere at 4.7 km. As developed by M.I. Mishchenko et al. [2], the δ_p-ratio is related to the Stokes's normalized scattering matrix elements a_1 and a_2 and $\delta_p = (a_1 - a_2)/(a_1 + a_2)$. The δ_p-value for ash particles can thus be determined from O. Munoz et al.'s laboratory measurements on randomly oriented volcanic ash particles [1], by using their synthetic scattering matrices elements in the Lidar backscattering case. The retrieved δ_p-value for ash particles, $\delta_p(ash) = (40.5 \pm 2.0)\%$, correlates, within our error bar, with the maximum observed δ_p-value so that the corresponding air masses are composed of volcanic ash particles. Observed δ_p-variations are then due to variations in the backscattering coefficients of the spherical and non spherical particles. Hence, care must be taken to interpret Lidar depolarization measurements, as the presence of small-sized spherical particles may lower the observed depolarization ratios. Moreover, the non spherical particles backscattering vertical profile β_{ns} can be retrieved by combining our Lidar measurements ($\beta_{p,\|}$, δ_p) with the ash particles depolarization ratio $\delta_p(ash)$:

$$\beta_{ns} \equiv \beta_{ash} = \beta_{ash,\|} + \beta_{ash,\perp} = \beta_{p,\|}\delta_p[1 + 1/\delta_p(ash)] \qquad (1)$$

by assuming the Lidar perpendicular channel to be only sensitive to non spherical ash particles. The non spherical ash particles number concentration N_{ns} is then retrieved from β_{ns} by considering the definition of β_{ns} recalled in section 1. The ash particles backscattering cross-section $(d\sigma/d\Omega)_{ns}$ is equal to $a_1 \times < C_{scat} > /(4\pi)$, where a_1 is deduced from [1] and $< C_{scat} >$ is the averaged scattering cross section per ash particle, calculated by applying Mie theory on equivalent ash particles spheres by considering a 355 nm-refractive index and a double log-normal size distribution taken from [1]. This assumption leads to a 15 %-uncertainty and T-Matrix formalism should be applied to lower this uncertainty. The N_{ns}-vertical profile exhibits less pronounced variations with altitude than the δ_p-profile.

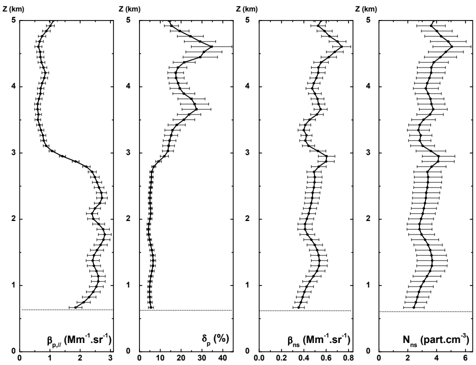

Figure 3. Vertical profiles of $\beta_{p,\parallel}$, δ_p, backscattering coefficient β_{ns} and number concentration N_{ns} for non spherical (ns) ash particles on April 19^{th} at 18h30.

This confirms that care must be taken in the interpretation of UV-particles scattering and polarization properties. In counterpart, δ_p relies on in situ atmospheric scattering properties, which are difficult to retrieve from scattering matrix evaluations.

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