# MULTIWAVELENGTH LIDAR PSC MEASUREMENTS MADE AT ALOMAR (69°N) DURING WINTER 2005

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## ABSTRACT

A case study of a Polar Stratospheric Cloud (PSC) was performed above ALOMAR in December 2005. Multiwavelength measurements (355, 532 and 1064 nm) were associated to Raman detection (387, 607, 529 and 530 nm). The rotational Raman wavelengths allowed for temperature profile retrieval simultaneously with PSC observations. At the peak altitude of the PSC layers, we test a method of PSC size distribution retrieval using look-up tables of backscattering coefficients. Comparing data with the tables give access to microphysical parameters and hence to surface area density used to estimate chlorine activation rate.

## 1. INTRODUCTION

PSC play a key role in ozone depletion by providing the surfaces for chlorine activation through heterogeneous chemistry [1,2]. Understanding and characterizing the formation processes and the lifetime evolution of these clouds is thus a major concern. Surface area density and volume can be derived from their geometrical properties, i.e. their size distribution. Knowledge of surface areas allows for calculating the rate of activated chlorine and thus for assessing the subsequent ozone depletion. If lidar measurements are used to characterize stratospheric particles since the early 1960s [3], direct retrieval of the particles' size distribution from one wavelength lidar measurements is precluded [4]. In addition, retrieving particles' optical parameters from lidar signals requires several assumptions : a reference altitude in the aerosol free air at the top of the altitude range and also a relationship between extinction and backscattering coefficients, the so called lidar ratio [5,6]. This dependence link prohibits going back to the microphysical properties.

However, the addition of Raman channels enables a precise determination of the particles' backscattering coefficient, as the inelastic Raman backscattered signal is only affected by particles' extinction but not by the backscattering [7]. Significant improvements in microphysical characterisation of particles have now been made with multiwavelength Raman lidar [8].

Lidar observations of stratospheric particles at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR), Andenes, Norway are under the responsibility of Service d'Aéronomie, IPSL, Paris, France. Here we present a case study of PSC microphysical properties retrieval using the multiwavelength lidar observations performed at ALOMAR on December, 6$^{th}$ 2005.

Then we describe the methodology used. The measurements are combined with microphysical modelling to gain access to the size distribution parameters of PSC particles.

Finally, before concluding, we discuss this methodology and its applications. This case study can be regarded as a first validation for both the signal inversion code and the size distribution retrieval method.

## 2. OBSERVATIONS

The ALOMAR Rayleigh/Mie/Raman lidar operating wavelengths are 355, 532 and 1064 nm, produced by a 30-Hz repetition rate pulsed Nd-YAG laser [9]. The backscattered light is received on a 60 cm diameter Newton telescope and detected with photomultipliers tubes in photo-counting mode. Vibrational (387 and 607 nm, associated respectively to the 355 and 532 nm wavelengths) and rotational (529 and 530 nm) Raman signals are also detected. The vertical resolution is 150 m and the signals are averaged on 3 minutes.

The PSC was observed roughly between 15:00 and 20:00 UT at the 22-27 km altitude range. Two layers can be distinguished, at about 23 and 26 km. A meteorological PTU sonde was also launched at 15:40 UT at the Andøya Rocket Range and reached the altitude of the cloud at about 16:30 UT.

On December, 6$^{th}$ 2005, the outputs of the high resolution transport MIMOSA model indicate that the polar vortex was centered between 80° and 90°N at the 475 K and 550 K potential temperature surfaces and was spread over Norway, indicating favourable PSC formation conditions above ALOMAR.

## 3. METHODOLOGY

In order to follow the time evolution of the PSC with an acceptable Signal to Noise Ratio (SNR), the lidar signals were averaged on 10 minutes, during the time of PSC observations.

First, the rotational Raman channels at 529 and 530 nm are used to restore the temperature profile up to 30 km. This profile is needed in the lidar signals inversion to calculate the molecular backscattering, but also to analyse the PSC case. Indeed, PSC form in the lower polar winter stratosphere, when temperatures become low enough. Thus, simultaneous and co-located temperature profiles greatly help in understanding PSC formation processes. This technique uses the temperature dependency of the nitrogen and oxygen molecules rotational lines [10,11,12]. The PTU sonde was used to get the optimal temperature calibration. Uncertainties on the calculated temperature profiles are directly related to lidar SNR but also to the data filter used. Here they reach 2-3 K, especially at high altitudes (above 27 km) where the SNR is bad. The temporal variability on temperature profiles is shown on Fig. 1.

Lidar signals at 355 and 532 nm were inverted using the Raman scattering theory to get the backscatter ratio, defined as $1+\beta_{par}/\beta_{mol}$, where $\beta_{par}$ and $\beta_{mol}$ are respectively the particlular and molecular backscattering coefficients. The 1064 nm signal was inverted using the Klett inversion method [5,6]. Examples of backscatter ratio profiles obtained at 355, 532 and 1064 nm are shown on Fig. 2, whereas Fig. 3 displays the time evolution of backscatter ratio at the three wavelengths between 15:00 and 20:00 UT on December 6th 2005. Uncertainties on the backscatter with the Raman technique are estimated to be less than 10%, whereas Klett inversion errors, at 1064 nm, can reach 20-30% due to the errors in determining the backscatter coefficient at the reference altitude.

From the particles backscatter profiles at three wavelengths, we have developed a method to derive information on the particle size distribution using look-up tables calculated with both optical and microphysical models. The Polar Stratospheric Clouds – Microphysical and optical model from the Danish Meteorological Institute [13] was used to calculate the refractive index of the PSC particles at each wavelength, in the thermodynamical conditions prevailing during our observations and with 5 ppm of water vapour and 10 ppbv of gas phase $HNO_3$. The model does not enable calculations at wavelength less than 360 nm. Even if the refractive index mainly drives the backscatter coefficient [4,14], the uncertainty induced by the refractive index wavelength dependency between 355 and 360 nm is insignificant as compared to the other error sources.

The Larsen's model optical module is based on the Mie theory [15] for spherical particles. Our optical calculations are thus made assuming that we observed a Type 1b PSC, composed of a liquid supercooled ternary solution ($HNO_3/H_2O/H_2SO_4$). Actually, a second lidar located at ALOMAR is able to detect 532 nm cross-polarised signal and showed no significant depolarization signal at the time and altitude range of the PSC, indicating that the observed particles are spherical.

The backscatter coefficient can be expressed by Eq. 1:

$$\beta_\lambda = \int_0^\infty n(r).\frac{d\sigma_b}{d\Omega}(r,\lambda,\eta).dr \qquad (1)$$

where $\lambda$ is the incident wavelength, $\eta$ the refractive index, $d\sigma_b/d\Omega$ the Mie backscattering differential cross section and n(r) is the particles size distribution. PSC type 1b form by an uptake of $HNO_3$ and $H_2O$ vapour in sulphuric acid background aerosols to stay in thermodynamical equilibrium when temperature is decreasing [1,2]. They can thus be represented by an unimodal lognormal size distribution [16, 2 and references herein] :

$$n(r) = \frac{N_o}{\sqrt{2\pi}.r.\ln(\sigma)}.\exp\left(-\frac{\ln(r/r_m)^2}{2\ln(\sigma)^2}\right) \qquad (2)$$

with $N_0$ being the total number of particles per unit volume, $r_m$, the median radius and $\sigma$ the geometric standard deviation.

As a first step, the optical module was run for a large range of size distributions at the three detected wavelengths to produce look-up tables of backscattering coefficients. In these runs, $N_0$ was chosen between $10^{-3}$ and 10 $cm^{-3}$, $r_m$ interval is $10^{-3}$ to 10 µm, with a step of 0,005µm and $\sigma$ ranges between 1 and 3, by 0,001. Then, the three ratios of observed $\beta_{par}$ at one $\lambda$ to the other ones are calculated: thereby, $N_0$ disappears and a matching solution for $r_m$ and $\sigma$ is read in the look-up tables. $N_o$ is easily determined in a second step. The $\beta_{par}$ values are taken at the peak of each PSC layer.

## 4. DISCUSSION AND CONCLUSIONS

Multiwavelength measurements made at ALOMAR on December 6th 2005, with both Rayleigh/Mie and Raman channels (vibrational and rotational), are used to characterize a PSC case. The pairs 355/387 and 532/607 nm were used to obtain backscatter coefficients values for particles, whereas the 529 and 530 nm wavelength allowed for temperature retrieval simultaneously with PSC observations. The PSC was mainly observed from 15:00 to 19:00 UT. It ranges from 22 to 27 km, in two layers centered on 23 and 26 km (Fig. 2 and 3). Comparing backscatter ratios at 355, 532 and 1064 nm with the calculated temperatures (Fig. 1), we can state that the temperature dependence of PSC formation is confirmed, since the cold episodes appear prior to the strong values of backscatter ratios, observed around 17:00 UT. The temperature profiles clearly show that temperatures between 16:00 and 18:00 UT are cold enough for type

1b PSC to condense. A slight warming is observed at 19:00 UT, in agreement with the PSC disappearance on the measurements. The waves that seem to appear on the temperature profiles are likely to indicate gravity waves propagation.

With the backscatter information, we gained access to the size distribution by crossing the 355, 532 and 1064 nm backscatter ratios with the results of microphysical and optical simulations. The size distribution retrieval method was applied on the time interval in which the temperature is the coldest and the PSC backscatter ratios are the strongest. Afterwards, we do not find any acceptable match in the look-up tables. The results for the size distribution parameters between 16:00 and 18:00 UT are presented in Fig. 4.

When the PSC appears for the first time on the measurements, around 15:00 UT, particles are found to have $r_m$=1.44 µm with σ=1.8 and a relatively low concentration of 0.004 $cm^{-3}$. Around 16:20 UT, temperature drops below 185 K during half an hour, then increased to 190 and later to 195 K, until 19:00 UT with a punctual warming around 17:00 UT. During the coldest period, $N_0$ grew up to 0.06 $cm^{-3}$. The particles' radius then increases as the total number density returns to values around 0.015 $cm^{-3}$. The fact that a maximum of particles condense around 23 km in the lower layer around 17:00 UT is consistent with the maximum of the backscatter ratio seen on Fig. 2 and 3.

Median radii plotted on Fig. 4 compared to temperatures shown on Fig. 1 support the idea that the observed PSC particles are mainly liquid particles. Solid PSC type 2 particles present larger typical radii. However, further analysis are needed in order to asses that we observed type 1b PSC or intermediate type PSC [17].

It is worth noting that our calculated values of $N_o$, $r_m$ and □ represent a rough estimation rather than a precise determination, as the uncertainties in the retrieval method induced by the various error sources are still large. Meanwhile, for the multiwavelength lidar running routinely in polar regions, this method allows for getting a relatively good microphysical characterization for liquid type PSC. From this, total particles surface area density and volume can be calculated (Fig. 5). We can see that between the first observation and the time where the signals were the strongest, surface area density is multipled by about 3 and particles volume by about 4, with consequences on the chlorine activation rates.

Further investigations will include backward trajectories using the FLEXPART model [18], but also wavelet decomposition of the temperature profile to state on possible gravity waves propagation.

## 5. REFERENCES


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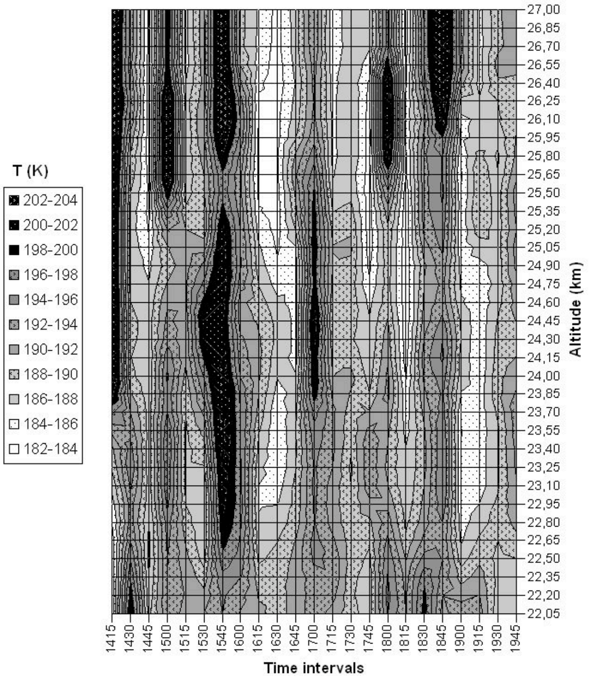


**Fig. 1.** Temperature profiles between 15:00 and 20:00 UT calculated with the 529 and 530 nm Raman wavelengths.

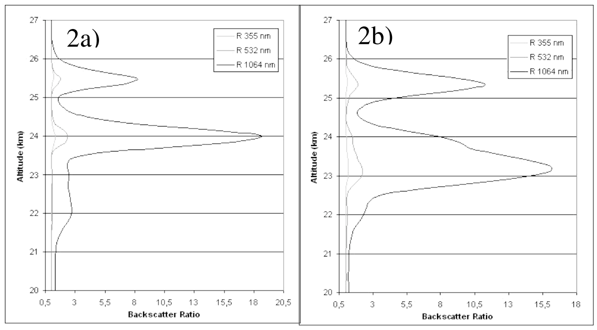


**Fig. 2.** Backscatter ratios at 355, 532 and 1064 nm for 16:00-16:20 UT (2a), and 17:15-17:40 UT (2b).

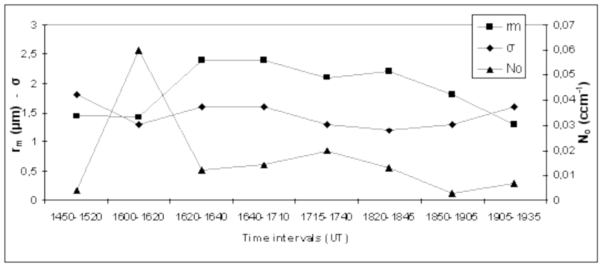


**Fig. 4.** Size distribution parameters retrieved by crossing multiwavelength lidar backscatter coefficients with microphysical and optical calculations.

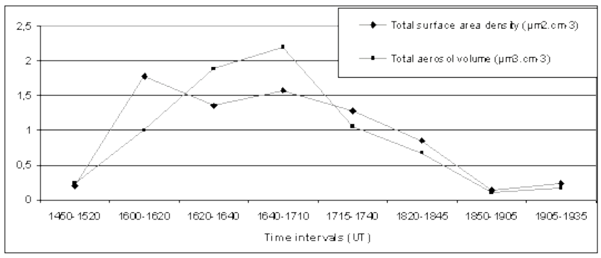


**Fig. 5.** Total surface area density and volume of aerosols calculated with size distributions of Fig. 4.

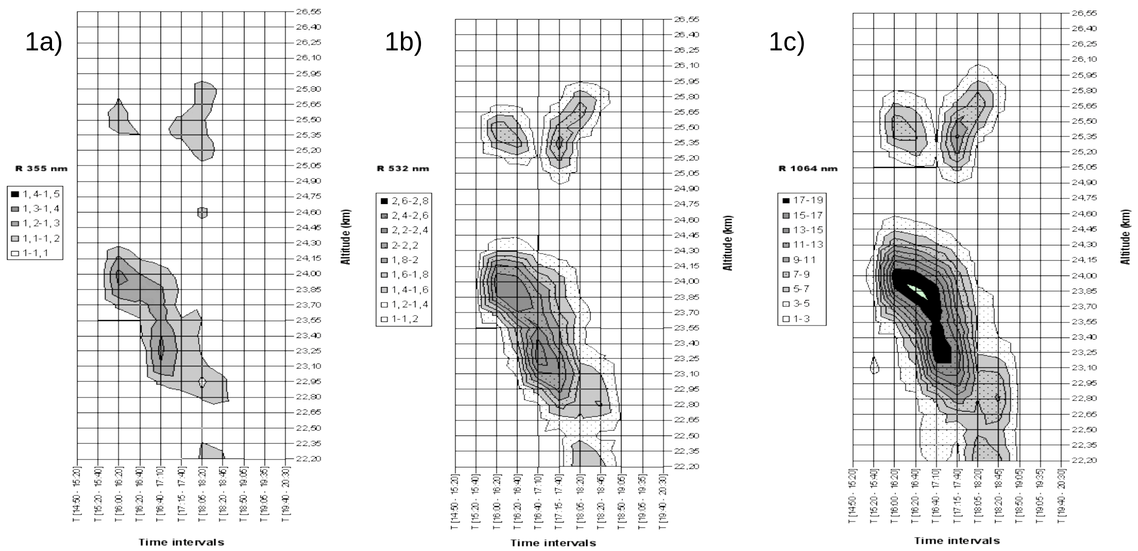


**Fig. 3.** Backscatter ratio at 355 (3a), 532 (3b) and 1064 nm (3c) calculated on multiple time intervals between 15:00 and 20:00 UT from PSC measurements made at ALOMAR on december. 6th 2005.