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Retrieval of Pinatubo aerosol size distribution from backscattering and optical thickness measurements

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Introduction.

In the present paper we discuss a method for single-mode lognormal aerosol size distribution retrieval based on two-wavelength lidar measurements.

Aerosol dimensional characteristics are deduced from integrated backscattering and optical thickness measurements at 351 nm and 580 nm. The retrieval method is based on the use of Mie scattering theory and the assumption of a single-mode lognormal size distribution of particles. The method makes use of the following parameters: $C_1=\tau_A(351nm)/BI(351nm)$, $C_2=\tau_A(580nm)/BI(580nm)$, $C_3=BI(580nm)/BI(351nm)$, with $BI(\lambda)$ and $\tau_A(\lambda)$ being respectively the aerosol integrated backscattering and optical thickness at λ=351 and 580 nm. $BI(\lambda)$ and $\tau_A(\lambda)$ are independently obtained from the lidar elastic return at λ.

The theoretical values of C_1, C_2 and C_3 have been computed for different values of the aerosol median radius r_m and size distribution width σ, on the basis of the Mie scattering theory. Fitting the measured values of C_1, C_2 and C_3 to the theoretical ones, it is possible to determine both r_m and σ. The use of three parameters sensibly reduces the possibility of ambiguous solutions (a wide range of r_m and σ values for which measured and computed values are consistent) and leads to the possibility to determine both dimensional terms within the single-mode lognormal size distribution (r_m and σ) as well as the aerosol number density N(z).

The method was tested over three nights of measurement following the Mount Pinatubo eruption, for which both 351 nm and 580 nm lidar data are available. The selected nights of measurement were chosen in order to evidence different development stages of the stratospheric aerosol particles. The first night (27 April 1992) is about 10 months after the major eruption and corresponds to a period of maximum aerosol loading [1]. The second night (31 May 1993) is about 24 months after the eruption and is representative of a period of reduced stratospheric aerosol load. The third night (7 March 1994), about 33 months after the eruption, corresponds to almost background aerosol conditions in terms of aerosol number density. The dimensional parameters found for the nights of measurement are in agreement with the results expected from theory, as well as with measurements reported by other authors [1-5].

Experimental.

The lidar system located in Napoli (Italy, 41°N-16°E) is operational since July 1991. The system is based on a Xe:F laser (λ= 351 nm), with a single pulse energy of approximately 100 mJ and a repetition rate up to 200 Hz. The receiver consists of a vertically pointing cassegranian telescope with a 500 mm diameter primary mirror. The collected radiation is divided into two parts, each passing through a double grating monocromator and detected by a photomultiplier. Signals are amplified and sent to a photon counting chain. In order to maximize signal-to-noise ratio, operation is limited to night time. At the beginning of April 1992 the transmitting system was implemented through the introduction of a Dye laser (Xe:F pumped) using rhodamine 580,(spectral range=570-600 nm). Data are integrated over 90000 laser shots (corresponding to a time integration of 10 minutes at 150 Hz) and the vertical resolution is 300 m.

Results.

Data analysis is based on the assumption of a single mode lognormal size distribution [6]. We assume the aerosol particles within the stratospheric layer to be characterized by a size distribution not changing with height, so that the parameters $C_1=\tau_A(351)/BI(351)$, $C_2=\tau_A(580)/BI(580)$, $C_3=BI(580)/BI(351)$ are independent from height, but strictly depend on aerosol optical properties and dimensional characteristics. At a fixed wavelength λ they depend only on r_m, σ and m. We suppose to deal with a 75% H_2SO_4/H_2O solution aerosol; this leads to a modal refractive index of 1.45-0i and 1.43-0i, respectively at 360 nm and 560 nm [7]. Assuming aerosol scattering to follow Mie scattering theory, we computed the theoretical values of C_1, C_2 and C_3 as function of r_m and σ.

In order to determine the experimental values of C_1, C_2 and C_3, the values of $\tau_A(351)$, BI(351), $\tau_A(580)$, BI(580) have to be measured. The values of BI(λ) and τ_A (λ) are independently determined from the elastic backscatter return.

Fig. 1 shows the vertical profiles of $\beta_A(351,z)$ and $\beta_A(580,z)$ for 27 April 1992. The aerosol layer is located between 10 and 27 km and the maximum values of $\beta_A(\lambda,z)$ are around 22 km. The average value of $\beta_A(351,z)$ and $\beta_A(580,z)$ within the stratospheric layer are 3.4×10^{-7} $m^{-1}sr^{-1}$ and 1.6×10^{-7} $m^{-1}sr^{-1}$ respectively; these values are an order of magnitude larger than those found in pre-volcanic conditions [8]. Figure 2 shows the profiles of $\beta_A(351,z)$ and $\beta_A(580,z)$ for 31 May 1993; the aerosol layer extends from 10 to 23 km and the average values of $\beta_A(351,z)$ and $\beta_A(580,z)$ are respectively 1.3×10^{-7} $m^{-1}sr^{-1}$ and 8.3×10^{-8} $m^{-1}sr^{-1}$ respectively. Figure 3 shows the profiles of $\beta_A(351,z)$ and $\beta_A(580,z)$ for 7 March 1994. The vertical extent is 10-23 km and the average values of $\beta_A(351,z)$ and $\beta_A(580,z)$ are 9.4×10^{-7} $m^{-1}sr^{-1}$ 5.6×10^{-7} $m^{-1}sr^{-1}$ respectively.

A reliable evaluation of r_m and σ is obtained by locating the experimental values of C_1, C_2, C_3 on the bidimensional maps representing the theoretical values of C_1, C_2 and C_3 as a function of r_m and σ.

Once the values of r_m and σ are known and assuming the aerosol size distribution independent from height, the vertical profile of the aerosol number density $n_0(z)$ can be retrieved from the vertical profile of $\beta_A(\lambda,z)$.

The measurements performed on 27 April 1992 lead to an aerosol particle with a median radius of $r_m=0.3$ μm and a distribution width $\sigma=1.3$, the measurements of 31 May 1993 lead to $r_m=0.16$ μm and $\sigma=1.95$, while the measurements of 7 March 1994 lead to $r_m=0.20$ μm and $\sigma=1.8$.

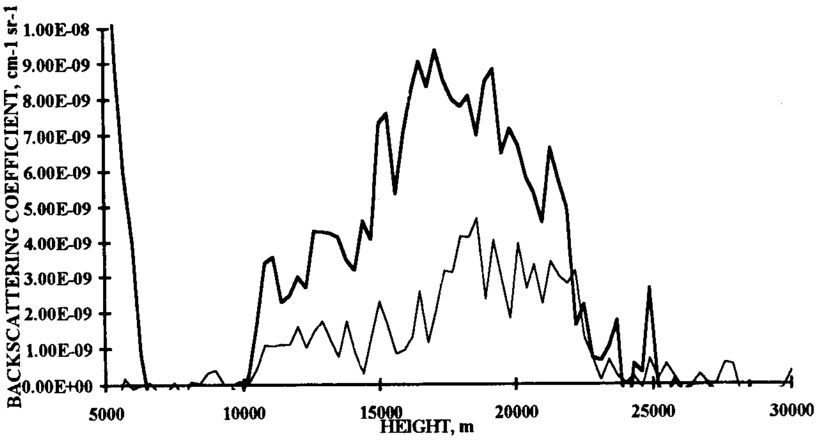

FIG. 1. Vertical profiles of βA(351,z)(solid line) and βA(580,z)(thin line) for 27 April 1992.

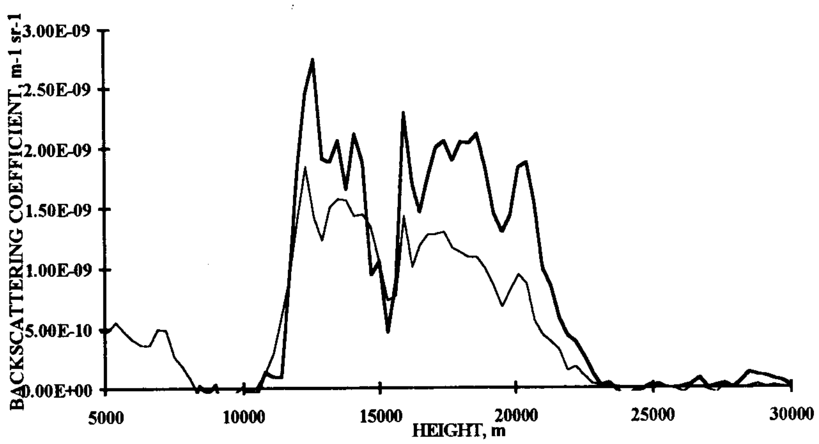

FIG. 2 Vertical profiles of βA(351,z)(solid line) and βA(580,z)(thin line) for 31 May 1993.

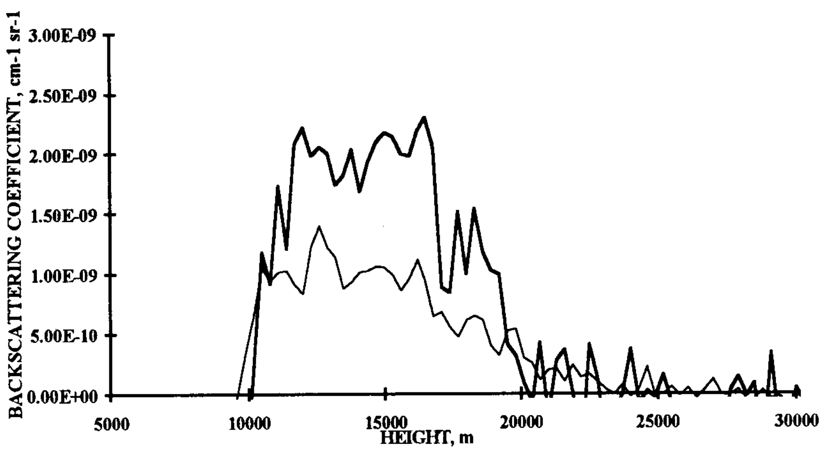

FIG. 3 Vertical profiles of βA(351,z)(solid line) and βA(580,z)(thin line) for 7 March 1994.

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