Int'l Geos. And Remote Sensing Symposium
(IGARSS'94), Pasadena, CA, Aug. 8-12, 1994
IEEE Geos. And Remote Sens. Society

Two-Wavelength Lidar Monitoring of Stratospheric Particles After Pinatubo Volcano Eruption

Yi-Chung Rau* and C. R. Philbrick'
*Caelum Research Corp., 11229 Lockwood Dr., Silver Spring, MD 20901.
(TEL) (301)593-1748, (FAX) (301)593-3951, e-mail: ycr@eclx.psu.edu
'Department of Electrical Engineering, The Pennsylvania State University, University Park, PA16802, e-mail: crp@ecl.psu.edu

ABSTRACT

Monitoring of stratospheric dust particles after the Pinatubo Volcano eruption, June 1991, has been made with a two-wavelength lidar. A novel two-wavelength particle backscattering ratio, R_{12}, was used to observe the stratospheric particle distribution with altitude. This ratio is defined as a ratio between particle backscattering signal at *532 nm* and particle backscattering signal at *355 nm*. Different particle group in the atmosphere presents different two-wavelength particle backscattering ratio. By observing this two-wavelength particle backscattering ratio profiles, we noticed the presence of different particle groups in stratosphere and the sedimentation of the Pinatubo volcanic particles. The changing of two-wavelength particle backscattering ratio and wavelength dependence values at latter time are discussed.

INTRODUCTION

Rayleigh lidar technique is a unique tool to observe the stratospheric dust layer. To separate the particle scattering components from the total return signal, the lidar profiles are presented in terms of lidar backscatter ratio,

$$R(Z) = \frac{(B_a(Z) + B_m(Z))}{B_m(Z)}, \quad (1)$$

where $B_a(Z)$ and $B_m(Z)$ are respectively, the aerosol and molecular backscattering signals. The upper term, $B_a(Z)+B_m(Z)$, is proportional to the lidar signal times the squared distance, Z, from ground. In our study, the model of U.S. Standard Atmosphere, 1976 was used for molecular density estimation. A backscatter ratio $R(Z) = 1$ represents an aerosol (cloud) free atmosphere. The backscatter ratios, R_1 and R_2, at two wavelengths, *532* and *355 nm*, and the novel two-wavelength particle backscattering ratio, R_{12}, were used to observe the stratospheric particle distribution with altitude during the Penn State LADIMAS (LAtitudinal DIstribution Middle Atmospheric Structure) Campaign 1991.

TWO-WAVELENGTH LIDAR DETECTION OF STRATOSPHERE

During October 8, 1991 and January 2, 1992, the Penn State LAMP (Laser Atmospheric Measurements Program) lidar was on board the German research vessel *RV POLARSTERN* to study the latitudinal distribution of middle atmosphere structure [Philbrick et al. 1992; Rau and Philbrick 1994]. Beside the study of the latitudinal distribution of atmospheric structure, this campaign provided a unique opportunity to monitor the stratospheric dust layer latitudinal distribution after the eruption of the Pinatubo volcano in June 1991. The lidar backscatter ratios for two-wavelength lidar measurements, R_1 and R_2 are:

$$R_1(Z) = 1 + \frac{B_{a1}(Z)}{B_{m1}(Z)}, \quad (2)$$

and,

$$R_2(Z) = 1 + \frac{B_{p2}(Z)}{B_{m2}(Z)}, \quad (3)$$

where, subscripts *1* and *2* represent the measurements from *532 nm* (green) and *355 nm* (UV), respectively.

The backscatter ratio profiles, *R(Z)*, from ground to *40 km* for a thirty-minute integration period at 22:00 UT on 22 November 1991, at both *532 nm* and *355 nm*, are shown in Figure 1. By assuming a particle free atmosphere above *40 km*, the normalization of lidar return profiles to $R_1(Z) = 1$ and $R_2(Z) = 1$ were performed in the region near *40 km*. In Figure 1, the scattering ratio profiles of both *532 nm* and *355 nm* are close to unity above *35 km*, which confirmed the assumption of a particle-free atmosphere above *40 km*. The Pinatubo volcanic particle layer caused strong scattering in the lower stratosphere between *20* and *30 km*, and some volcanic particles penetrated all the way up to *33 km*.

From the lidar backscatter ratios R_1 and R_2, the backscatter signals contributed by particles at both wavelengths, B_{p1} and B_{p2}, can be calculated as,

$$B_{p1} = (R_1 - 1)B_{m1}, \quad (4)$$

and

$$B_{p2} = (R_2 - 1)B_{m2}, \quad (5)$$

respectively. Another way to observe the distribution of atmospheric particles or clouds is by using the two-wavelength particle backscatter ratio profile. This ratio profile is defined as the ratio of the volume particle backscattering cross-section at both wavelengths, represented by backscattered signal, at *532 nm*, B_{p1}, to the backscattered signal at *355 nm*, B_{p2}, as,

$$R_{12} = \frac{B_{p1}}{B_{p2}}, \quad (6)$$

This two-wavelength particle backscatter ratio profile provides a measurement of aerosol and cloud properties. Figure 2 shows an example *30*-minute integration of the two-wavelength particle backscatter ratio profile from ground to *40 km* at 22:00 UT on 22 November 1991. Although the lidar backscatter ratio profiles, *R(Z)*, of *532 nm* and *355 nm*, are changing with altitude, this two-wavelength particle backscatter ratio (R_{12}) profile has a nearly constant value at the stratospheric volcanic dust layer, from *19 km* to *32 km*. The value of R_{12} is about *0.5*, and it was nearly constant during the three-month period of the LADIMAS Campaign. For the cirrus cloud layer between *8.5* and *13 km*, this R_{12} has a wide range of values.

For the stratospheric volcanic aerosol layer that we observed on the night of 22 November 1991, the particles over this region were the volcanic aerosols resulting from the Pinatubo volcano eruption in June 1991. By the time of the observation, sedimentation took away most volcanic dust, leaving only the small particles with uniform size through this region. The uniform size and other properties of the particles is deduced from the stable value of the wavelength dependence. The wavelength dependence, *q*, of stratospheric volcanic aerosol layer particle scattering is derived from the following relation,

$$\frac{B_{p1}}{B_{p2}} = \left(\frac{\lambda_2}{\lambda_1}\right)^q. \qquad (7)$$

Thus, the wavelength dependence *q* of stratospheric particle is

$$q = \frac{\ln\left(\frac{B_{p1}}{B_{p2}}\right)}{\ln\left(\frac{\lambda_2}{\lambda_1}\right)}. \qquad (8)$$

The wavelength dependence value *q*, which we calculated from the LADIMAS Campaign measurements ranged between *1.1* and *2.3*, with a mean value of *1.66*. This value can be compared to the lidar polar stratospheric cloud observations by Toon and his group. [Toon et al. 1990]. In their polar stratospheric cloud (PSC) observations at *603 nm* and *1064 nm*, they found the wavelength dependent value, *q*, ranging from *2* to *3* for PSC type 1b clouds. They suggested that these particles were most likely to be nearly spherical and with radii on the order of *0.5 μm*. From our lidar observations and Toon's results, five months after the Pinatubo eruption, we can infer that the stratospheric volcanic aerosols were most likely to have a size from *0.5 μm* to *0.75 μm* with wavelength dependence $q = 1.66$.

On 29 March 1992, nine months after the Pinatubo eruption, lidar observations of the stratospheric aerosol layer were performed at Penn State. The measured two-wavelength lidar profiles are shown in Figure 3. On the left of the figure, the two-wavelength returns from ground to *40 km* are shown with a model molecular profile at each wavelength (shown by a dotted line). The two-wavelength particle backscatter ratio profile is shown on the right of the figure. From the comparison of the two-wavelength particle backscatter ratio profiles, R_{12}, on 29 March 1992 and on 22 November 1991, we notice the settling of the volcanic aerosol layer. On the two-wavelength particle backscatter ratio profiles of 29 March 1992, there appeared to be two different groups in the altitude region from *17 km* to *32 km*. Between *17* and *22 km*, the ratio was about *0.5*, which was about the same as the value that we observed during the LADIMAS measurements, four month early. While at higher altitudes, *22* to *32 km*, that ratio dropped to about *0.25*. This smaller ratio corresponds to particles with wavelength dependence $q = 3.4$, and with size around *0.25 μm*. From the lidar observations, we concluded that nine months after the Pinatubo eruption, the volcanic dust layer at *41 °N* latitude with particle size of *0.5* to *0.75 μm* had settled to a lower region, below 22 *km*. Smaller particles, with a diameter of about *0.25 μm*, were left in the higher region, 22 to *32 km*.

REMARKS

From the observations of two-wavelength particle backscatter ratio profiles, we found that there were usually two or more groups of particles present in the stratospheric volcanic aerosol layer six months after the eruption of Pinatubo Volcano. The wavelength dependence of stratospheric volcanic particles was derived from the two-wavelength particle backscatter ratio with a mean value of 1.66. The study of stratospheric particles properties using two-wavelength lidar needs further research and improvement.

REFERENCE

Philbrick, C.R., D.B. Lysak, T.D. Stevens, P.A.T. Haris, Y.C. Rau, Atmospheric Measurements Using the LAMP lidar during the LADIMAS Campaign, *16th International Laser Radar Conference*, Proceedings of the NASA Conference, MIT, Cambridge, Massachusetts, 1992

Rau, Y.C., and C.R. Philbrick, Capability of Two-wavelength Raman Lidar to Describe Aerosol Effects on Optical Properties, SPIE's International Symposium on Optical Engineering in Aerospace Sensing, Orlando, Florida, 4-8 April 1994.

Toon, O.B., E.V. Browell, S. Kinne, J. Jordan, An Analysis of Lidar Observations of Polar Stratospheric Clouds, *Geophysical Research Letters*, 17, 393-396, 1990.

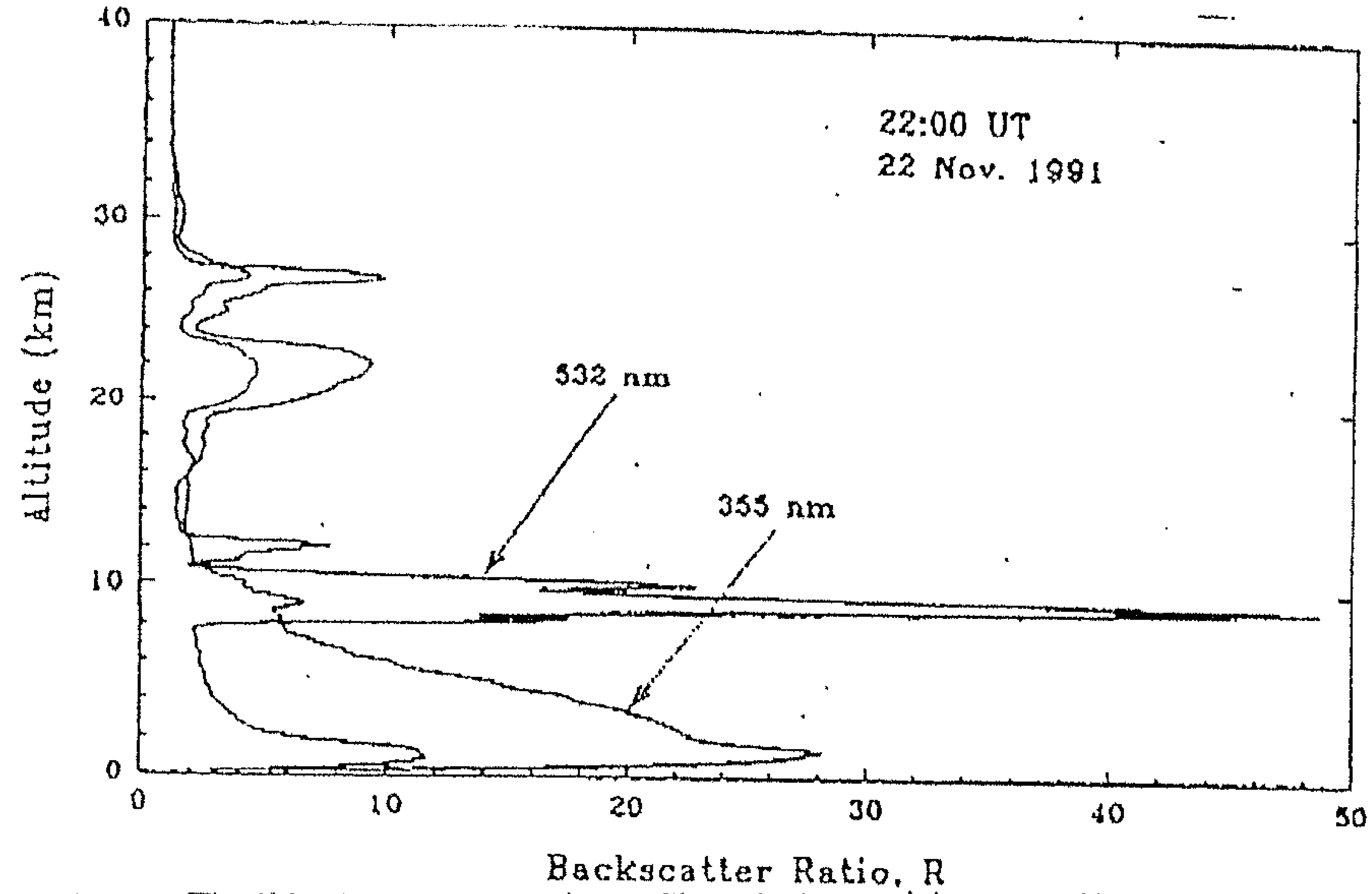

Figure 1. The lidar backscatter ratio profiles of *532 nm* and *355 nm* measured at 22:00 UT on 22 November 1991.

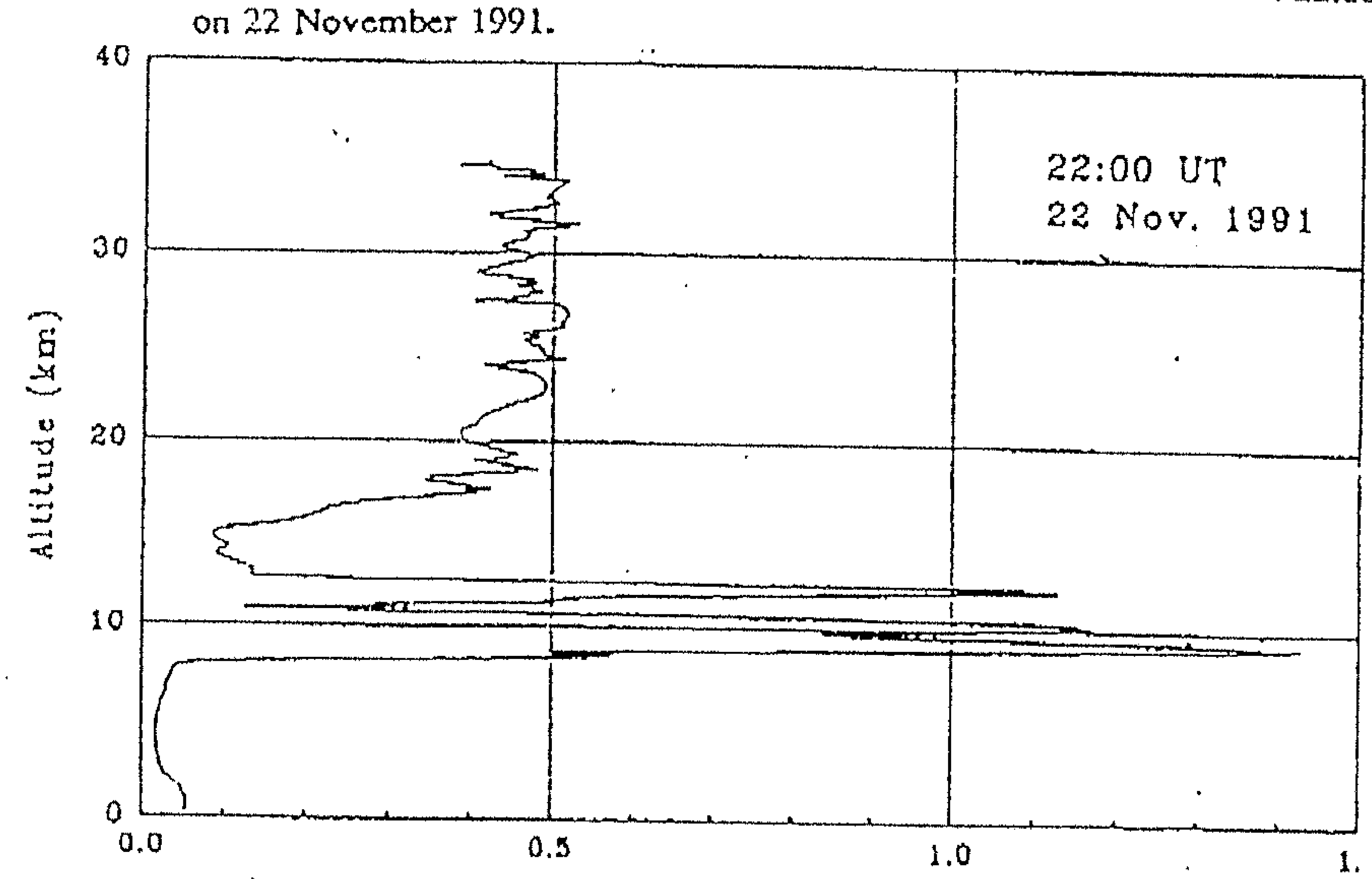

Figure 2. The two-wavelength particle backscatter ratio (R_{12}), β_{a1}/β_{a2}, measured at 22:00 UT on 22 November 1991.

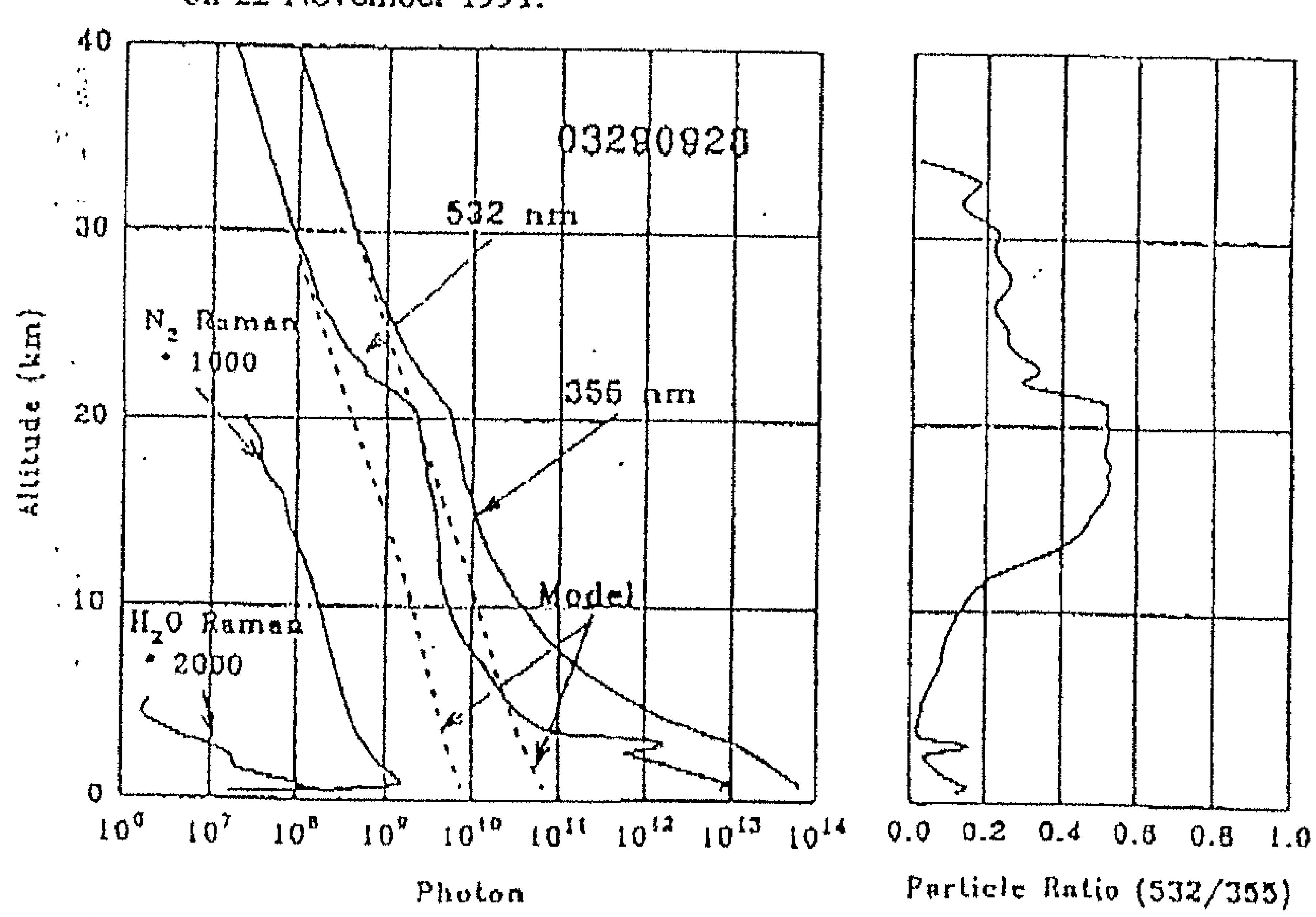

Figure 3. The two-wavelength lidar return profiles and two-wavelength particle backscattering ratio (R_{12}) profile measured at 09:28 UT on 29 March 1992.