OPTICAL PROPERTIES AND DISTRIBUTION OF STRATOSPHERIC AEROSOLS

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Introduction

Stratospheric aerosols significantly influence both the Earth's climate and the chemical composition of the stratosphere. Volcanic aerosols injected into the stratosphere, due to large volcanic eruptions, further enhance the effect on the climate and possibly lead to ozone depletion in the middle latitude stratosphere. Our studies focus primarily on the change in the distribution of stratospheric aerosols before and after volcanic activity. The particle backscatter and other properties of stratospheric aerosols are studied to describe their variations. The Penn State Rayleigh/Raman lidar utilizes a Nd:YAG laser transmitting at both the doubled (532 nm) and tripled (355 nm) frequencies. The detector is equipped with separate channels to measure the low and high altitude signals from both the 532 nm and 355 nm as well as the Raman shifted returns due to N_2 and H_2O (660 nm and 607 nm). The LAMP lidar was first deployed on board the RV Polarstern during the LADIMAS campaign and has since been in operation in the United States. Scattering due to stratospheric aerosols from volcanic activity has been studied across different latitudes and over time. The effects due to Mt. Pinatubo (Philippines) and Mt. Hudson (Chile) eruptions have been compared.

Background

A multi-wavelength Rayleigh/Raman lidar was built at the Pennsylvania State University in 1991. The Laser Atmospheric Measurement Program (LAMP) was developed to study the properties of the lower and middle atmosphere (0-80 km). The lidar utilizes a Nd:YAG laser with 1064 nm seed wavelength. The instrument transmits the doubled frequency (532 nm, visible) and tripled frequency (355 nm, UV). The detector box consists of eight channels for Rayleigh scattered and Raman shifted return signals. The LAMP lidar's monostatic configuration allows near field as well as far field measurements. Table 1 summarizes the system specifications [1].

Table 1: Penn State lidar parameters

LIDAR PARAMETERS			
Power aperture product	1.5 W·m²		
Type	Continuum NY-82, Nd:YAG		
Wavelength (nm)	1064	532	355
Max. Pulse Energy (mJ)	1500	600	250
Bandwidth	80 MHz		
Pulse Length	6 ns		
Pulse Rate	20 Hz		

RECEIVER	
Telescope	f/15, Cassegrain
Focal Length	609 cm
Primary Diameter	40.6 cm
Secondary Diameter	10.2 cm

During October 1991 - January 1992, the LAMP lidar was deployed aboard the German research vessel, RV Polarstern, as part of the LAtitudinal DIstribution of Middle Atmospheric Structure (LADIMAS) campaign [2]. Ship board lidar and rocket range coordinated measurements were made between the latitudes 70°N and 65°S to study atmospheric structure, dynamics and chemistry. During the LADIMAS campaign, aerosols due to volcanic activity of Mt. Pinatubo and Mt. Hudson were observed. Mt. Pinatubo erupted on June 15, 1991 in the Philippines (15.14°N, 120.35°E). The volcanic dust could be observed between 20 and 30 km altitude. Mt. Hudson erupted on August 8, 1991 in Chile. The explosion produced a dust cloud that reached up to 10 km. The large dust particles that were ejected by both Mt. Hudson and Mt. Pinatubo quickly fell to the ground, while sulfur gases remained in the atmosphere. The SO_2 gases then combined with water vapor to form a sulfuric acid aerosol layer [3]. Aerosol effects contribute to cooling of the Earth's surface due to scattering of solar radiation back into space, and warming of the stratosphere where the particles reside [4].

This paper focuses on the optical properties of volcanic aerosols such as particle size distribution and backscattering ratios of the 532/355 nm wavelengths. The data set consists of measurements made during the LADIMAS campaign and at Penn State University during March-April 1992.

Theory

Molecular and aerosol backscattering are both included in the backscatter returns. The signal backscatter ratio is given by [1],

$$R(\lambda,z)=[\beta_a(\lambda,z)+\beta_m(\lambda,z)]/\beta_m(\lambda,z), \qquad (1)$$

where β_m is the volume backscatter cross section for aerosols, and β_a is the volume backscatter for molecules. The signal backscatter ratio is used in the calculations of the particle backscattering ratio (PBR), given by [1],

$$PBR=\frac{\beta_{a532}}{\beta_{a355}}=\frac{(R_{532}-1)\beta_{m532}}{(R_{355}-1)\beta_{m355}}. \qquad (2)$$

This ratio provides useful information about atmospheric species and clouds at a given altitude. Figure 1 shows a profile of the backscatter ratio. The straight lines represent the U.S. Standard Atmosphere (USSA) model backscatter in the absence of aerosols. Two conclusions can be drawn from the plot immediately. First, we observe a cirrus cloud layer

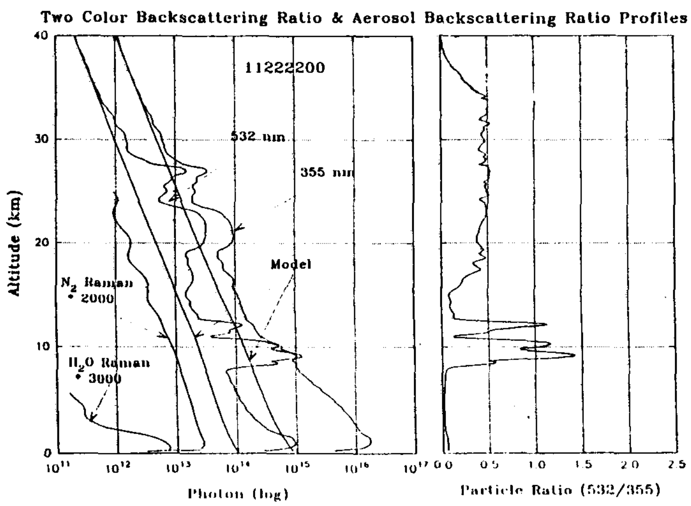

Figure 1: November 22, 1991 LAMP data (LADIMAS)

around 10 km that shows as a peak in both the 532 and 355 nm signals. Between 8 and 10 km, the cloud layer has a much greater return at the 532 nm than at 355 nm.

The second interesting structure in the profile is due to the presence of volcanic aerosols around 25 km altitude. The molecular backscattering cross section is proportional to λ^{-4}. Thus the cross section for 355 nm is approximately 5 times that of the 532 nm backscattering cross section ($532^{-4}/355^{-4} = 5.04$) [1]. Inferences can be made about how the aerosol layer disperses in the atmosphere over a period of time by comparing such profiles over a period of time and from different locations. This plot was obtained on board the RV Polarstern on November 22, 1991. The location of the vessel was near the equator and the plot is indicative of aerosol effects due to Mt. Pinatubo. The PBR profile shows a uniform aerosol layer with ratio 0.5 between 18 and 33 km. The maximum signal return corresponds to an altitude of 22 km.

Figure 2 shows a similar profile obtained on December 13, 1991. The location is at the 50°S latitude in this case. The profile represents aerosol effects from Mt. Hudson. A ratio of 0.5 is observed in this case also but at an altitude of 15 to 30 km. The peak signal return for Mt. Hudson is from 22 km.

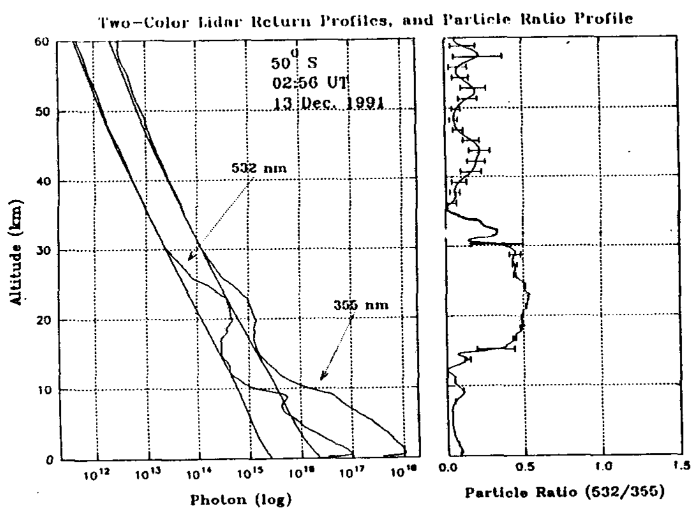

Figure 2: December 13, 1991 LAMP data (LADIMAS)

Figure 3 shows a profile obtained at Penn State University (41°N) in March 1992, nine months after the Mt. Pinatubo eruption [5]. We can see from this plot that the aerosol layer has moved to a lower altitude of 15 to 25 km. This can be explained due to the settling of heavier particles over nine months. Figure 3 also shows the PBR. This verifies the claim that settling of heavier particles around 20 km occurred over time [5]. The lighter particles remain suspended at a higher altitude around 30 km.

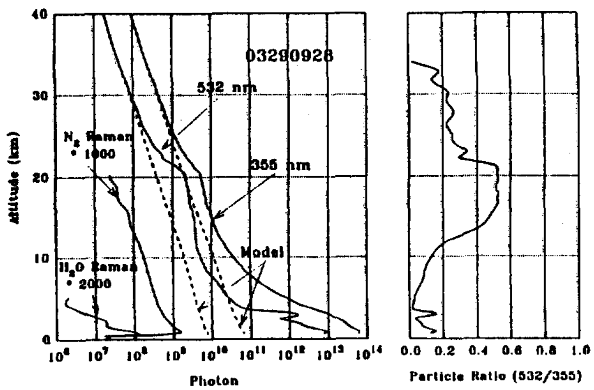

Figure 3: LAMP data from March 1992

Summary

Aerosol backscatter measurements due to volcanic dust from two different eruptions have been presented. The particle backscatter ratio has been investigated and compared for both volcanoes. Inferences can be made from this data set about the volcanic dust settling in the atmosphere with heavier particles settling at a lower altitude. This is consistent with the particle backscattered intensity versus wavelength relationship. The spatial distribution of the aerosols over a period of approximately 10 months and over different latitudes is shown.

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References

1. Stevens, T.D., P. A. T. Haris, Y.-C. Rau, and C. R. Philbrick, "Latitudinal Lidar Mapping of Stratospheric Particle Layers", Adv. Space Res., v 14, n 9, pp. 193-198, 1994.

2. Philbrick, C. R., D. B. Lysak, and Y.-C. Rau, "Lidar Measurements of Aerosol Scattering in the Troposphere and Stratosphere", Proceedings of the IEEE Topical Symposium on Combined Optical-Microwave Earth and Atmosphere Sensing, pp. 203-206, 1993.

3. Schäfer, P. S., M. Langer, K. H. Fricke, and U. von Zahn, "Lidar Observations of Polar Stratospheric Clouds at Andøya, Norway, in January 1992", Geophysical Research Letters, v 21, n 13, pp. 1307-1310, 1994.

4. McCormick, M. P., and R.E. Veiga, "SAGE II Measurements of Early Pinatubo Aerosols", Geophysical Research Letters, v 19, pp. 155-158, 1992.

5. Yi-Chung Rau, "Multi-Wavelength Raman-Rayleigh Lidar for Atmospheric Remote Sensing", Ph.D. dissertation, Pennsylvania State University, 1994.