A-1.2.2 Studies on the movement of the stratospheric aerosols by laser radar observations in Hokkaido, Japan.

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Abstract The stratospheric aerosols, which affect the ozone chemistry through the heterogeneous reaction, were observed by the lidar at Wakkanai, Hokkaido, and at Kushiro,Hokkaido during winter. The amount of the stratospheric aerosols ejected by Mt.Pinatubo eruption was decreasing until 1996 and seems to become stable after 1997. Wavelength exponent of backscattering coefficient at 532nm and 1064nm became larger with time; particles with a radius smaller than 0.1 μ m seem to have become more predominant. The lidar system used at Kushiro was moved to Rikubetsu in November 1997 since observations from here were possible during the summer, and the system was improved to permit automatic observations.

Key words lidar, stratospheric aerosols, backscattering coefficient

1. Introduction

As the size of the ozone hole in the antarctic region expands every year, a sustained tendency towards decrease in the concentration of ozone has been observed in the middle and high latitude regions in the northern hemisphere, where the population is high. With the advancement in the understanding of the processes responsible for the depletion of the ozone layer in the polar regions, it has been clarifiezd that heterogeneous reactions on the surfaces of aerosol particles in the stratosphere play an essential role in the depletion of the ozone layer. During the course of these studies, the possibility of aerosols in the stratosphere playing an important role in the chemistry of ozone in the middle latitude regions was also pointed out. It is important to clarify the following issues to understand the cycling of aerosols and to understand atmospheric chemistry. The issues are how long aerosols injected by the eruption of Mt. Pinatubo in June 1991 continues before the amount reached a steady state, how much aerosol still remains in the steady state, and how the particle size distribution of the aerosol in the steady state is. It is also important to compare lidar data of aerosols with data of satellite sensors and rare molecule data of ground-based sensors for prediction of high altitude atmospheric environments.

2. Objectives

The purpose of this study is to obtain data on the height profiles of aerosols in the stratosphere by lidar observations in Hokkaido, the northernmost region of Japan, where the degree of reduction of the ozone layer is the greatest in Japan and air masses originating in the polar regions pass several times in the winter season. These data can be compared with those obtained by lidar observations at other points. From these comparisons, we can obtained information of the amount of aerosol in the stratosphere, the vertical and horizontal distribution and transportation of the aerosols in middle-and high-altitude regions. Furthermore, it is also important to compare the results of the lidar observations with the data obtained by satellite sensors and on-ground monitoring of rear molecules to study the physical and chemical processes taking place in the stratosphere. Since Wakkanai has a low frequency of clear days during the winter and the days available for observation are limited, the lidar observations were also performed in Kushiro during the winter season. In November 1997, we moved the Lidar system to Rikubetsu, where observations during the summer season were also is possible. As a result, we have been successful in obtaining data on the vertical distribution of aerosols throughout the year in Hokkaido.

3. Observation system

The Lidar system used at Wakkani is designed to operate at the fundamental wavelength of Nd:YAG laser with a wavelength of 1.064 μ m, and at its second harmonic wavelength of 0.532 μ m where we can measure depolarization ratio. The sensitivity at 1.064 μ m became insufficient after 1995; making the measurement of aerosols in the stratosphere thereafter impossible. However, a more sensitive system has since been introduced, thereby making the observations possible once again. From late 1996 to early 1997, the p-channel (0.532 μ m) of the systems in Wakkani and Kushiro was designed to receive signals with two channels for low and high altitudes, enabling highly sensitive aerosol measurements in the stratosphere at high signal-to-noise ratio, even if the amount of aerosol were low. Figure 1 shows a block diagram of the observation system in Kushiro.

We cooperated with the Tohoku Institute of Technology for observations during the winter at Kushiro. The system observes the height profiles and depolarization profiles of aerosols at 0.532 μ m. In November 1997, the lidar system located at Kushiro was moved to Rikubetsu, and at this time, we improved the system to allow automatic observations in the future; motorized the opening of the covers of the telescope mirrors and transmission mirrors.

4. Results of Observations

Seven years after the eruption of Mount Pinatubo, long term variation of aerosols injected into the stratosphere from the eruption become to be seen. Figure 2 shows the results of recent observations at Wakkanai. Aerosols in the stratosphere were detected at altitudes ranging from 12 km to 32 km, and the scattering ratio has decreased to 0.1 or less. Figure 3 shows the time variation of integrated backscatterint coefficient (IBC) at 1.064 μ m and 0.532 μ m at Wakkanai since 1991. Figure 4 shows the results of monitoring in Kushiro and

Rikubetsu during the winter, and the data obtained during the summer at Wakkanai, since 1995. The IBC observed at Wakkanai decreased sharply until 1996; however, the values after 1997 have remained relatively stable. At Kushiro and Rikubetsu, the IBC values decreased from 1995 to 1996, while little change was observed from 1996 to 1998.

Figure 5 shows the height profiles of the scattering ratio and depolarization ratio before and after part of the polar vortex hit the tip of Hokkaido. Aerosols were observed in the stratosphere at altitudes ranging from 12 km to 30 km, but the effect of the polar vortex is not clearly seen in the height profiles of aerosols.

As shown in Fig. 3, monitoring at two wavelengths (1.064 and 0.532 μ m) at Wakkanai was performed from the latter half of 1992 to 1994. Comparison of the results obtained at the two different wavelengths revealed that the ratio of IBC at 0.532 μ m to that at 1.064 μ m wavelength gradually increased. This indicates that the average particle size of the aerosol in the stratosphere has decreased with time. Furthermore, the IBC ratios obtained in 1998 were close to those obtained around 1994; the change in the aerosol particle size from 1992 to 1994 was rather small. Figure 6 shows height profile of the wavelength exponent (γ) in October 1992 when the amount of aerosol was high. Here, γ is the wavelength exponent defined by β (backscatteing coefficient) $\propto$ $\lambda^{-\gamma}$. The value of γ is approximately 1.3 at a height of 12 km; however the value at the height of 20 km was close to 2.0, indicating that the particle size decreased with increasing altitude.

5. Discussion

The amount of aerosol in the stratosphere, which increased with the eruption of Mount Pinatubo in June 1991, stabilized by 1997 and seems now to have approached a steady state. However, careful inspection of the data shows that the amount of aerosol in the stratosphere seems to be still decreasing. The IBC values measured recently seem to have returned to the values before the eruption. Furthermore, the values have even returned to the values measured before the eruption of El Chichon in 1982. However, the IBC values before the eruption of Mt.St.Helen in 1980 might have been lower than those before the El Chichon eruption; thus it is necessary to continue the monitoring until the IBC values reach a steady state and to measure the amount of aerosol in the stratosphere in the steady state.

The effect of the polar vortex as it approached the measurement locations, on the altitude distribution of the aerosols was unclear, partly because of the relatively small number of observations. The lidar system at Rikubetsu is being improved to allow remote-controlled observations. Once the improved system is in place, monitoring in early spring can be carried out at higher frequencies than is possible now.

Figure 7 shows the calculated results of the wavelength dependence for a sulfuric acid solution, which is considered to be the major constituent of aerosols in the stratosphere. For particle sizes larger than 0.1 μ m, the γ value obtained at 0.532 μ m and 1.064 μ m was 1.6 or less. To obtain a value of γ of approximately 2, a particle size of less than or equal to 0.07 μ m is required. Accordingly it is considered that since 1994, particles of 0.07 μ m or less in size have become predominant in aerosols distributed in the stratosphere. As shown in Fig. 6, with increasing altitude, the amount of smaller-sized particles increases. Immediately after the eruption of Mt. Pinatubo, the amount of larger sized particles was higher; however, these large-sized particles precipitated rapidly with time. That the amount of small particles increases with increasing altitude conforms with the basic principles in physics. The difference in particle size distribution affects the estimation of the surface area of the aerosol, which heterogeneous reaction rate depends on.

Conclusions

To clarify the dynamic behavior of aerosols in the stratosphere. and to study the heterogeneous reactions at the surface of aerosols in the stratosphere and their effects on the depletion of the ozone layer, we have performed lidar observations in Wakkanai since August 1991 and in Kushiro since December 1994. We moved the lidar system installed at Kushiro to Rikubetsu in November 1994 to facilitate observations throughout the year. The effect of the eruption of Mt. Pisnatubo was found to become small, and the amount of aerosol seems to have now reached a steady state. We shall continue this monitoring till a steady state is confirmed, and determine the amount of aerosol in the steady state. After the eruption of Mt. Pinatubo, with time, the relative amount of small-sized particles in the stratosphere has steadily increased. We feel that it is important to determine the particle size distributions in the steady state; we will compare these values with those obtained from the OPC balloon. We will continue lidar observations in Hokkaido and compare the data obtained from our observations with those obtained at other locations or those obtained by satellite sensors.

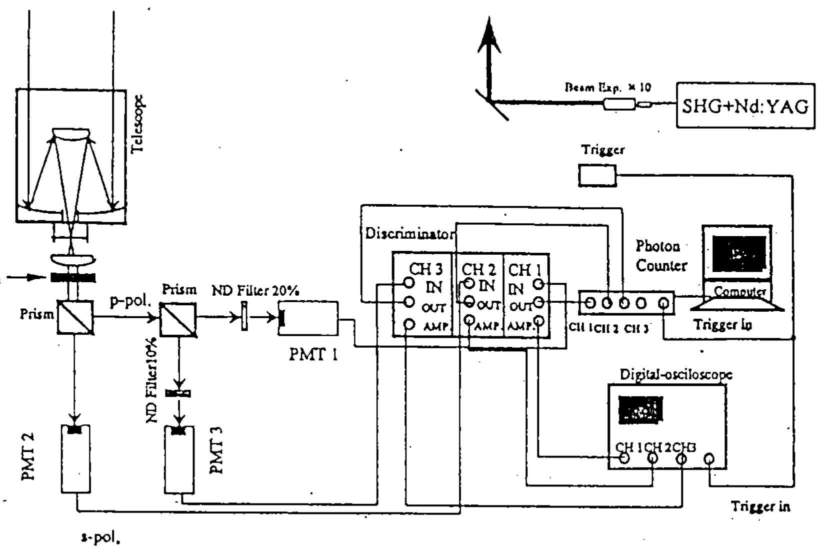

Figure 1. Block diagram of lidar system at Kushiro.

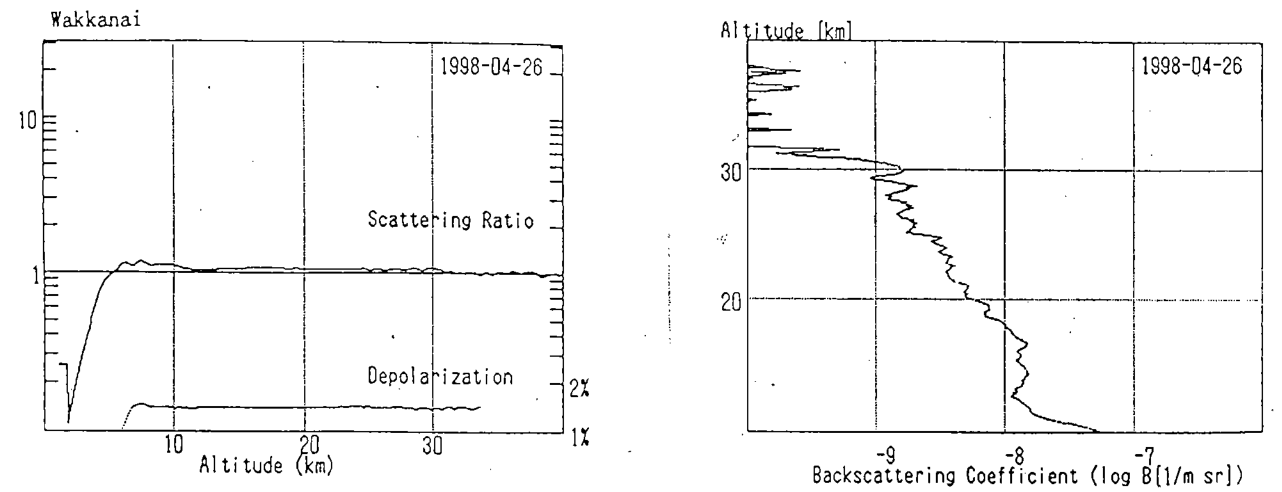

Figure 2. Height profiles of scattering ration and backscattering coefficient on Apr.26, 1998.

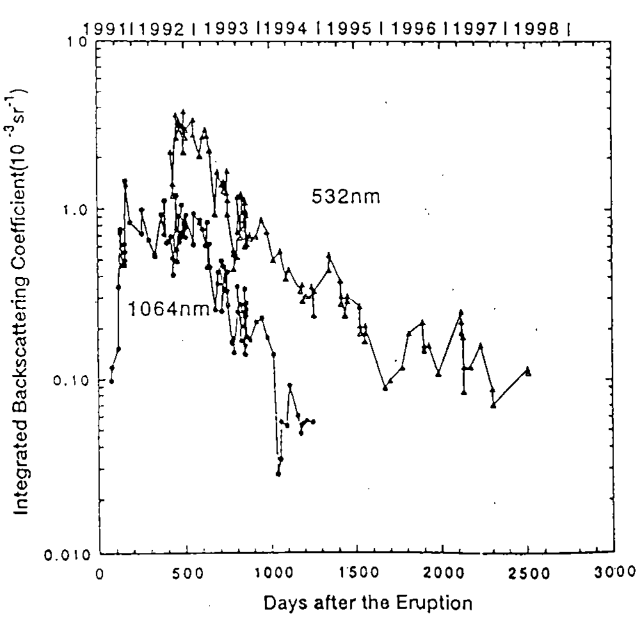

Figure 3. Time variation of IBC at Wakkanai

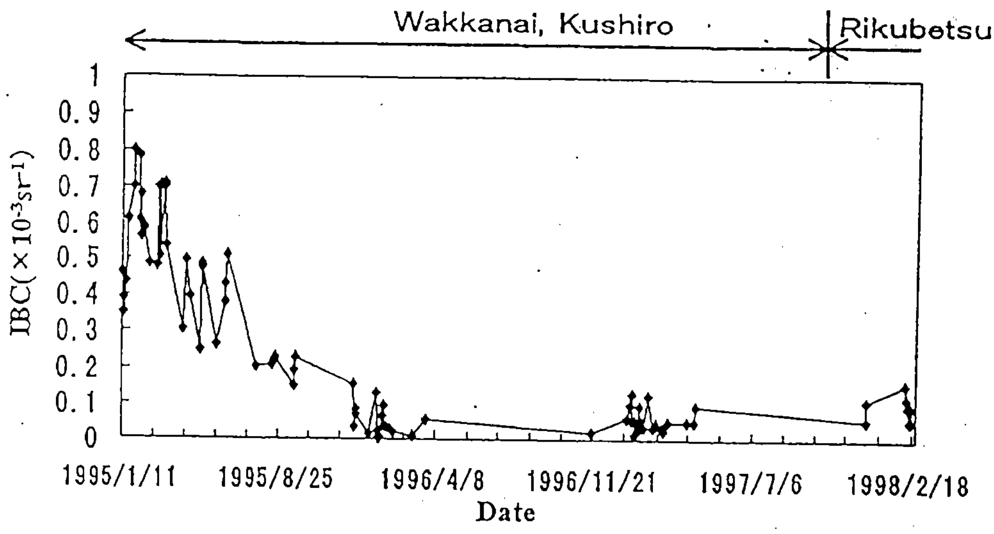

Figure 4. Time variation of IBC at 532nm in Kushiro/Rikubetsu (Dec.-Mar.) and Wakkanai (Apr.-Nov.)

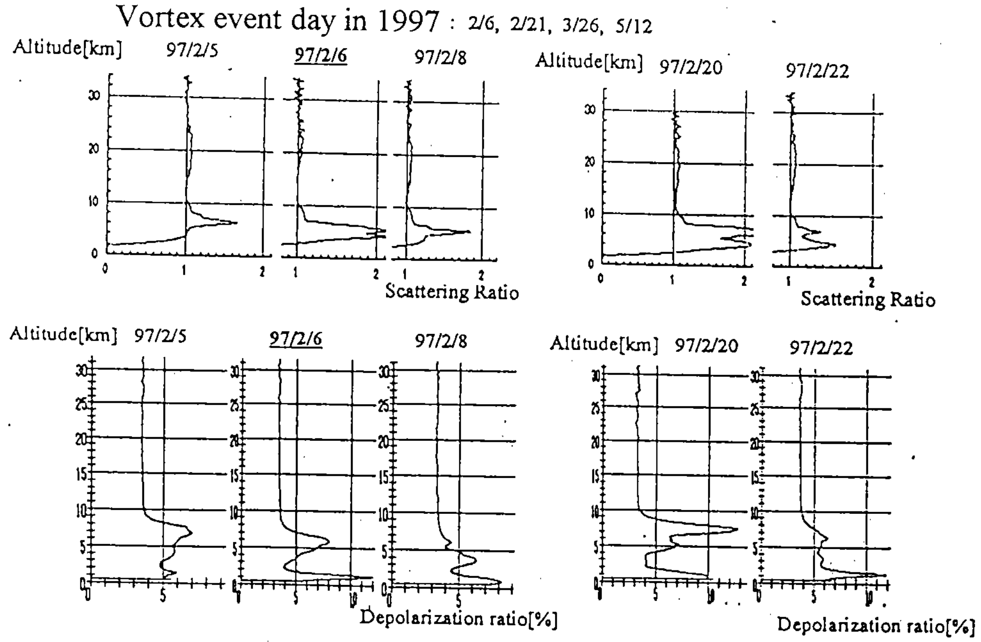

Figure 5. Height profiles of backscattering coefficient and depolarization ratio before and after the polar vortex events.

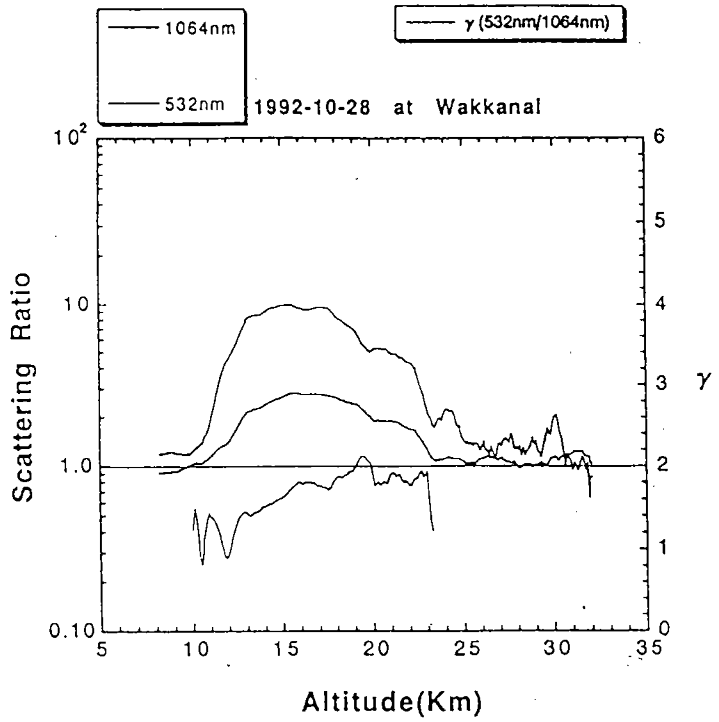

Figure 6. Height Profiles of scattering ratio and depolarization ratio at Wakkanai on Oct.28, 1992

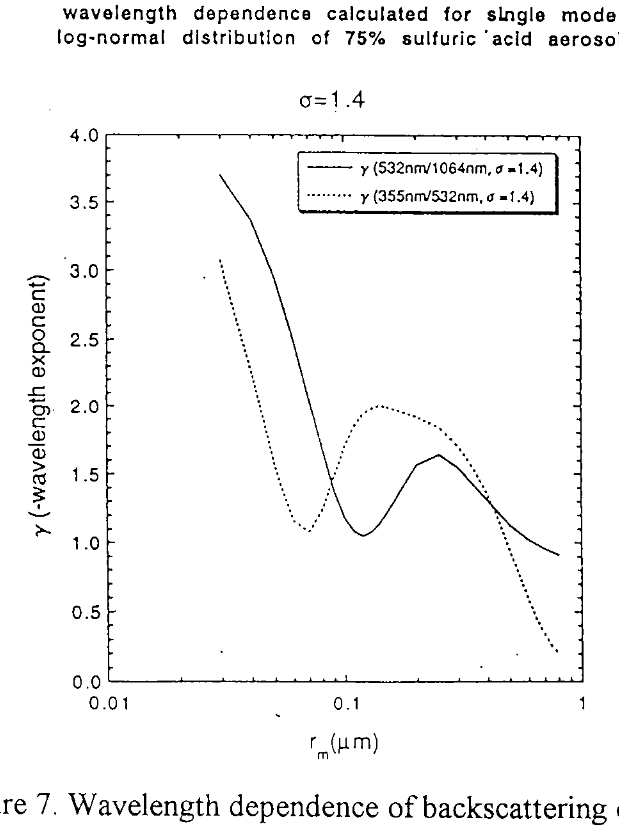

Figure 7. Wavelength dependence of backscattering coefficient