Results of Long-Term Lidar Observation of Eruption Aerosol Formations in the Stratosphere Over Tomsk After the Mount Pinatubo Eruption

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Introduction

The investigations of scattering and absorbing characteristics of stratospheric aerosol layer after high-power volcanic eruptions make it possible to separate out and evaluate the influence of anomalous high aerosol concentrations on the radiation transfer in the atmosphere and the general radiation balance of the Earth. The violent eruption of Mt. Pinatubo in the Philippines in June 1991 injected into the atmosphere an estimated total aerosol mass loading of ~30 Mt, which is over twice the amount produced by the eruptions of El Chichon in 1982 (McCormick et al. 1992).

This paper presents some results of lidar investigations of optical and microphysical characteristics of stratospheric aerosol after the Mount Pinatubo eruption obtained at the Siberian Lidar Station (SLS) of the Institute of Atmospheric Optics, Tomsk (56, 5^{O} N/85, 1^{O} E). At SLS the possibility exists of simultaneous aerosol sounding at the wavelengths of 532, 628 nm and 1064 nm as well as ozone sounding at the wavelengths of 308 and 353 nm. The lidar returns are detected using telescopes with the receiving mirrors of diameters 2,2 m and 1 m. Regular sounding of stratospheric aerosol (at the wavelength of 532 nm) have been performed since 1986 and ozone sounding since 1989.

Optical Characteristics of Stratospheric Aerosol at Wavelength 532 nm

Figure 1 gives the temporal series of altitude profiles of the scattering ratio *R*, illustrating the dynamics of stratospheric perturbation by volcanic aerosol over the period from 1991 to 1993.

The first, weakly expressed aerosol layers with the values *R*~1,5 began to appear over Tomsk since June 29, 1991, in the altitude range from 12 km to 16 km. On July 9, 1991, the value of *R* in the layer maximum at an altitude of 16 km reached 2,7. At altitudes of about 20 km and higher, the stratosphere, until October, remained practically unperturbed. A marked increase in aerosol content in the altitude range from 20 km to 30 km can be observed in mid-October 1991. The maximal values of *R* were detected on January 21 and 22, 1992. At the altitude of 23,5 km in the layer the above values were 9,5 in this case at altitudes below 20 km we also observed the relatively powerful aerosol layers with the values *R*~5. Since the end of February 1992 we can observe the decrease of altitude of localization of layers with maximal aerosol content as well as the decrease of the values *R* in these layers and the reduction of the integral coefficient of aerosol backscattering. In 1993 the structure of sharply defined aerosol layers was not observed, the major portion of aerosol was diffused in the altitude range from tropopause up to ~20 km. The maximal values of *R* by the end of year decreased to 2.

For a period of aerosol perturbation of the stratosphere in 1991-1993 the temporal instability of aerosol stratification and values of *R* in the layers is typical. During short periods of time, from one day to the other, the characteristics of altitude distribution of aerosol varied significantly in accordance with variations of atmospheric circulation.

In 1994 (Figure 2) the aerosol situation in the stratosphere over Tomsk was of more stable character. The altitude stratification of layers sharply defined and varied in time gradually disappeared. The maximum of aerosol layer was formed at altitude, typical for localization of the Junge layer in a corresponding season at Tomsk latitude.

The possibility exists of comparison of the sounding results obtained during this period of measurements at SLS with the results of simultaneous spaceborne laser sounding of stratospheric aerosol (Figure 2a). In September 1994 the stratospheric aerosol sounding at SLS was performed in the framework of ground-based correlative measurements under the NASA program LITE (The Lidar in Space Technology

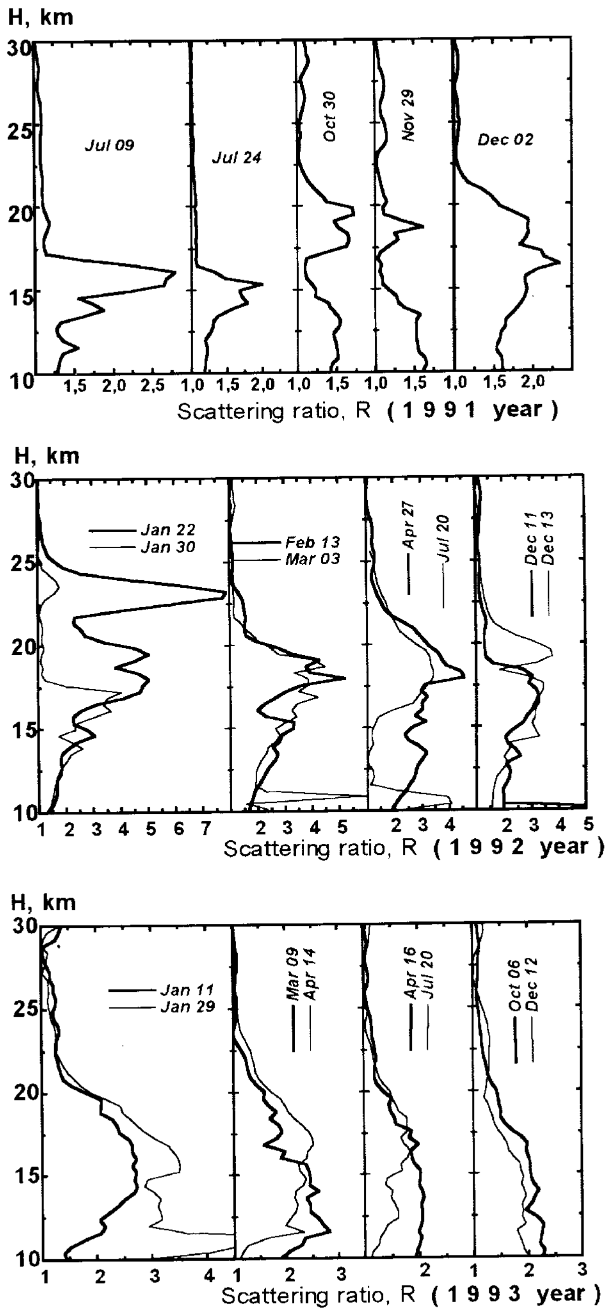

Figure 1. The profiles of scattering ratio 1991-1993.

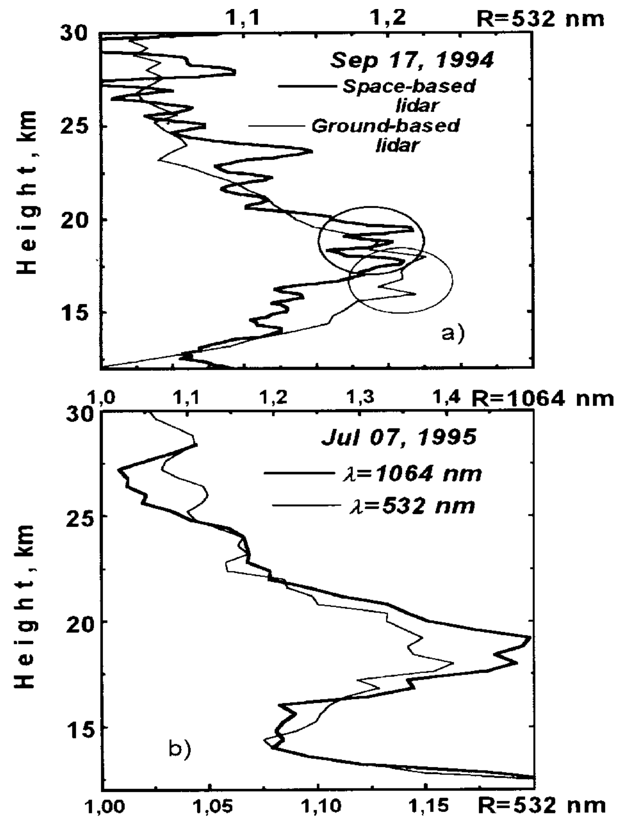

Figure 2. The typical profiles of scattering ratio: a) 1994; b) 1995.

Experiment) (McCormick et al. 1993). We have obtained from the Program Coordinators the spaceborne data at the wavelength of 532 nm for September 17. The sounding was coordinated in time and performed simultaneously. The coordinates of space lidar at the instant of sounding in longitude coincide practically with the Tomsk coordinates, in latitude the point of spaceborne sounding for the orbit being considered was located 1000 km to the south. The tropopause altitude in the area of spaceborne sounding exceeded the tropopause altitude above the standing point of ground-based lidar by 2 km (12 km and 10 km, respectively). The figure gives the altitude profiles of the scattering ratio *R* measured in the stratosphere at a wavelength 532 nm onboard the Shuttle (heavy line) and on the ground surface (thin line). For the sake of simplicity of comparison the results of lidar sounding were smoothed by averaging time strobes providing the resolution of 450 m for the spaceborne sounding and 400 m for the ground-based sounding. The maximal values of *R* in both cases are comparable and ranging from 1,22-1,24. The cut structure of the profiles and the value of *R* point to the presence of aerosol residual traces of volcanic origin in the lower stratosphere. The behavior of the profiles of *R* in ranges of maximal values (in the figure these regions 1 and 2 are denoted by circles) is identical. Only for the data of space-borne sounding this area is 2 km higher as in the case of the tropopause altitude. Thus taking account of latitude separation of saunding areas, the stratospheric profiles of *R* are in good agreement.

The background values of the scattering ratio in the maximum of stratospheric aerosol layer, corresponding to the pre-

Pinatubo values, were observed by us only in summer 1995. Figure 3 gives the averaged over the summer measurement data mean summer profiles of backscattering aerosol coefficients for 1987-1995. The variation of profiles shows the relaxation process of perturbation of the stratosphere by volcanic aerosol from 1992 to 1995 when the level of aerosol filling of the stratosphere was equal to the background conditions of 1988 and 1989.

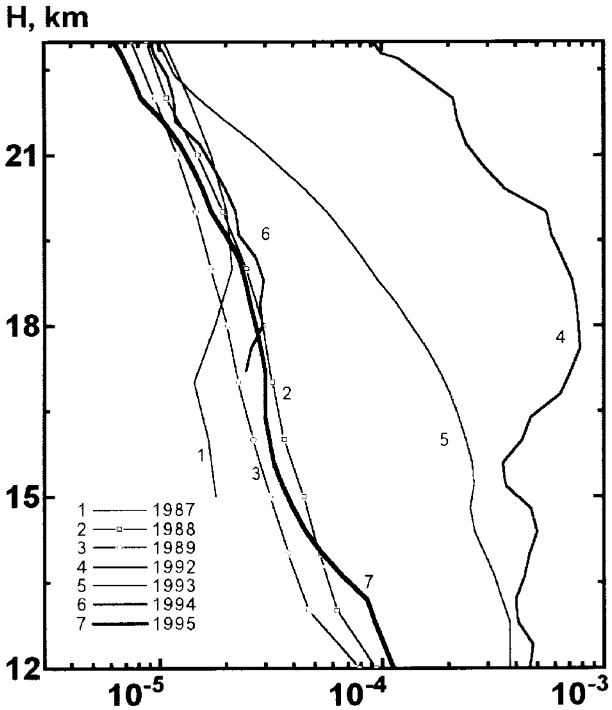

Figure 3. Summer mean profiles of the back-scattering aerosol coefficient for the different years (km*sr)$^{-1}$.

Figure 4 presents the variation of the integral backscattering coefficient, obtained based on the results of our long-term measurements. The coefficient variation shows the process of development of stratospheric perturbation by volcanic aerosol, with the attainment of the perturbation peak in January and February 1992 and its relaxation up to the background level by summer 1995. The peaks of aerosol scattering were observed also in winter periods (mainly in January) of 92/93 and 93/94. During these periods we observed the maximal values of the aerosol backscattering integral coefficient and the scattering ratio with the decreasing from year to year amplitude. The observed maxima can be explained by seasonal winter aerosol transfer from the equatorial reservoir to polar areas. The time dependence of the integral scattering and the scattering ratios correspond to the observation results at the other lidar stations of the north midlatitudes, for

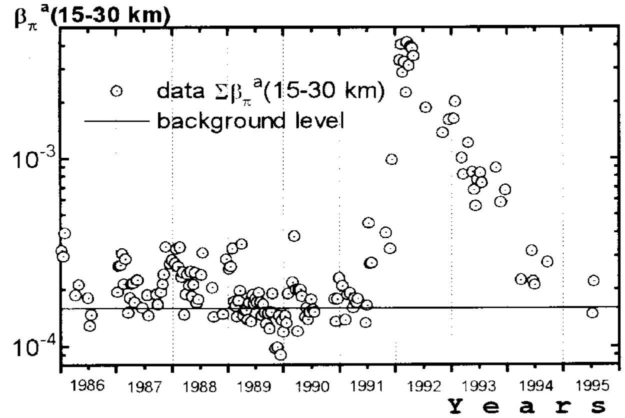

Figure 4. The time behavior of integral aerosol backscattering coefficient (Tomsk, Russia).

example, the stations of Garmisch-Partenkirchen. The observations made at this station enabled the authors (Jager et al. 1994) in the beginning of 1994 to assume that the pre-Pinatubo level of stratospheric aerosol will be attained 1995.

Microstructure Characteristics of Stratospheric Aerosol from the Multi-Frequency Sounding Data

The dynamics of aerosol particle size spectra was investigated using the method of the inverse problem solution based on the data of the four -wavelength sounding.

The altitude profiles of the particle number density were retrieved and the temporal dynamics of aerosol content at different altitudes in the lower stratosphere was investigated. Transformation of particle size distribution was studied under conditions of the disturbed stratosphere, and spectral dependencies of volume aerosol extinction coefficients were calculated.

Some of these results are given in Figure 5 where we present the distributions of particle size geometrical cross-section *S(r)* at different altitudes restored by the data of laser sensing of the stratosphere at the wavelengths of 308, 353, 532, 628 nm in 1991 - 1992. Analysis of the obtained results has shown that in July 1991 in the lower stratosphere the aerosol layer with the peak concentration at 15 km altitude was developed intensively, in which the value of particle concentration with the radius of more than 0.15 µm exceeded the background values by more than one order of magnitude. In this period

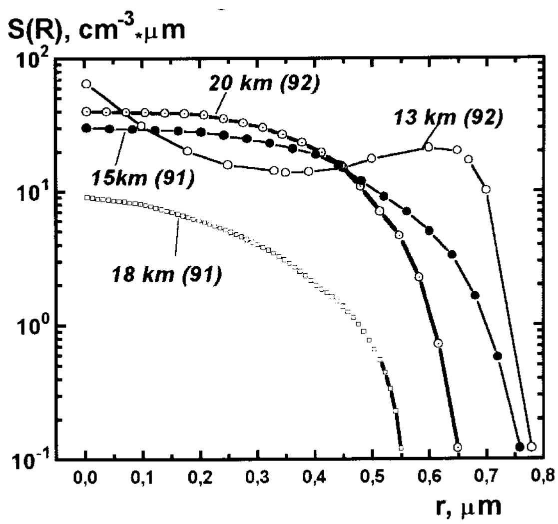

Figure 5. The size distribution of particle.

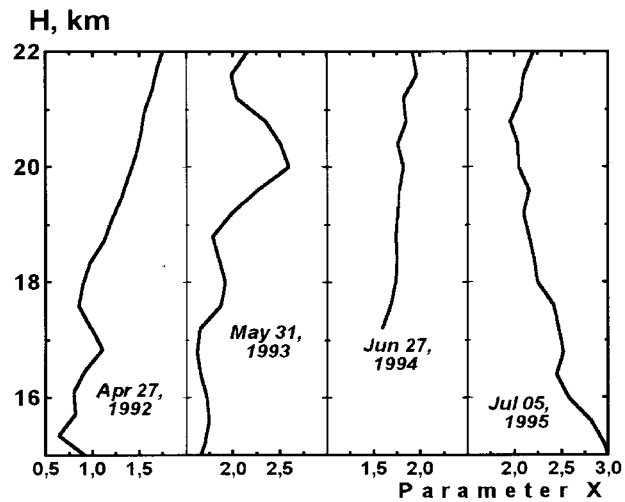

Figure 6. The change of parameter X (1992-1995).

the particle size distributions were typical for the "perturbed" stratosphere and were localized in the submicron range of radius. The increased concentration of particles at the altitudes close to 15 km was the same in 1992. At the same time, in April 1992 the particle concentration of the second aerosol layer with the peak at 20 km altitudes increased considerably. Another special feature of distributions of *S(r)* for April 1992, as seen in Figure 5, is the increase of large particles content at separate altitudes (in particular, at 13 km altitude in the aerosol layer above the tropopause) that is, evidently, a consequence of aerosol aging.

For a qualitative estimate of the aerosol particle size spectra from the data of double-frequency sounding, we used the parameter *X*, determined as

$$X = \ln\left[\beta_a(\lambda_1)/\beta_a(\lambda_2)\right]/\ln(\lambda_2/\lambda_1) \qquad (1)$$

where $\beta_a(\lambda_i)$ - aerosol backscattering coefficient, λ_1 and λ_2 are the larger and smaller wavelengths, respectively. Lesser values of *X* characterize the predominance of the large particle fraction, which are more optically active for the long-wave spectral range. The large values of X characterize the finely divided aerosol.

Figure 6 presents the altitude profiles of *X(H)*, typical for the corresponding years. The distribution of 1992 is characterized by larger particles as compared with the period of 1993-1995, the values of *X* are smaller. In this case larger particles were concentrated at lower altitudes as demonstrated by the marked tilt of *X*. Large particles also prevailed at lower altitudes in 1993, that indicates the sedimentation process, however, the *X* values became larger since the greater particles have already precipitated in the troposphere. The process of the particle size decrease was also observed in 1994, however, the particle size distribution in the altitude became more homogeneous. In 1995 the tilt of *X* changed to the opposite, the lower stratosphere is characterized by finely divided aerosol, and larger particles are concentrated at altitudes of the generated Junge layer.

Conclusion

In the dynamics of aerosol pollution of the stratosphere over Tomsk after the Mt. Pinatubo eruption, several stages can be separated:

- registration of primary aerosol layer at altitudes of 16-18 km in July-August 1991 two weeks after Mt. Pinatubo eruption
- observation of maximum aerosol layer in January-February 1992 at 20 km altitudes and higher
- increase of aerosol particles is spring-summer 1992 , precipitation under the effect sedimentation and subsequent entrance into the troposphere
- aerosol content in the stratosphere has reached its background level only by summer of 1995.

References

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