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The Post-Pinatubo Evolution of Stratospheric Aerosol Surface Area Density as Inferred from SAGE II

L. R. Poole
and
L. W. Thomason
Atmospheric Sciences Division
Mail Stop 475
NASA Langley Research Center
Hampton VA 23681-0001

1. INTRODUCTION

Following the eruption of Mount Pinatubo in June of 1991, the aerosol mass loading of the stratosphere increased from ~1 Mt to approximately 30 Mt. This change in aerosol loading was responsible for numerous radiative and chemical changes observed within the stratosphere. As a result, the ability to quantify aerosol properties on a global basis during this period is important.

Aerosol surface area density is a critical parameter in governing the rates of heterogeneous reactions, such as $ClONO_2 + H_2O \rightarrow HNO_3 + HOCl$, which influence the stratospheric abundance of ozone. Following the eruption of Mt. Pinatubo, measurements by the Stratospheric Aerosol and Gas Experiment (SAGE II) indicated that the stratospheric aerosol surface area density increased by as much as a factor of 100. Using SAGE II multi-wavelength aerosol extinction data, aerosol surface area density as well as mass mixing ratio, and total mass are derived for the period following the eruption of Mt. Pinatubo through the present.

2. INSTRUMENTATION

The SAGE II instrument was launched in 1984 as a part of the Earth Radiation Budget Satellite and has produced a long-term history of aerosol optical properties. SAGE II uses the occultation of the sun by the limb of the earth's atmosphere during each sunrise and sunset encountered by the satellite to infer vertical profiles of atmospheric transmittance at 7 wavelengths in the visible and near-infrared. From these profiles, 1-km resolution profiles of aerosol extinction are derived at 4 wavelengths (0.385, 0.453, 0.525, and 1.02 μm) as well as the molecular density of O_3, NO_2, and H_2O [Chu et al., 1989]. SAGE II encounters 15 sunrises and sunsets a day with each event separated by approximately 24° in longitude. The latitude of measurement, which is different for sunrise and sunset events, varies seasonally between about 80°N and 80°S.

Aerosol properties such as mass mixing ratio and surface area density can be derived from the multiwavelength aerosol extinction data using a variety of techniques. Analyses discussed in the following sections are based on the principal component method described by Thomason and Poole, [1993].

3. DERIVED AEROSOL PROPERTIES

Figure 1 shows the zonal mean aerosol surface area density as a function of height for SAGE II sweeps between April 1991 through April 1993. Prior to the eruption (Figure 1a), the largest surface area densities were observed at

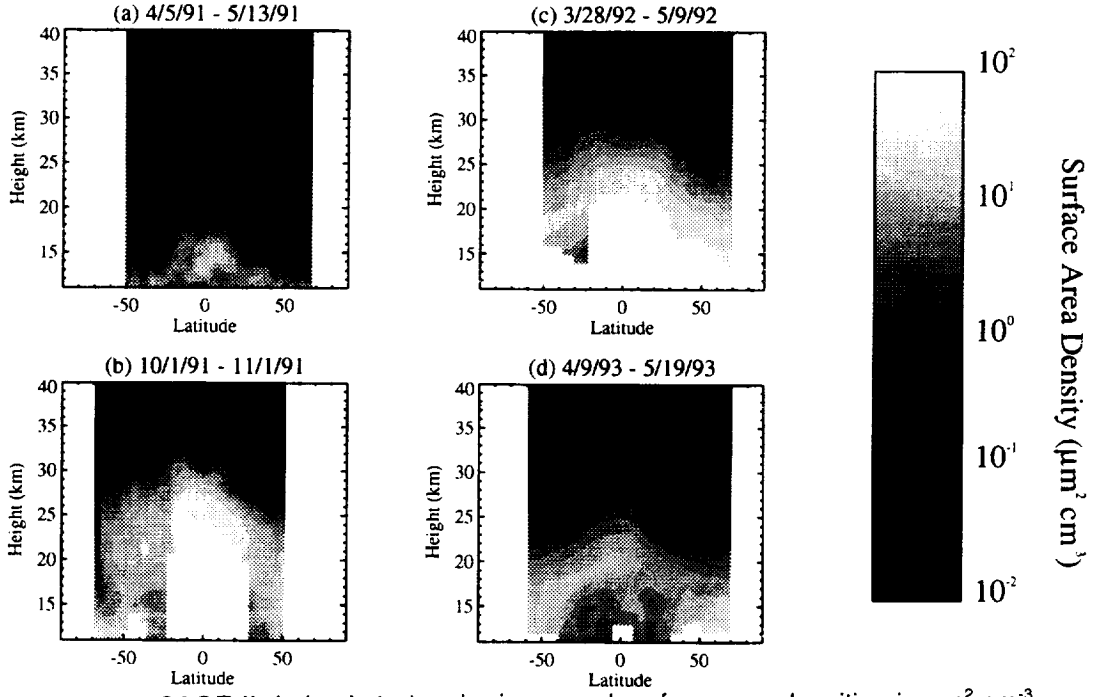

Figure 1. SAGE II-derived stratospheric aerosol surface area densities in μm^2 cm^{-3}.

high latitudes between 15 and 20 km where values exceeded 1 μm^2 cm^{-3}. Following the eruption, values approached the effective SAGE II saturation value of ~40 μm^2 cm^{-3} in tropical latitudes between 20 and 25 km. The extreme opacity of the aerosol cloud at this time in the tropics is reflected by the absence of data below ~25 km where slant path optical depths exceeded the maximum measurable by SAGE II. Some transport below 20 km toward northern latitudes was also apparent in the immediate post-eruption period [McCormick and Veiga, 1992].

By October of 1991 (Figure 1b), values of aerosol surface area density exceeded 30 μm^2 cm^{-3} in a layer between 20 and 25 km from high northern latitudes southward to the Antarctic polar vortex. The remainder of the period (Figure 1c-1d) is marked by a gradual lowering of the height of the densest part of the layer, a trend toward greater homogeneity with latitude, and a decrease in the surface area density maximum to ~20 μm^2 cm^{-3}. In May 1993, the aerosol surface area density maximum was still more than a factor of 10 larger than that observed prior to the eruption.

Stratospheric aerosol removal mechanisms such as gravitational sedimentation and polar vortex processes ultimately transport these aerosol into the upper troposphere. As a result, elevated levels of aerosol surface area density were observed in the upper troposphere as soon as SAGE II data were again retrievable there in late 1992 and 1993. For example, Figure 2 shows the 1.02-μm aerosol extinction at an altitude of 12 km in northern mid-latitudes. While there were few data available at this altitude during 1992, aerosol extinction was nearly 50 times the pre-eruption value in the first half of 1993. Elevated aerosol amounts in the upper troposphere seem likely to persist for some time.

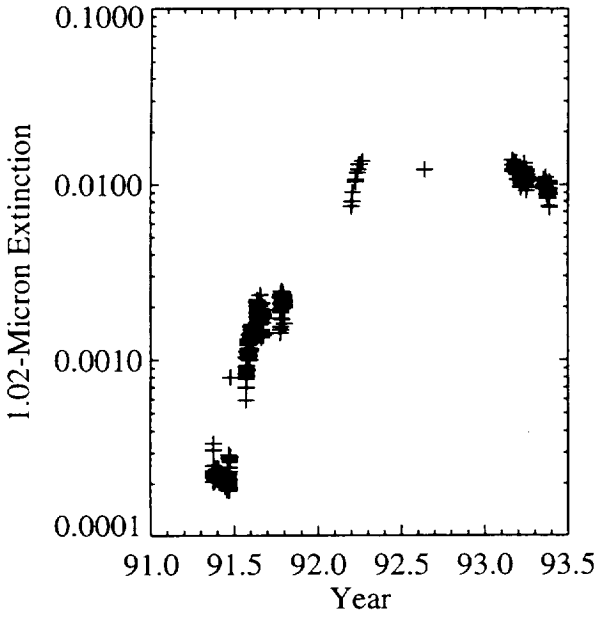

Figure 2. SAGE II-measured 1.02-μm aerosol extinction between 35 and 55°N at 12 km for April 1991 through May 1993.

Figure 3 shows the aerosol mass mixing ratio for the two years following the eruption. Prior to the eruption, peak mixing ratio values of 3-4 ppb were found in the tropics between 23 and 25 km. After the eruption, mixing ratio values increased to levels approaching 300 ppb near 27 km in the tropics. As in the case of surface area density, the subsequent 2 year period is marked by a slow decrease of the altitude of the maximum (e.g., from ~27 km in September 1991 to ~21 km in April 1993 in the tropics), a trend toward greater homogeneity with latitude, and a steady decrease in the maximum mixing ratio (e.g., from ~300 ppb in September 1991 to ~40 ppb in April 1993 in the tropics).

Since the lowest part of the stratosphere was effectively opaque at SAGE II measurement wavelengths during part of the 2-year period,

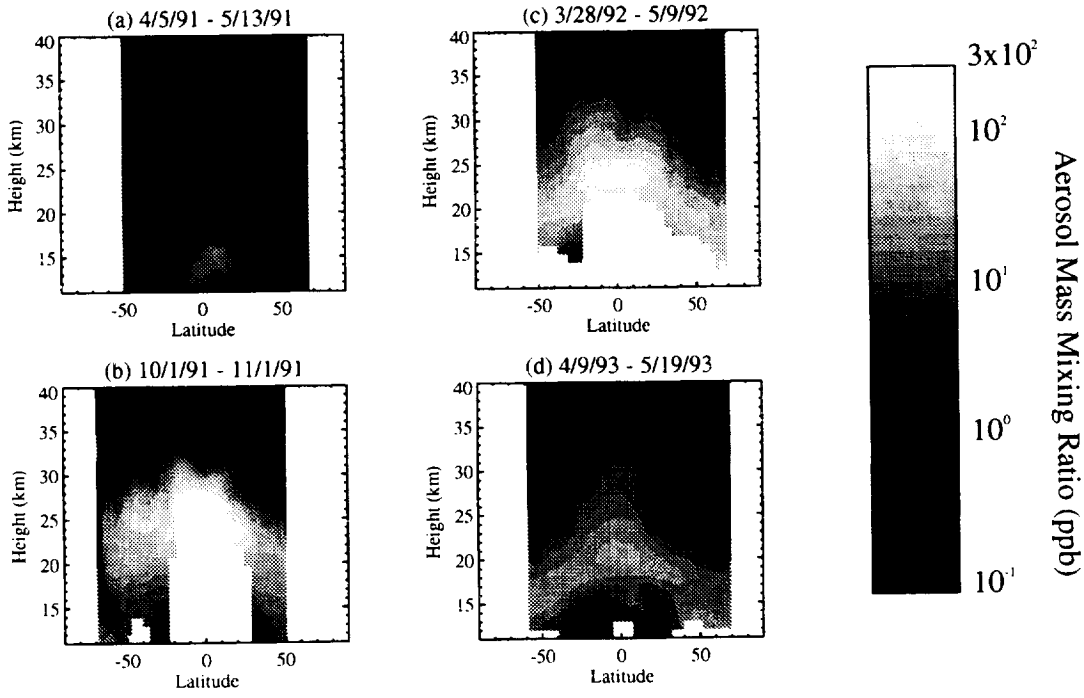

Figure 3. SAGE II-derived stratospheric aerosol mass mixing ratios in ppb.

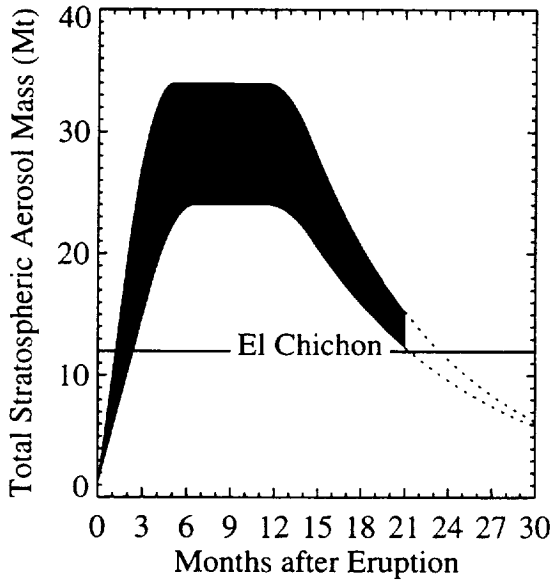

Figure 4. SAGE II derived total stratospheric aerosol mass in months following the eruption of Mt. Pinatubo.

estimation of total stratospheric aerosol mass is dependent on extrapolation of retrieved data through the opaque regions. One method of extrapolation is to extend the last retrievable extinction measurement downward to the tropopause. In general, this will over-estimate the mass except perhaps during the immediate period after the eruption, when extinction profiles may have been truncated well above the maximum. Other semi-empirical methods can also be used to provide more conservative estimates [Thomason et al., 1993]. Figure 4 shows the range of estimated stratospheric aerosol mass as a function of time derived by Thomason et al. The peak mass was between 25 and 35 Mt, up from approximately 1 Mt prior to the eruption. This value was relatively steady for nearly a year following the eruption, due mainly to the persistently high altitude of the main aerosol layer. By June of 1992, this layer had moved downward sufficiently for stratosphere-troposphere exchange mechanisms to become effective and aerosol removal has since exhibited an 1/e-folding time of about 1 year. Interestingly, the total stratospheric aerosol mass reached values comparable to the peak value reached after the 1982 eruption of El Chichon (~12 Mt) in May of 1993, nearly 2 years after the Pinatubo eruption.

4. Conclusions

The 1991 eruption of Mt. Pinatubo resulted in large increases in the stratospheric aerosol surface area and mass densities, and concomitant perturbations in both radiative and chemical processes occurring within the stratosphere. Ultimately, the upper troposphere may also be affected significantly as this aerosol is transported downward from the stratosphere. These effects may include changes in the frequency and optical properties of thin cirrus and increased heterogeneous chemical processing efficiency.

5. References

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