JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 102, NO. D7, PAGES 8967–8976, APRIL 20, 1997

# A global climatology of stratospheric aerosol surface area density deduced from Stratospheric Aerosol and Gas Experiment II measurements: 1984–1994

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**Abstract.** A global climatology of stratospheric aerosol surface area density has been developed using the multiwavelength aerosol extinction measurements of the Stratospheric Aerosol and Gas Experiment (SAGE) II for 1984–1994. The spatial and temporal variability of aerosol surface area density at 15.5, 20.5, and 25.5 km are presented as well as cumulative statistical distributions as a function of altitude and latitude. During this period, which encompassed the injection and dissipation of the aerosol associated with the June 1991 Mount Pinatubo eruption as well as the low loading period of 1989–1991, aerosol surface area density varied by more than a factor 30 at some altitudes. Aerosol surface area density derived from SAGE II and from the University of Wyoming optical particle counters are compared for 1991–1994 and are shown to be in generally good agreement though some differences are noted. An extension of the climatology using single-wavelength measurements by the Stratospheric Aerosol Measurement II (1978–1994) and SAGE (1979–1981) instruments is also presented.

## 1. Introduction

The 1991 eruption of Mount Pinatubo increased the aerosol loading of the stratosphere from ~1 Tg to nearly 30 Tg [*McCormick and Veiga*, 1992]. Through the observed changes in radiative and chemical processes and the numerical modeling of such alterations, this event fostered a greater understanding of the global influences of stratospheric aerosols on the atmosphere [*McCormick et al.*, 1995]. In the first two years after the eruption, significant decreases were observed in stratospheric ozone [e.g., *Gleason et al.*, 1993; *Herman and Larko*, 1994; *Hofmann et al.*, 1994] and $NO_2$ [*Johnston et al.*, 1992; *Koike et al.*, 1993]. Observations suggest that stratospheric odd nitrogen was repartitioned from reactive forms such as $NO_2$ into relatively nonreactive $HNO_3$ [*Rinsland et al.*, 1994] as the result of increased heterogeneous chemical processing on the surfaces of the volcanically derived aerosol. This repartitioning of odd nitrogen increased the susceptibility of ozone to chlorine-catalyzed destruction during the post-Pinatubo period. Climatological studies of aerosol changes during the post-Pinatubo period using primarily in situ [e.g., *Langford et al.*, 1995] or satellite estimates of stratospheric aerosol optical depth [e.g., *Russell et al.*, 1996] have also been produced. Numerical model results also support a significant role for heterogeneous processes in the destruction of ozone in this period [*Hanson et al.*, 1994; *Kinnison et al.*, 1994; *Rodriguez et al.*, 1994; *Solomon et al.*, 1996]. In fact, *Solomon et al.* [1996] have made a compelling case for a significant role for aerosols in observed ozone trends [*McCormick et al.*, 1992; *McPeters et al.*, 1994], even during times that may be considered approaching "background" aerosol levels.

Since heterogeneous processes play such a significant role in stratospheric chemistry, it is important to develop and maintain a climatology of stratospheric aerosol properties, particularly surface area density. Herein, we present a climatology of aerosol surface area density deduced from Stratospheric Aerosol and Gas Experiment (SAGE) II multiwavelength aerosol extinction data for the period from late 1984 through the end of 1994. SAGE II uses the solar occultation technique to derive 1-km vertical resolution extinction profiles at wavelengths of 0.385, 0.453, 0.525, and 1.02 μm. Near-global coverage (~80°S–80°N) is achieved over time spans of about 1 month. The calibration-independent nature of SAGE II makes it well suited to observe the long-term variability of aerosols. The long life of the instrument (1984 to present) is an asset in developing an aerosol climatology since aerosol variability has been dominated during this period by volcanic events that have effectively masked the natural, nonvolcanic background loading [*Thomason et al.*, 1997].

## 2. Theoretical Basis

The SAGE II instrument has approximately 30 measurement opportunities (events) each day, which occur as the orbiting spacecraft (the Earth Radiation Budget Satellite) encounters either a sunrise or a sunset. During these events, profiles of transmission through the atmospheric limb are obtained in seven spectral channels. The transmission profiles are then inverted to yield profiles of $O_3$, $NO_2$, and $H_2O$ concentration and aerosol extinction. The estimation of aerosol surface area density ($S$) is based on the magnitude and wavelength dependence of aerosol extinction in the four-wavelength ensemble. Methods for estimating $S$ uniformly



Paper number 96JD02962.
0148-0227/97/96JD-02962$09.00

assume that the aerosols are spherical (thus Mie scattering) $H_2SO_4$-$H_2O$ solution droplets [*Thomason and Poole*, 1993; *Russell et al.*, 1993]. These are appropriate assumptions for the stratosphere except for cases of polar stratospheric clouds (PSCs) [*Poole and Pitts*, 1994], volcanic ash [*Winker and Osborn*, 1992], or thin cirrus, whose presence has been noted on occasion above the tropopause [*Kent et al.*, 1993]. *Kent et al.* [1993] developed an effective method for the identification of clouds (both cirrus and PSCs) in the SAGE II data based on the wavelength dependence of extinction. Cloud events have been eliminated from this study using that approach. Volcanic ash is considered to be a relatively short-lived phenomenon following an eruption, and its impact has not been accounted for in the following work.

On the basis of these assumptions the extinction at a given wavelength and altitude is given by

$$k_\lambda = \int_0^\infty \pi r^2 Q(r, m_\lambda) \frac{dn(r)}{dr} dr, \quad (1)$$

where $Q$ is the Mie extinction efficiency as a function of particle radius ($r$) and refractive index ($m_\lambda$), which in turn depends both on wavelength and on particle composition, and $dn(r)/dr$ is the number of particles per unit volume per unit radius in the interval between $r$ and $r + dr$. The aerosol surface area density can be expressed in a similar form as

$$S = \int_0^\infty 4\pi r^2 \frac{dn(r)}{dr} dr. \quad (2)$$

For aerosol with $r > 0.5$ $\mu$m, $Q(r, m_l)$ for the SAGE wavelengths approaches a value of 2, and the relationship between $S$ and extinction simplifies to

$$S \approx 2000 k_\lambda, \quad (3)$$

where $k_l$ is expressed in units of $km^{-1}$ and $S$ in $\mu m^2\ cm^{-3}$. More generally, the relationship between $S$ and extinction is highly nonlinear, and the estimation of $S$ from SAGE II observations is not so straightforward.

There are several techniques by which $S$ can be estimated from the aerosol extinction ensemble measured by SAGE II. To some degree, all require that the aerosol size distribution be retrieved as an intermediate step. However, since there are only four measurements, and these are not totally independent (particularly the three shorter wavelength measurements) and are measured with ~10% uncertainty, it is not possible to uniquely identify the underlying size distribution [e.g., *Twomey*, 1977]. In fact, all the retrieval techniques which have been used with the SAGE II aerosol data constrain the size distribution (and hence $S$) by either using a model such as the lognormal [*Yue et al.*, 1986] or imposing a smoothness constraint [*Thomason and Poole*, 1993]. Such constraints can have a pathological impact on the estimation of quantities that depend heavily on either tail of the size distribution, such as mean radius or total number density. However, more reliable information can be derived on higher-order integral properties of the aerosol size distribution, such as $S$ and total volume. It has also been found [*Yue et al.*, 1995; *Thomason and Poole*, 1993] that estimates of $S$ are not highly sensitive to the details of the retrieval process. Herein, we employ principal component analysis (PCA) [*Twomey*, 1977; *Thomason and Poole*, 1993], a method that is reliable and requires little computational effort. In the PCA formulation, aerosol surface area density is given by

$$S = \sum_{i=1}^{4} a_i k_{\lambda_i} \quad (4)$$

where $a_i$ are derived coefficients. For the results presented here, only the two highest-order components are retained. The coefficients depend on aerosol composition (the mass of $H_2SO_4$ relative to $H_2O$), which itself depends on the $H_2O$ concentration of the stratosphere [*Steele and Hamill*, 1981]. The effects of variable composition are small relative to the uncertainties resulting from measurement uncertainty, and furthermore, SAGE II $H_2O$ profiles are presently available for only the period from 1985 to 1990. Therefore a constant aerosol composition of 75% $H_2SO_4$ and 25% $H_2O$ (by weight) has been assumed in this paper. The amplification of error from extinction to $S$ produces algorithmic uncertainties (as opposed to bias) averaging ±30% for values of $S$ around 0.1 $\mu m^2\ cm^{-3}$ and ±15% for values of $S$ greater than 10 $\mu m^2\ cm^{-3}$.

## 3. Comparison of SAGE II and Optical Particle Counter Surface Areas Estimates

The accuracy of using SAGE II extinction data to estimate $S$ can be evaluated by comparison with estimates of $S$ derived from the University of Wyoming balloon-borne in situ optical particle counter (OPC) measurements. The OPCs provide observations of integral number densities and have been used to study midlatitude stratospheric aerosols since 1972 [*Hofmann et al.*, 1975; *Deshler et al.*, 1993] and polar stratospheric clouds since 1987 [*Hofmann et al.*, 1989; *Hofmann and Deshler*, 1991; *Deshler et al.*, 1994]. For measurements after 1989, particles with radii larger between 0.15 and 2.0 or 10 $\mu$m in eight size ranges are measured. The upper size range is preselected based on the particular application. To measure concentrations of condensation nuclei (CN), a growth chamber is added to the inlet of a second optical instrument.

To provide a functional form for the OPC particle measurements, lognormal size distributions are assumed. An adequate representation of measurements after large volcanic eruptions and in stratospheric clouds usually requires bimodal distributions. Each lognormal distribution is specified by three parameters, the total number concentration $N_i$, the median radius $r_i$, and the distribution width $s_i$. In an optimization scheme, values for these parameters are selected to minimize the difference between the calculated and the measured number concentration for each size measured [*Hofmann and Deshler*, 1991; *Deshler et al.*, 1993]. Uncertainty in measured aerosol concentration increases as the number of particles counted decreases, due to counting statistics. The impact of this uncertainty on the lognormal parameters and on the derived surface area has been estimated using a Monte Carlo simulation. The result is an average surface area variation of 10 to 20% with a maximum variation of 30 to 40%.

Figures 1a–1c compare time series of estimates of $S$ near 15, 20, and 25 km for the period from 0 to 1300 days after the June 1991 eruption of Mount Pinatubo. Insets in Figures 1b and 1c show a blowup of the respective record for days 700–1300, during which estimated values of $S$ were much lower than during the first year after the eruption. The SAGE II values plotted (circles with error bars) are monthly zonal medians

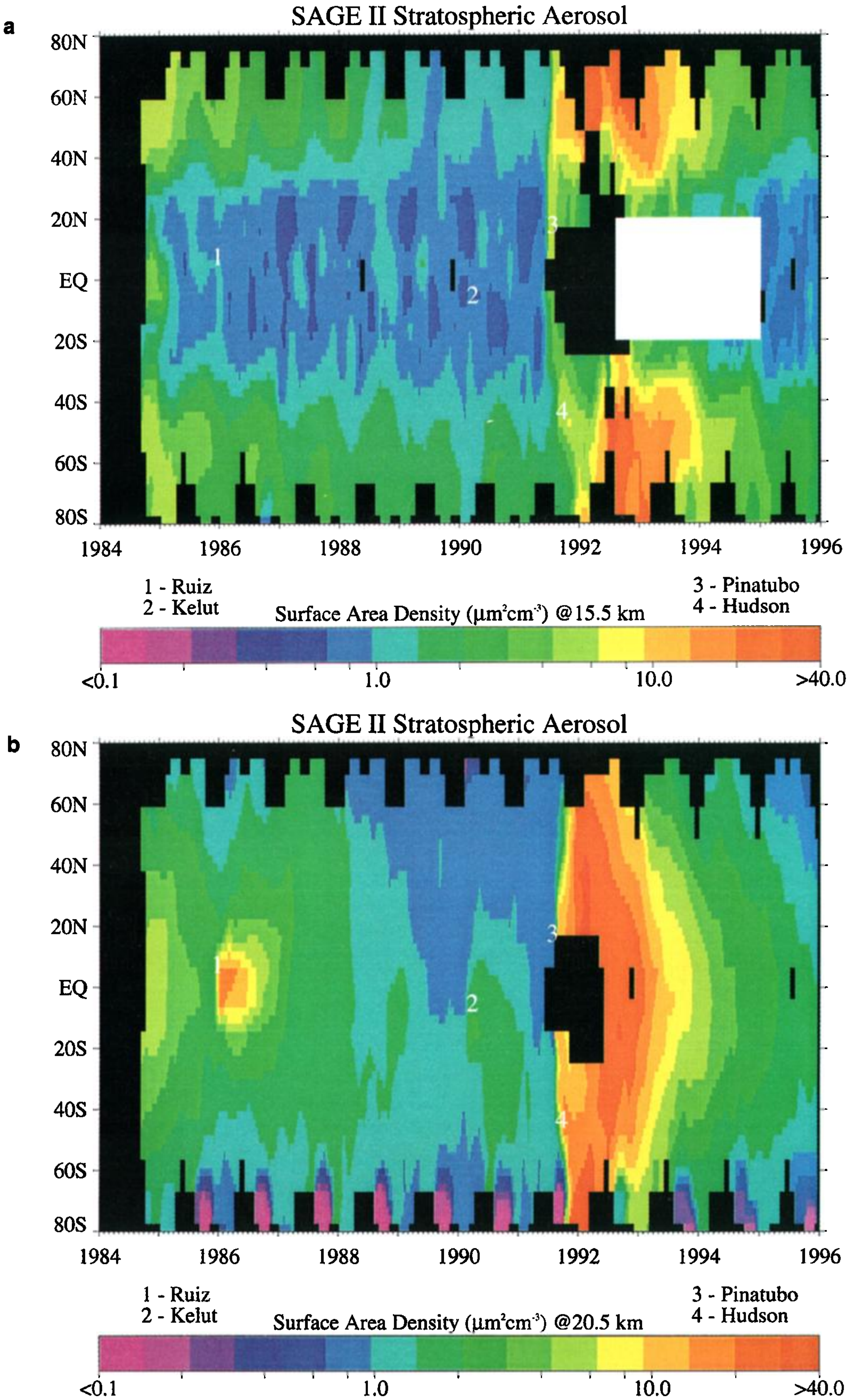


**Plate 1.** Aerosol surface area density as a function of time and latitude at the altitudes of (a) 15.5, (b) 20.5, (c) 25.5, and (d) 30.5 km. Black regions denote sections in which no data are available. White regions in Plate 1a denote sections for which cloud clearing is not currently available. The latitude and time of significant volcanic events are noted.

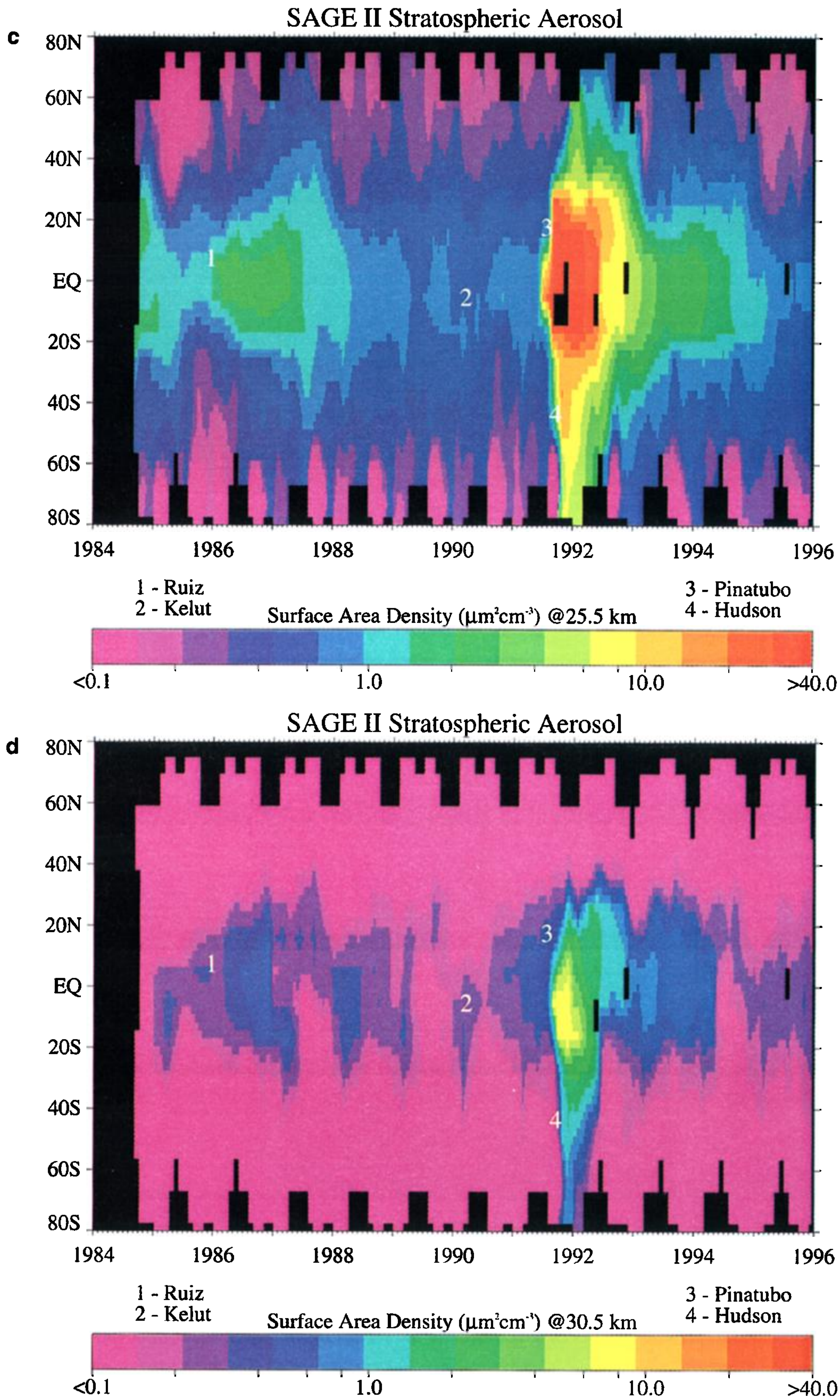


**Plate 1.** (continued)

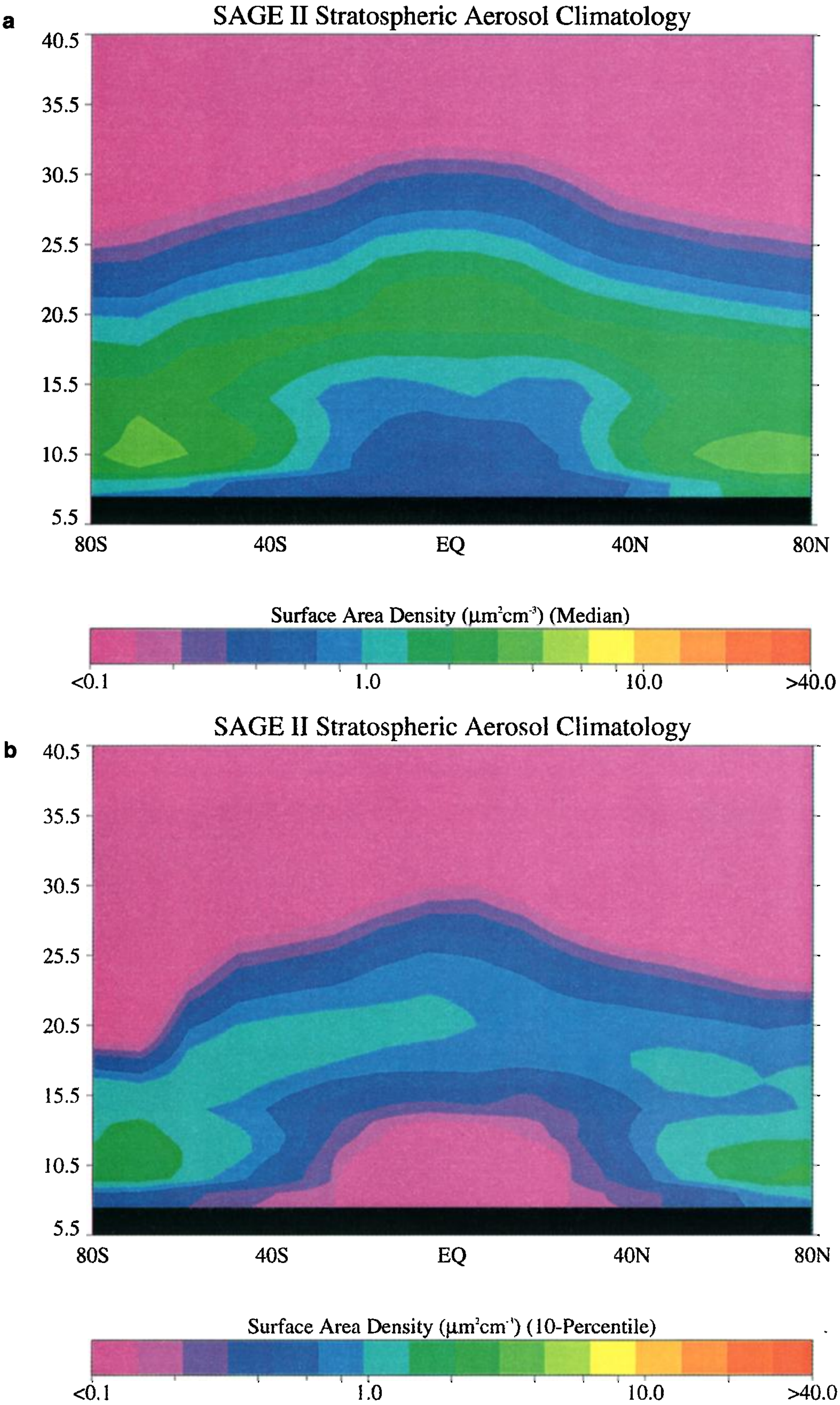


**Plate 2.** Cumulative distributions of *S* as a function of altitude and latitude for the period 1985–1994: (a) median, (b) 10-percentile, (c) 1-percentile. Black regions denote those sections in which no data are available.

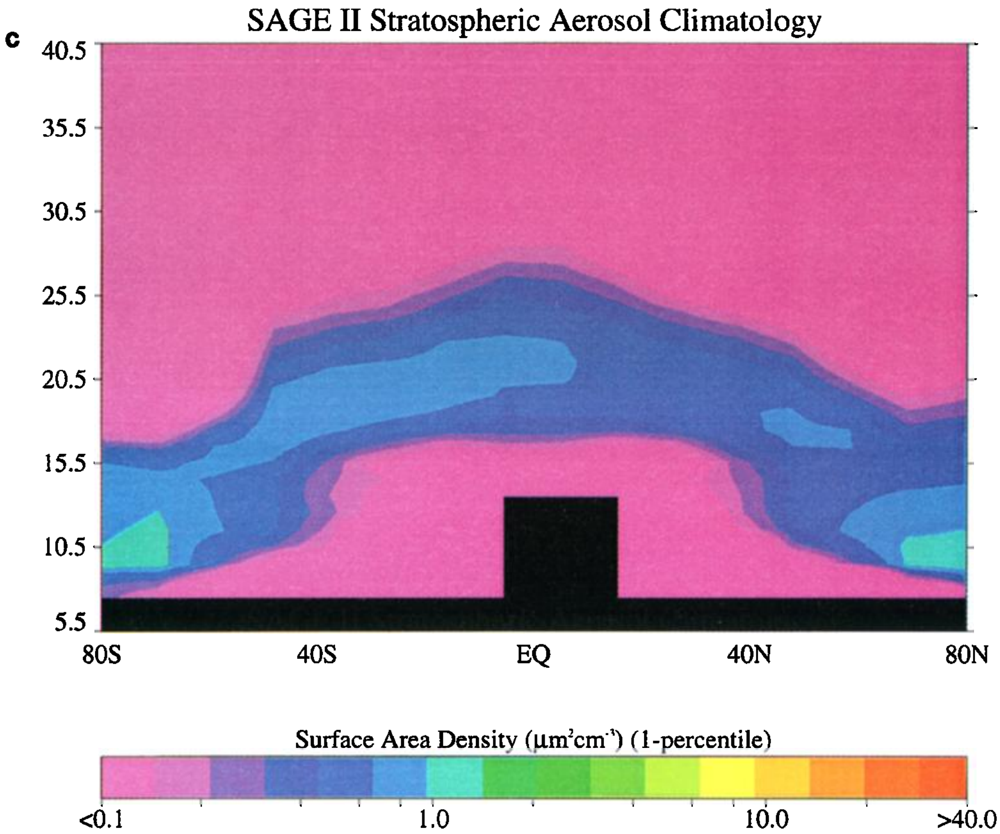


**Plate 2.** (continued)

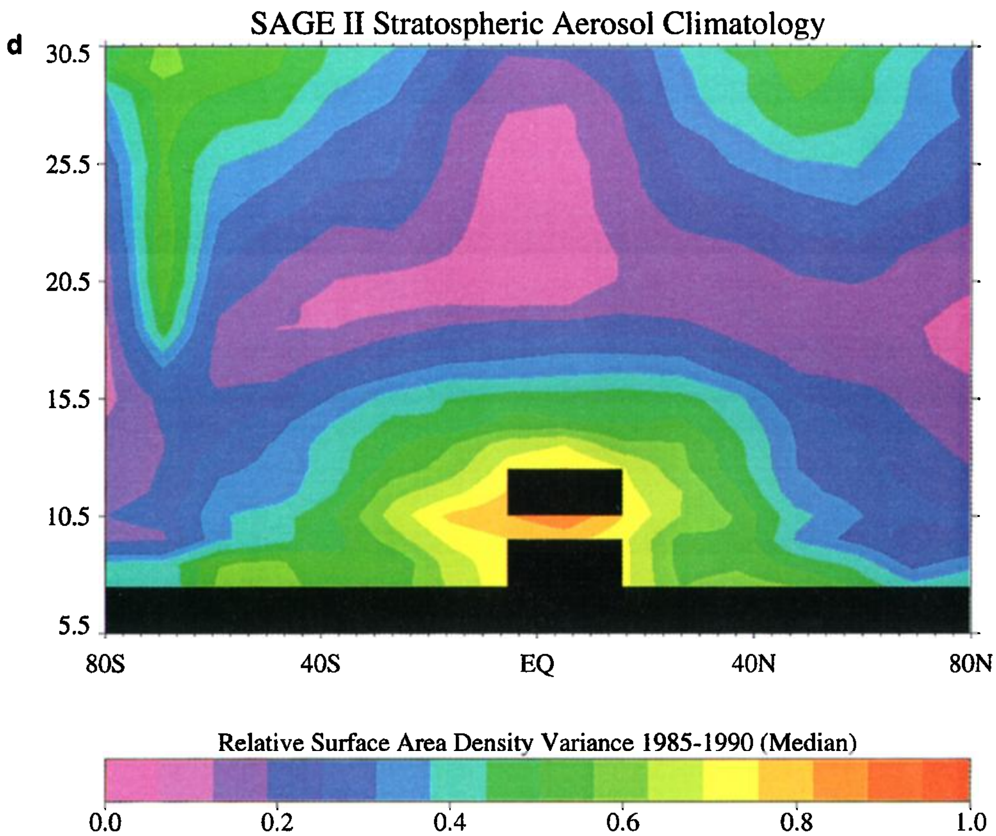


**Plate 3.** Median values of zonal standard deviation of $S$ normalized by the zonal mean as a function of altitude and latitude for the period 1985–1990.

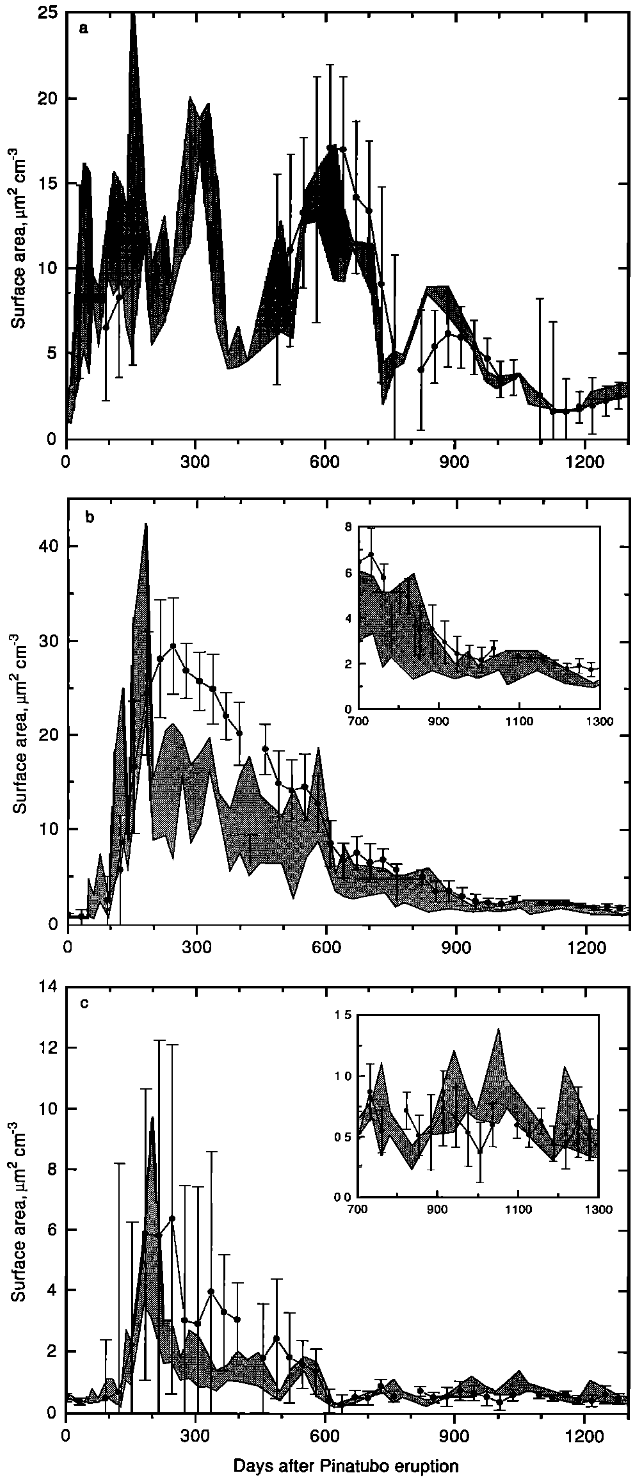


**Figure 1.** Time series of $S$ near (a) 15 km, (b) 20 km, and (c) 25 km for 0–1300 days after the June 1991 Mount Pinatubo eruption estimated from Stratospheric Aerosol and Gas Experiment (SAGE) II and University of Wyoming optical particle counter (OPC) data. SAGE II estimates are circles with error bars, representing monthly zonal medians ±1 standard deviation for the 35°–45°N latitude band constructed from data at altitudes 0.5 km above and below the indicated altitude. Wyoming OPC estimates are shaded areas, representing the range of values for each (approximately monthly) ascent at Laramie (41°N) in the altitude band from 1 km below to 1 km above the indicated altitude. Insets in frames Figures 1b and 1c show a blowup of the respective records for days 700–1300.

(±1 standard deviation) for the 35°–45°N latitude band estimated from data at altitudes 0.5 km above and below the indicated altitude. Note that SAGE II values at 15 km are missing between days 150 and 500, when data retrievals in this altitude region were impossible due to the opaqueness of the overlying Pinatubo aerosol layer. The Wyoming OPC values plotted (shaded area) represent the range of values for each (approximately monthly) ascent at Laramie (41°N) in the altitude band from 1 km below to 1 km above the indicated altitude. The SAGE II and OPC estimates of $S$ agree quite well between days 0–200 and days 500–1300, capturing the initial posteruption increase and the later gradual decline as well as seasonal fluctuations, which are particularly noticeable at 15 km. On the other hand, during the period from days 200 to 500, SAGE II zonal median values at 20 km are approximately 2 standard deviations above the maximum OPC values. The SAGE II values at 25 km during this period also systematically exceed the maximum OPC values but by less than 1 standard deviation. The observed disagreement could be a reflection of zonal variability or of the basic differences in the two measurement approaches. In general, SAGE II and the OPC appear to yield similar estimates when $S$ is less than about 15 $\mu m^2\ cm^{-3}$.

## 4. SAGE II Climatology

### 4.1. Time Series

Plates 1a–1d show the temporal evolution of $S$ at altitudes of 15.5, 20.5, 25.5, and 30.5 km derived from a gridded data set consisting of bins which are 10° latitude by one month with a 2-month sampling window. At 15.5 km, $S$ is dominated at higher latitudes by the recovery of the lower stratosphere from the El Chichon eruption from 1984 to mid-1991 (a drop in $S$ from 6 to about 1 $\mu m^2\ cm^{-3}$) and the Mount Pinatubo eruption from mid-1991 to the end of 1994. During the post-Pinatubo period, $S$ reached values in excess of 20 $\mu m^2\ cm^{-3}$ and remained in the 2–3 $\mu m^2\ cm^{-3}$ range at the end of 1994. In the tropics, $S$ at 15.5 km is much smaller in magnitude than at higher latitudes since this altitude lies primarily within the upper troposphere. There is a modest trend in the tropics, with $S$ decreasing from about 0.9 $\mu m^2\ cm^{-3}$ in early 1985 to about 0.6 $\mu m^2\ cm^{-3}$ in mid-1991. In the tropics, white regions indicate periods for which aerosol-cloud separation was not possible [*Kent et al.*, 1993], and black regions indicate periods for which data are unavailable. During late 1991 and with decreasing frequency into 1993, some SAGE II aerosol extinction profiles terminated well above 15.5 km due to the extreme opacity of the Mount Pinatubo aerosol.

At 20.5 km, $S$ has ranged in magnitude by more than a factor of 30 over the lifetime of SAGE II. At this altitude the impact of the eruptions of the relatively small eruptions of Nevada del Ruiz (0.5 Tg, November 1985) and Kelut (0.3 Tg, February 1990) is clearly evident. On the other hand, the influence of the Cerro Hudson eruption (3.0 Tg, August 1991) is difficult to separate from that of Mount Pinatubo [*Pitts and Thomason*, 1993]. In this Plate 1b a negative gradient in $S$ is observed between the equator and the high latitudes. Also apparent during the last quarter of each year is the Antarctic polar vortex, where extremely low aerosol loading has been noted previously during the late austral winter and spring [*Kent et al.*, 1985; *Thomason and Poole*, 1993]. A similar signature of the Arctic vortex can be seen in some years, but it is much less obvious than that of its southern counterpart because of the smaller size and shorter lifetime of the Arctic vortex.

At both 25.5 and 30.5 km the tropical aerosol reservoir associated with the quasi-biennial oscillation (QBO) is clearly evident between 20°N and 20°S [*Trepte and Hitchman*, 1992]. At 25.5 km the tropical values of $S$ ranged from a high of 40 $\mu m^2$ $cm^{-3}$ to a low of 0.6 $\mu m^2$ $cm^{-3}$ (or over almost 2 orders of magnitude). Outside the tropics the variability in $S$ is much smaller, with the exception of episodic transport events such as occurred in late 1991 and early 1992 and brought highly elevated aerosol levels to polar latitudes in both hemispheres. The elevated aerosol levels at 30.5 km, even in the tropics, are a temporary phenomenon associated with the Pinatubo eruption. Aerosol-induced heating at lower altitudes during late 1991 was sufficient to loft aerosol to this altitude and promote subsequent transport to southern latitudes (but not significantly to northern latitudes). In the tropics and southern latitudes, $S$ at 30.5 km increased by a factor of 10 or more (e.g., 0.1 to 1 $\mu m^2$ $cm^{-3}$ in southern midlatitudes) and was a key factor in the record low levels of $NO_2$ observed at the end of 1991 and into 1992 [*Koike et al.*, 1993].

### 4.2. Cumulative statistics

Plate 1 shows that variations in $S$ in the stratosphere over the lifetime of SAGE II have been driven by episodic volcanic eruptions, especially those of El Chichon and Mount Pinatubo. Hence statistical distributions of $S$ derived from the SAGE II record cannot be considered fully representative of the long-term variability of the stratosphere because the statistics are not stationary over the 10-year sampling period. Nevertheless, such representations can be valuable for parameterizing stratospheric aerosols in photochemical assessment models. Plates 2a–2c show the zonally averaged median, 10-percentile, and 1-percentile distributions for the SAGE II measurement period as a function of altitude and latitude. All three distributions show values of $S$ that are significantly smaller than those typical of the immediate post-Pinatubo period (Plate 1). In a spatial sense, the distributions typify the latter stages of recovery from a major tropical volcanic perturbation. All show a diffuse maximum centered around 20 km in the tropics and more localized maxima around 10 km in the polar regions that are due to downward transport of aerosol during the winter and early spring. The 10-percentile distribution is very similar to that observed in early 1989, which was the basis for the recommended United Nations Environmental Program (UNEP) background aerosol [*World Meteorological Organization* (*WMO*), 1992]. The overall shape of the 1-percentile distribution is very similar to that of the 10-percentile distribution, but with values of $S$ lower by about 50%. It should be noted that particularly for the 1-percentile distribution these statistical cross sections emphasize different seasons as a function of latitude because of the seasonal variations of the latitudinal sampling by SAGE II.

Another issue of interest in evaluating the usefulness of two-dimensional photochemical models is the zonal homogeneity of aerosol-catalyzed chemical processes. Plate 3 shows the zonal standard deviation of $S$ divided by its median for the period 1985–1990. We have omitted the post-Pinatubo period since the very large spatial variability in late 1991 and early 1992 would have dominated this statistic for the entire SAGE II sampling period. The figure shows that there is generally low (<20%) zonal variability in the tropics from the tropopause to 30 km and out to midlatitudes in both hemispheres between about 15 and 20 km. Variability in the midlatitudes increases below 15 km and above 20 km, and there is a sharp maximum near 70°S associated with the edge of the Antarctic polar vortex [*Thomason and Poole*, 1993]. The large maximum below 15 km in the tropics shows the high variability in aerosol loading in the upper troposphere there, but it may also indicate imperfect removal of clouds from the analysis.

### 4.3. Extended Climatology Using SAGE I/SAM II Data

The surface area densities presented thus far have been derived using the full four-wavelength SAGE II aerosol extinction data ensemble. Aerosol extinction data are also available from the Stratospheric Aerosol Measurement (SAM) II (1978–1994, high latitudes only) and SAGE (1979–1981, near-global coverage) instruments but only at the single wavelength of 1.0 $\mu m$ for SAM II and at wavelengths of 1.0 and 0.45 $\mu m$ for SAGE. This limited number of channels means that estimating $S$ with these data sets is impractical using PCA or other standard techniques. However, a well-behaved empirical relationship can be demonstrated between $S$ estimated from the full SAGE II data ensemble and extinction at any one of the four wavelengths. Specifically, we can derive a relationship between $S$ and SAGE II extinction at 1.02 $\mu m$ and, neglecting the small wavelength difference, use it to estimate $S$ with the 1.0-$\mu m$ extinction data from SAM II and SAGE. Figure 2 shows the mean and standard deviation (in bins of equal logarithmic width) of the ratio of $S$ to 1.02-$\mu m$ extinction plotted as a function of 1.02-$\mu m$ extinction for all SAGE II data between 1984 and 1994. For extinction values greater than $10^{-4}$ $km^{-1}$ the relative standard deviation in this ratio is less than 30%. For extinctions greater than $6 \times 10^{-3}$ $km^{-1}$ the relative standard deviation is less than 20%, or only about 50% larger than the wholly random error associated with using PCA to derive $S$ from the full SAGE II extinction data ensemble. A fit to the mean value plotted in Figure 2 is given by

$$S = \begin{cases} 425. \cdot k^{0.68}, & \text{for } k < 4 \cdot 10^{-3}, \\ 1223. \cdot k^{0.875}, & \text{for } 4 \cdot 10^{-3} < k < 2 \cdot 10^{-2}, \\ 2000. \cdot k, & \text{for } k > 2 \cdot 10^{-2}, \end{cases} \quad (5)$$

where the units of $S$ are $\mu m^2$ $cm^{-3}$ and $k$ is 1.02-$\mu m$ extinction in $km^{-1}$. This relationship (the dotted curve in Figure 2) has been used by *Solomon et al.* [1996], who found a generally satisfactory agreement between these estimates of $S$ and those derived from University of Wyoming OPC measurements.

Single wavelength estimates of $S$ such as this implicitly assume that aerosol size and extinction scale similarly at all times and locations. *Thomason* [1992], however, noted substantial departures from such a relationship in the lower stratosphere of the northern hemisphere several months following the eruption of Mount Pinatubo. The observed behavior was characteristic of new particle formation following the eruption. While not a common feature of the SAM/SAGE data set, such time periods lie outside the domain of practical application of the relationship given in (5). *Hitchman et al.* [1994] presented a single-wavelength relationship between extinction and $S$ with an implicit aerosol distribution that depends only on height above the tropopause. This relationship is valid under the background aerosol conditions for which it was derived, but it does not work well under the volcanic conditions which have existed in the stratosphere since 1991. The Hitchman et al. relationship calculated for an altitude 6 km above the tropopause is plotted as the long-dashed line in Figure 2, where it

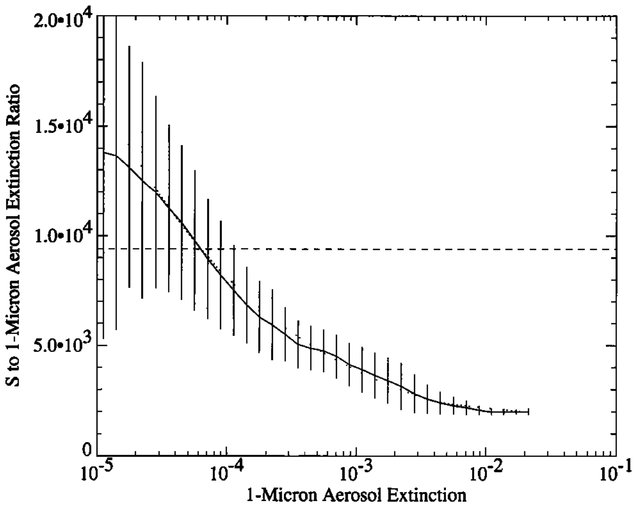


**Figure 2.** Relationship between $S$ and extinction at 1 mm based on SAGE II 1.02-$\mu$m extinction and $S$ derived using equation (4). The solid curve is the mean ratio of derived $S$ to 1-$\mu$m extinction and the associated vertical bars represent the 2-s range in this ratio. The dotted line is the fit to this relationship given by equation (5). The dashed line is the relationship suggested by *Hitchman et al.* [1994] for 6 km above the local tropopause.

can be seen that the relationship overestimates $S$ for large 1-$\mu$m extinction values by as much as a factor of 4.

The advantage of estimating $S$ using (5) with combined 1-$\mu$m aerosol extinction data from SAM II, SAGE, and SAGE II can be seen in Plate 4, which shows $S$ at 20.5 km for the period from 1978 to 1994. There is still a substantial gap in the tropics and midlatitudes from 1982 to 1984 (between the end of the SAGE and the beginning of the SAGE II data records), which unfortunately covers a significant part of the El Chichon period. Even after the beginning of the SAGE II data set, including SAM II, data significantly improve high-latitude coverage. Nonetheless, it is clear that such an extended data set represents a valuable resource to photochemical modelers and others interpreting long-term global change.

## 5. Summary

A global climatology of stratospheric aerosol surface area density ($S$) has been developed using the four-wavelength aerosol extinction data ensemble from SAGE II for 1984–1994. The principal component analysis technique was used to estimate $S$, with the assumption of a constant aerosol composition of 75% $H_2SO_4$ and 25% $H_2O$ by weight. Both polar stratospheric and cirrus clouds were screened from the SAGE II extinction database prior to the analysis. Estimates of $S$ derived from SAGE II and from the University of Wyoming optical particle counters for 1991–1994 were quite similar for levels of $S$ below about 15 $\mu m^2$ $cm^{-3}$, but there were significant differences during the period from 200 to 500 days following the June 1991

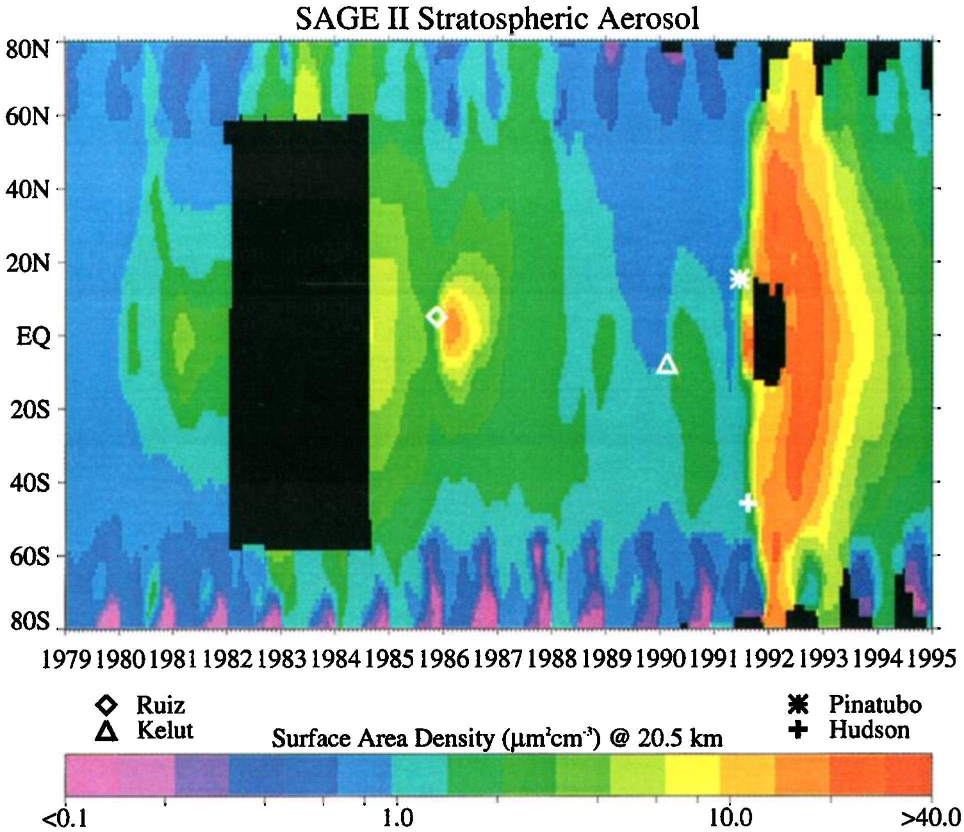


**Plate 4.** $S$ as a function of time and latitude at 20.5 km, constructed from SAGE II values derived using equation (4), and Stratospheric Aerosol Measurement II and SAGE values derived using equation (5). Black regions denote those sections in which no data are available. The latitude and time of significant volcanic events are noted.

Mount Pinatubo eruption. Cumulative median, 10-percentile, and 1-percentile distributions for the 1984–1994 period were presented as a function of altitude and latitude that can be used to parameterize aerosol-driven heterogeneous processes in global photochemical models. An empirical method was also presented for extending the climatology using aerosol extinction measurements at 1.0 $\mu$m by the Stratospheric Aerosol Measurement (SAM) II (1978–1994) and SAGE (1979–1981) instruments.

## Appendix

Seasonal zonal median cross sections of $S$ derived from SAGE II data using PCA are available for 1985 through 1994 via anonymous ftp from the Aerosol Research Branch at NASA Langley Research Center. The interested user should log in as anonymous on sisyphus.larc.nasa.gov. The cross sections of $S$ are located in the ASCII file sfc_84-94.dat with associated documentation located in the file sfc_84-94.txt. The cumulative (10 years) zonal median, 10-percentile, and 1-percentile cross sections of $S$ can be found in the files sfc_median.dat, sfc_10p.dat, and sfc_1p.dat, with documentation in matching *.txt files. Seasonal and monthly median average cross sections of 1-$\mu$m aerosol extinction from SAM II, SAGE, and SAGE II are also available in this directory in the files zonal_k_78-81.dat, zonal_k_82-84.dat, and zonal_k_85-94.dat. Documentation for these files is located in the file zonal_k.txt. The location of this data will eventually shift to the Langley Distributed Active Archive Center and the SAGE II Worldwide Web site at http://arbs8.larc.nasa.gov/sage2/sageii.htm.

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(Received February 3, 1996; revised July 10, 1996; accepted July 28, 1996.)