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BACKGROUND STRATOSPHERIC AEROSOL REFERENCE MODEL

M. P. McCormick* and P. Wang**

*Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23666
**Science and Technology Corporation, Hampton, VA 23666

INTRODUCTION

The objective of this paper is to present a proposed reference model for the background stratospheric aerosol based on currently available data from satellite observations. Information on the characteristics of stratospheric aerosols is important to climate and remote sensing studies through radiative transfer processes. Measurements of stratospheric aerosols actually date back nearly 30 years. Using balloon-borne particle counters, Junge et al. /1/ discovered a layer of high particle concentration several kilometers thick in the lower stratosphere which has become known as the Junge layer. Primarily, measurements of stratospheric aerosols have been made by two different approaches, either using in situ mechanical/optical particle counters or by remote optical sensing techniques. In order to obtain more information on the stratospheric aerosol layer, NASA has launched three satellite instruments since October 1978: the Stratospheric Aerosol Measurement (SAM II) on Nimbus 7, and the Stratospheric Aerosol and Gas Experiments I and II (SAGE I and II) on the Applications Explorer Mission 2 satellite and the Earth Radiation Budget Satellite, respectively. These satellite instruments all utilize the solar occultation technique to measure vertical profiles of limb attenuated solar intensity at desired wavelengths during each sunrise and sunset experienced by the satellite. The SAM II instrument is a one-channel sunphotometer measuring aerosol extinction at 1.0 µm in the polar regions. The SAGE I instrument is a four-channel sunphotometer which measures aerosol extinction at 1.0 µm and 0.45 µm with nearly global coverage. In addition, it also provides simultaneous observations of stratospheric O_3 and NO_2 at 0.60- and 0.45-µm wavelengths, respectively. The detailed aspects of the SAM II and SAGE I systems have been described by McCormick et al. /4/. The SAGE II satellite instrument was launched in 1984 and is an advanced version of SAGE I. It has three additional channels centered at 0.448-, 0.525-, and 0.94-µm wavelengths which provide a differential NO_2 measurement, additional aerosol extinction data, and an H_2O vapor concentration channel. Thus, the SAGE II satellite instrument measures aerosol extinction at four different wavelengths, and the simultaneously determined stratospheric H_2O is of particular importance in understanding the aerosol microphysical processes as well as their composition. The data processing of SAGE II observations is currently in progress, and the data set will be available to the scientific community beginning in 1987.

Unlike the stratospheric gaseous species, which can be fully characterized by determining their concentration (number density or mixing ratio), a complete description of aerosol particles requires information about their composition/refractive index, size distribution, and shape. A complete set of such information is very much needed, especially in order to understand the radiative implications of aerosols. Fortunately, there is sufficient evidence that the stratospheric aerosol can be described reasonably well by assuming they are spherical liquid droplets of approximately 75 percent H_2SO_4 and 25 percent H_2O in composition by weight (Rosen, /7/); see also the Standard Radiation Atmosphere (SRA), /10/. In addition, analytic models have been recommended for the background stratospheric aerosol size distribution and composition by Russell et al. /8/ which have proved quite successful in the validation of SAM II and SAGE I (Russell et al., /9/). The current understanding of sources and sinks, and their distributions have been reviewed by Turco et al. /11/ who also pointed out which experimental and theoretical analysis are needed in order to enhance our knowledge about stratospheric aerosols.

Since aerosol extinction at 1.0-µm wavelength inferred from SAGE I satellite observations constitute the only available multi-year aerosol data set with nearly global-scale coverage, it is reasonable to use this data set to derive a reference model of stratospheric aerosols. It should be kept in mind that strictly speaking, this proposed reference model is an optical one. Nevertheless, it summarizes the general global-scale features of the stratospheric aerosol layer and can be used, for example, to derive parameters which are important to climate studies (McCormick, /5/; Lenoble and Brogniez, /3/; SRA, /10/).

REFERENCE MODEL

During its operation lifetime from February 1979 to November 1981, the SAGE I instrument produced 34 months of aerosol extinction data with nearly global coverage. Except for the very minor volcanic eruption of La Soufriere (13.3°N, 61.2°W; 17 April 1979), the stratospheric aerosol layer was practically unperturbed during the SAGE measuring period from February 1979 to May 1980 (Kent and McCormick, /2/). After that time, a number of large volcanic perturbations occurred. As a result, the SAGE aerosol 1.0-mm extinction data set obtained during this period will be adopted in this paper to establish a simple reference model for the background stratospheric aerosol. The meridional distribution of the zonal mean stratospheric aerosol extinction at 1.0-mm wavelength on a seasonal basis has been documented in tabulations and in graphic representations by McCormick /6/. This distribution is reproduced in Figure 1.

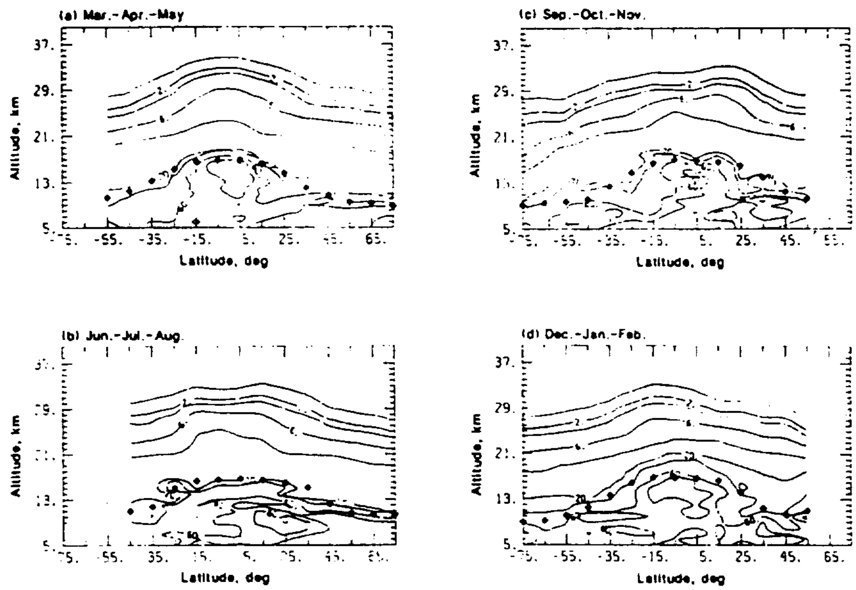

Fig. 1. Seasonal meridional distribution of aerosol extinction at 1.0 μm, in units of 10^{-5} km^{-1}, (a) March-April-May (1979), (b) June-July-August (1979), (c) September-October-November (1979), and (d) December (1979)-January-February (1980).

In order to obtain the vertical distribution of stratospheric aerosols in a climatological manner, the averaged profiles are computed for five different latitudinal bins: 75°S-40°S, 40°S-20°S, 20°S-20°N, 20°N-40°N, and 40°N-75°N on a seasonal basis. These latitude bins roughly correspond to the tropics and the mid- and high latitudes in both hemispheres. The results are tabulated in Tables 1-4 and Figures 2-5 using the northern seasonal period nomenclature, starting with spring, and are in all cases referenced to the tropopause height. The remarkable feature in Figures 2-5 is the similar vertical distribution of the averaged profiles from the five different latitudinal bins when referenced to the tropopause and the similarity in the four different seasonal plots. Figure 6 presents a plot of all the data of Figures 2-5 on one graph and shows the striking similarity in the data. This very similar vertical distribution of the 1.0-μm aerosol extinction in Figures 2-6 suggests that it is reasonable to construct a simple analytic representation for profiles from the five different latitudinal bins. The following third order polynomial is used for this representation:

$$\mathrm{Log}_{10}(\beta)=a + bZ + cZ^2 + dZ^3 \qquad (1)$$

where β is the 1.0-μm aerosol extinction at altitude z measured from the tropopause and a, b, c, and d are coefficients to be determined from the SAGE I satellite data set. This calculation was carried out to 20 km above the tropopause, the range over which the data are the most accurate. The results of the derived coefficients are given in Table 5. The computed profile using these coefficients for each of the seasonal periods is indicated in Figures 2-5 by the heavy curve. As one can see, the computed profiles represent the average of the vertical profiles from the five different latitudinal bins very well. It is understood that

TABLE 1 Zonally Averaged Stratospheric Aerosol Extinction at 1.0 Micrometer (1/km) for March, April, and May 1979

	LATITUDE				
ALT* (km)	75S-40S	40S-20S	20S-20N	20N-40N	40N-75N
0	1.921E-04	1.371E-04	5.779E-04	2.871E-04	7.013E-04
1	1.668E-04	1.189E-04	3.254E-04	1.771E-04	3.337E-04
2	1.507E-04	1.096E-04	1.708E-04	1.376E-04	1.973E-04
3	1.260E-04	1.109E-04	1.239E-04	1.221E-04	1.597E-04
4	1.276E-04	1.141E-04	1.136E-04	1.156E-04	1.433E-04
5	1.315E-04	1.128E-04	1.087E-04	1.130E-04	1.331E-04
6	1.323E-04	1.067E-04	1.020E-04	1.098E-04	1.262E-04
7	1.261E-04	9.676E-05	9.433E-05	1.044E-04	1.195E-04
8	1.140E-04	8.482E-05	8.748E-05	9.576E-05	1.118E-04
9	9.858E-05	7.255E-05	8.047E-05	8.750E-05	1.032E-04
10	8.205E-05	6.083E-05	7.300E-05	7.781E-05	9.428E-05
11	6.591E-05	4.967E-05	6.586E-05	6.748E-05	8.538E-05
12	5.152E-05	4.001E-05	5.865E-05	5.638E-05	7.626E-05
13	3.860E-05	3.203E-05	4.982E-05	4.599E-05	6.615E-05
14	2.900E-05	2.520E-05	3.829E-05	3.678E-05	5.468E-05
15	2.163E-05	1.954E-05	2.771E-05	2.806E-05	4.250E-05
16	1.594E-05	1.477E-05	1.935E-05	2.184E-05	3.139E-05
17	1.164E-05	1.083E-05	1.319E-05	1.642E-05	2.272E-05
18	8.423E-06	7.894E-06	8.857E-06	1.230E-05	1.663E-05
19	6.171E-06	5.720E-06	5.905E-06	9.026E-06	1.196E-05
20	4.596E-06	4.191E-06	4.000E-06	6.506E-06	8.653E-06
TROP-HEIGHT	10.75	14.21	16.60	13.15	9.54

*Altitude above tropopause

TABLE 2 Zonally Averaged Stratospheric Aerosol Extinction at 1.0 Micrometer (1/km) for June, July, and August 1979

	LATITUDE				
ALT* (km)	75S-40S	40S-20S	20S-20N	20N-40N	40N-75N
0	2.165E-04	1.542E-04	1.513E-04	1.475E-04	4.835E-04
1	1.795E-04	1.384E-04	1.157E-04	1.346E-04	2.241E-04
2	1.618E-04	1.275E-04	1.120E-04	1.128E-04	1.541E-04
3	1.489E-04	1.229E-04	1.108E-04	1.115E-04	1.338E-04
4	1.418E-04	1.235E-04	1.125E-04	1.096E-04	1.274E-04
5	1.405E-04	1.251E-04	1.101E-04	1.022E-04	1.258E-04
6	1.386E-04	1.209E-04	1.065E-04	9.679E-05	1.232E-04
7	1.329E-04	1.144E-04	1.023E-04	8.899E-05	1.169E-04
8	1.233E-04	1.049E-04	9.853E-05	7.755E-05	1.091E-04
9	1.095E-04	9.334E-05	9.290E-05	6.694E-05	1.005E-04
10	9.288E-05	7.913E-05	8.388E-05	5.731E-05	8.945E-05
11	7.709E-05	6.511E-05	7.292E-05	4.870E-05	7.697E-05
12	6.224E-05	5.282E-05	5.620E-05	3.756E-05	6.293E-05
13	5.038E-05	4.238E-05	3.679E-05	2.860E-05	4.820E-05
14	4.118E-05	3.448E-05	2.420E-05	2.182E-05	3.510E-05
15	3.332E-05	2.834E-05	1.660E-05	1.610E-05	2.496E-05
16	2.691E-05	2.160E-05	1.142E-05	1.199E-05	1.746E-05
17	2.010E-05	1.642E-05	7.904E-06	8.819E-06	1.251E-05
18	1.439E-05	1.242E-05	5.544E-06	6.572E-06	8.851E-06
19	1.026E-05	9.112E-06	3.947E-06	4.961E-06	6.327E-06
20	7.347E-06	6.616E-06	2.858E-06	3.771E-06	4.604E-06
TROP-HEIGHT	10.98	12.82	16.57	15.36	10.50

*Altitude above tropopause

TABLE 3 Zonally Averaged Stratospheric Aerosol Extinction at 1.0 Micrometer (1/km) for September, October, and November 1979

ALT* (km)	LATITUDE 75S-40S	40S-20S	20S-20N	20N-40N	40N-75N
0	3.843E-04	2.396E-04	3.432E-04	1.440E-04	2.702E-04
1	3.007E-04	1.639E-04	2.770E-04	1.205E-04	1.721E-04
2	2.393E-04	1.533E-04	1.691E-04	1.152E-04	1.423E-04
3	2.033E-04	1.411E-04	1.240E-04	1.170E-04	1.348E-04
4	1.818E-04	1.390E-04	1.148E-04	1.197E-04	1.349E-04
5	1.654E-04	1.354E-04	1.084E-04	1.187E-04	1.402E-04
6	1.488E-04	1.290E-04	1.044E-04	1.122E-04	1.407E-04
7	1.314E-04	1.180E-04	1.007E-04	1.023E-04	1.376E-04
8	1.129E-04	1.061E-04	9.502E-05	8.859E-05	1.291E-04
9	9.593E-05	9.340E-05	8.691E-05	7.723E-05	1.149E-04
10	7.863E-05	7.880E-05	7.521E-05	6.596E-05	9.819E-05
11	6.550E-05	6.656E-05	5.682E-05	5.494E-05	7.950E-05
12	5.398E-05	5.469E-05	3.977E-05	4.490E-05	6.220E-05
13	4.296E-05	4.190E-05	2.710E-05	3.619E-05	4.704E-05
14	3.387E-05	3.246E-05	1.848E-05	2.726E-05	3.524E-05
15	2.658E-05	2.487E-05	1.286E-05	2.029E-05	2.513E-05
16	2.052E-05	1.890E-05	9.053E-06	1.511E-05	1.827E-05
17	1.523E-05	1.442E-05	6.423E-06	1.082E-05	1.316E-05
18	1.107E-05	1.022E-05	4.640E-06	7.896E-06	9.563E-06
19	8.083E-06	7.369E-06	3.421E-06	5.762E-06	6.992E-06
20	5.920E-06	5.310E-06	2.555E-06	4.267E-06	5.128E-06
TROP-HEIGHT	9.70	13.49	16.77	14.99	10.77

*Altitude above tropopause

TABLE 4 Zonally Averaged Stratospheric Aerosol Extinction at 1 Micrometer (1/km) for December 1979, January and February 1988

ALT* (km)	LATITUDE 75S-40S	40S-20S	20S-20N	20N-40N	40N-75N
0	3.798E-04	2.909E-04	5.149E-04	2.479E-04	2.738E-04
1	3.044E-04	2.349E-04	4.376E-04	2.237E-04	2.340E-04
2	2.418E-04	1.930E-04	3.385E-04	2.286E-04	2.341E-04
3	2.121E-04	1.660E-04	2.939E-04	2.277E-04	2.376E-04
4	1.952E-04	1.439E-04	2.132E-04	2.182E-04	2.341E-04
5	1.743E-04	1.211E-04	1.342E-04	2.004E-04	2.175E-04
6	1.483E-04	1.024E-04	1.047E-04	1.778E-04	1.935E-04
7	1.252E-04	8.859E-05	9.617E-05	1.563E-04	1.682E-04
8	1.075E-04	7.722E-05	8.760E-05	1.311E-04	1.454E-04
9	9.471E-05	6.697E-05	7.679E-05	1.101E-04	1.242E-05
10	8.263E-05	5.818E-05	6.183E-05	9.256E-05	1.075E-04
11	7.141E-05	4.709E-05	4.638E-05	7.784E-05	9.328E-05
12	5.955E-05	3.762E-05	3.444E-05	6.337E-05	7.888E-05
13	4.800E-05	2.899E-05	2.496E-05	5.087E-05	6.676E-05
14	3.796E-05	2.174E-05	1.750E-05	3.915E-05	5.466E-05
15	2.940E-05	1.612E-05	1.247E-05	2.883E-05	4.197E-05
16	2.197E-05	1.145E-05	8.842E-06	2.047E-05	3.087E-05
17	1.596E-05	8.205E-06	6.294E-06	1.384E-05	2.134E-05
18	1.147E-05	5.860E-06	4.522E-06	9.776E-06	1.493E-05
19	8.272E-06	4.219E-06	3.276E-06	6.858E-06	1.054E-05
20	5.974E-06	3.065E-06	2.425E-06	4.885E-06	7.409E-06
TROP-HEIGHT	10.14	14.74	16.65	12.52	10.42

*Altitude above tropopause

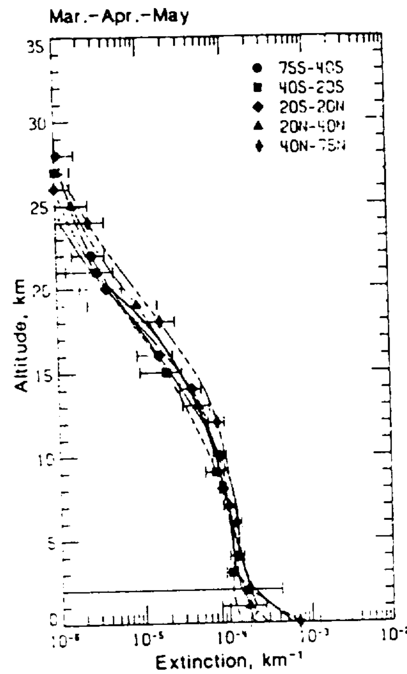

Fig. 2. Vertical distributions of aerosol 1.0-μm extinction for March-April-May (1979) at the tropics, and mid- and high latitudes in both hemispheres above the tropopause.

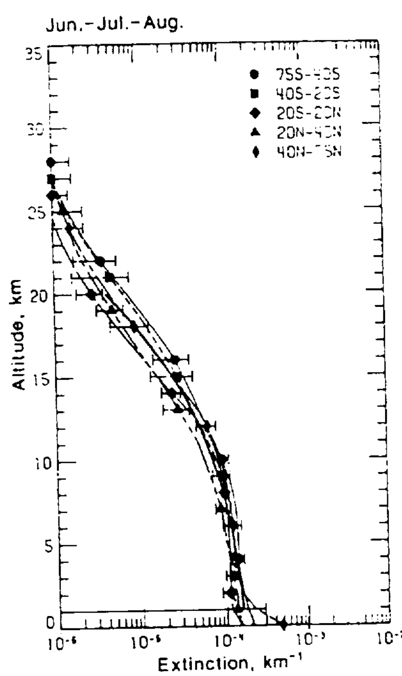

Fig. 3. Vertical distribution of aerosol 1.0-μm extinction for June-July-August (1979) at the tropics, and mid- and high latitudes in both hemispheres above the tropopause.

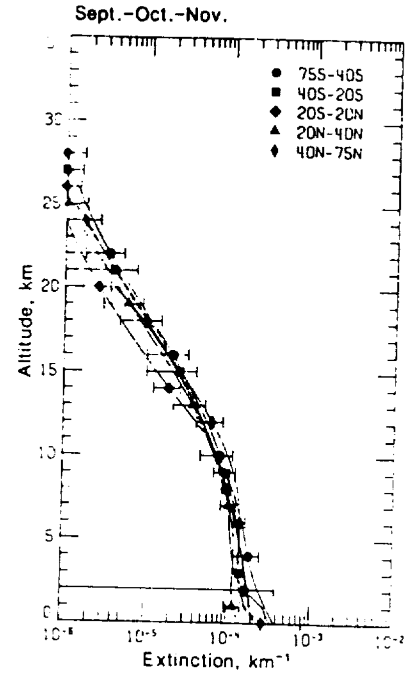

Fig. 4. Vertical distribution of aerosol 1.0-μm extinction for September-October-November (1979) at the tropics, and mid- and high latitudes in both hemispheres above the tropopause.

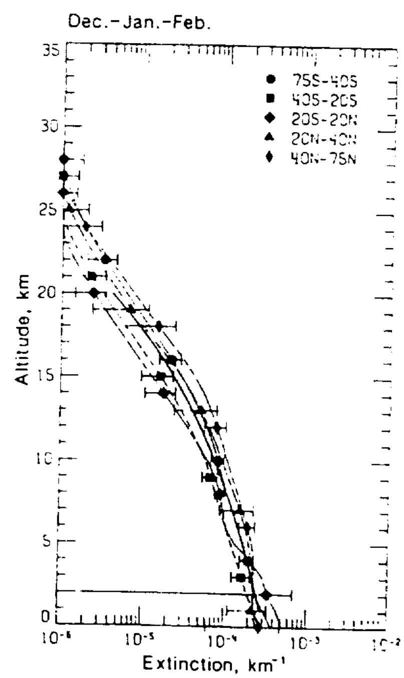

Fig. 5. Vertical distribution of aerosol 1.0-μm extinction for December (1979)-January-February (1980) at the tropics, and mid- and high latitudes in both hemispheres above the tropopause.

these heavy curves are only approximate representations of the globally-averaged vertical distribution since we have only used 1 year of the SAGE I data set, but it does appear to be a reasonable representation. Also listed in Table 5 is a separate fit to the data of Figure 6.

TABLE 5 Coefficients of the Polynomial (Eq. 1) Derived from SAGE 1.0-μm Aerosol Extinction (March 1979 to February 1980)

	COEFFICIENTS			
PERIOD*	a	b	c	d
MAM	-3.60	-8.59E-02	6.30E-03	-3.17E-04
JJA	-3.78	-1.79E-02	-5.66E-04	-1.27E-04
SON	-3.67	-3.26E-02	-2.99E-04	-1.20E-04
DJF	-3.50	-5.42E-02	4.01E-04	-1.21E-04
YEARLY MEAN	-3.64	-4.77E-02	-1.46E-03	-1.71E-04

*MAM (March, April, May)
JJA (June, July, August)
SON (September, October, November)
DJF (December, January, February)

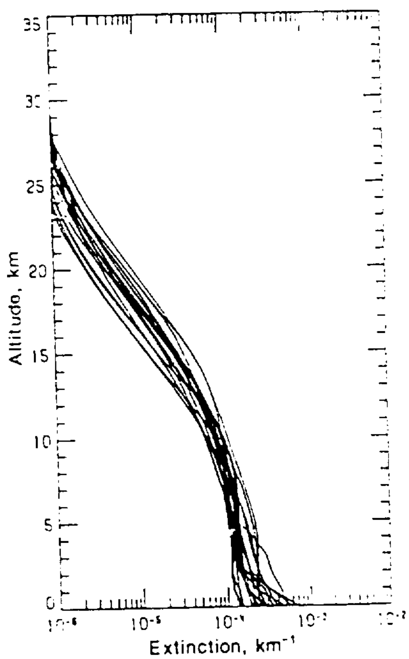

Fig. 6. The spreading of the vertical profiles from all the different seasons and latitudinal bins given in Figures 2-5.

SUMMARY

In this analysis, a reference background stratospheric aerosol optical model is developed based on the nearly global SAGE I satellite observations in the non-volcanic period from March 1979 to February 1980. Zonally averaged profiles of the 1.0-μm aerosol extinction for the tropics and the mid- and high altitudes for both hemispheres are obtained and presented in graphical and tabulated form for the different seasons. In addition, analytic expressions for these seasonal global zonal means, as well as the yearly global mean, are determined according to a third order polynomial fit to the vertical profile data set. This proposed background stratospheric aerosol model can be useful in modeling studies of stratospheric aerosols and for simulations of atmospheric radiative transfer and radiance calculations in atmospheric remote sensing.

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