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Comparison of aerosol extinction measurements by ILAS and SAGE II

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Abstract. Seventy-three pairs of nearly coincident profiles of aerosol extinction at visible wavelengths from the Improved Limb Atmospheric Spectrometer (Version 3.1) and the Stratospheric Aerosol and Gas Experiment (SAGE) II (Version 5.931) are compared for a week in January and February 1997. The comparisons require an interpolation of SAGE II multi-wavelength aerosol extinction profiles to compensate for the difference between the measurement wavelengths of the two instruments. The profiles are shown to agree within ten percent for the altitude range from approximately 15 to 24 km, with a small systematic bias that requires further study.

Introduction

The Improved Limb Atmospheric Spectrometer (ILAS) measured atmospheric extinction spectra by solar occultation, a method in which the transmission of sunlight through the limb of the atmosphere is measured during satellite sunrise and sunset. Due to the unique spectra of different species, information about the concentrations of various atmospheric components is obtainable from sunlight extinction data at different wavelengths. The usefulness of the solar occultation technique has been shown by several other instruments, including the Stratospheric Aerosol and Gas Experiment (SAGE) II and its predecessors [e.g., *Thomason, et al.,* 1997]. ILAS was on the Advanced Earth Observing Satellite (ADEOS) and it was routinely operated from November 1996 through June 1997. It traveled in a sun-synchronized polar orbit, allowing the instrument to observe fourteen sunrises and fourteen sunsets per day, all at high latitudes (57-73°N and 64-88°S). The target altitude range for all measurements was 10 to 60 km with a 2-km instantaneous field of view. In comparison, the SAGE II instrument, which has been operating aboard the Earth Radiation Budget Satellite (ERBS) since 1984, observes approximately fifteen sunrises and fifteen sunsets per day. These observations provide near-global coverage nominally extending from 70°S to 70°N and a full sweep takes 25 to 40 days. The reported altitude range for aerosol extinction data is cloud top to 40 km and the instrument has a 0.5-km vertical field of view.

ILAS was devised to provide insight into the chemistry of stratospheric ozone depletion. Accordingly, it measured the vertical distribution of important trace gases such as ozone, methane and water vapor, as well as aerosol extinction. The information about these quantities comes primarily from measurements made at infrared wavelengths, between roughly 6000 and 12000 nm. However, a visible wavelength band (753 to 784 nm) is used for the measurement of absorption by molecular oxygen that, in turn, serves in the determination of temperature and pressure profiles. A by-product of the visible wavelength measurements is the computation of aerosol extinction at 780 nm. This study compares ILAS Version 3.1 visible wavelength aerosol extinction profiles to coincident profiles obtained by SAGE II (Version 5.931).

The measurement of aerosol extinction at 780 nm is not affected by absorption by the near-by oxygen A band. The optical depth at this wavelength is attributable to three factors: Wulf band absorption by ozone, Rayleigh scattering by air molecules, and Mie scattering by aerosols. In early versions of the ILAS processing, the O_2 A-band absorption was to be used in the calculation of temperature and pressure profiles, which in turn would be used to calculate the amount of Rayleigh scattering [*Sasano, et al.,* 1998], [*Sasano,* 1996]. In the present version (Version 3.1), independent meteorological data (UKMO) are used to determine the Rayleigh scattering contribution. After the Rayleigh and ozone contributions are subtracted, the remainder is attributed to Mie scattering by aerosols.

An issue of interest in the ILAS processing is the tangent height determination. In the current method, the molecular oxygen A-band transmission is integrated over the P-branch, and the result is compared to a value obtained theoretically using independent meteorological data. The original method, which used data obtained by the sun-edge sensor, was not employed in Version 3.1 processing due to the unexpected

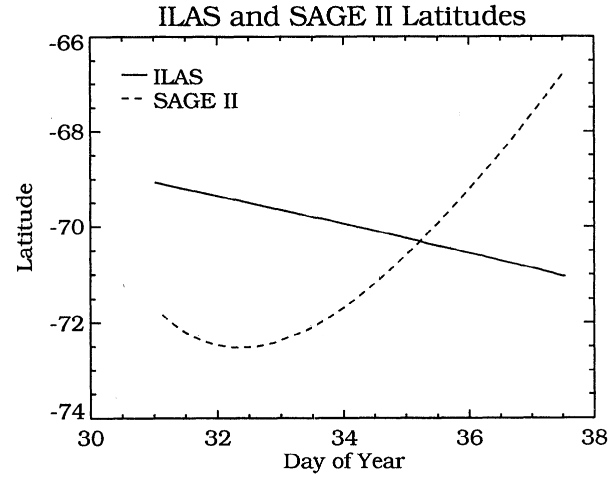

Figure 1. ILAS and SAGE II latitudes for 30 January 1997 to 6 February 1997.

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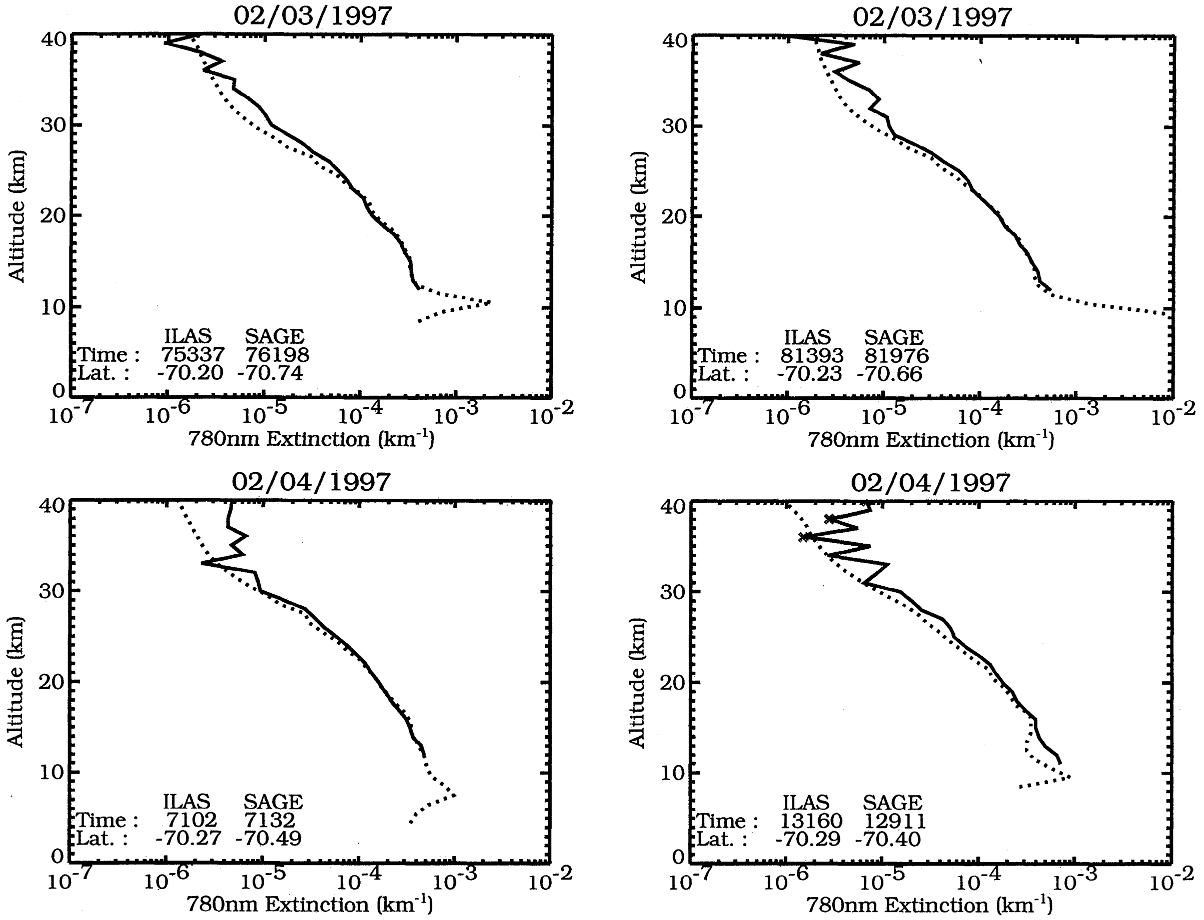

Figure 2. Four pairs of aerosol extinction profiles from ILAS (solid) and SAGE II (dashed) for February 3, 1997 (Figures a and b) and February 4, 1997 (Figures c and d). The log of the absolute value is shown here, with X's for ILAS values reported as negative. ILAS data are reported at integer altitudes, SAGE II data at odd half-integer altitudes. The SAGE II profiles have been interpolated to 780 nm using an assumed aerosol size distribution.

behavior of that instrument. It is believed that altitude registration is a significant factor in the error budget of the retrieved profiles.

The SAGE II instrument observes atmospheric transmission at seven wavelengths, and aerosol extinction is reported at a subset of these (1020, 525, 453 and 385 nm) [*Osborn et al.,* 1989]. Rayleigh scattering contributions at the seven wavelengths are calculated using temperature and pressure data from the National Centers for Environmental Prediction (NCEP). Nitrogen dioxide slant path optical depth is determined using data from a pair of channels with wavelengths 448 and 453 nm. After the Rayleigh and NO_2 components are removed, the contributions by ozone and aerosol are separated by inverting a system of linear equations in which the aerosol optical depth at 600 nm is approximated as a linear combination of the aerosol measurements at the four wavelengths, 1020, 525, 453 and 385 nm. The separation of NO_2, ozone and aerosol is iterated for increased stability. Finally, inversion of the slant path optical depths into vertical profiles occurs after the Rayleigh removal and separation of species, using an iterative Twomey-Chahine non-linear inversion algorithm with 5-km vertical smoothing for extinction levels at and below $2x10^{-5}$ km^{-1} [*Chu et al.,* 1989].

Methodology

The first task in this study was to find pairs of coincident measurements. Figure 1 shows the latitudes at which ILAS and SAGE II made sunset observations between 31 January 1997 and 6 February 1997. Seventy-three pairs of observations during this time coincide to within 3 hours and 500 km, and a few pairs are as close as 100 km and 15 minutes apart. This was one of only two time periods during which a significant number of coincident measurements are available. The other time period, November 1996, was excluded from this study because of the presence of a number of abnormal ILAS profiles, thought to be associated with the presence of sunspots. The coincident profiles studied here correspond to background aerosol conditions, unaffected by volcanic eruptions or the polar vortex.

In order to more meaningfully compare these pairs of profiles, SAGE II extinction data is interpolated to 780 nm, the ILAS wavelength. This calculation is performed using Mie scattering theory with a segmented power law size distribution, described in *Thomason,* 1991. This distribution was developed empirically based on observed characteristics of SAGE II extinction measurements, and tested against various

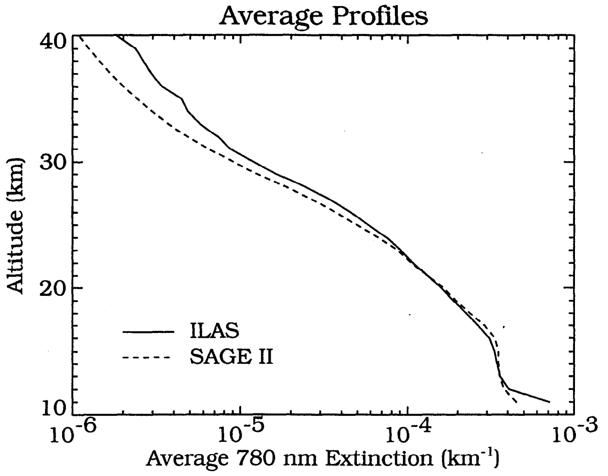

Figure 3. Mean ILAS and SAGE II aerosol extinction profiles. These profiles are obtained by averaging 73 profiles each from between January 30 and February 6, 1997.

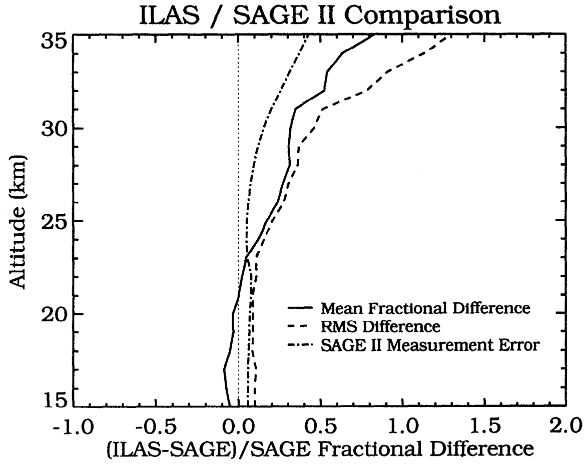

Figure 4. The mean and RMS fractional difference between SAGE II and ILAS aerosol extinction profiles are plotted along with the SAGE II measurement error.

other aerosol measurements including dustsondes, wire impactors and longwave lidar. Because it was developed as a tool for interpolating SAGE II aerosol extinction as a function of wavelength, and because it has only one free parameter, it is ideal for use in this context. This size distribution, dn(r)/dr, is given by

$$\frac{dn(r)}{dr} = \begin{cases} A\left(\frac{r}{r_c}\right)^{-1} & r < r_c \\ A\left(\frac{r}{r_c}\right)^{-8} & r \geq r_c \end{cases} \qquad (1)$$

where r_c is the single sizing parameter, called the "critical radius," and A is a constant related to the total aerosol number density. Using this model, the behavior of the aerosol extinction coefficient as a function of wavelength depends only on the critical radius. Therefore, we calculate the aerosol extinction for a particular altitude and event by solving for the critical radius there, using the ratio of the 525-nm aerosol extinction to the 1020-nm aerosol extinction at the same altitude, as described in *Thomason,* 1991. This critical radius is then used to infer the ratio of the 780-nm and 1020-nm aerosol extinctions. The adjusted SAGE II aerosol extinction profiles along with the corresponding ILAS profiles for the four closest coincidences appear in Figure 2.

For comparison, a simpler aerosol model was also examined briefly, one in which the ratio of the aerosol extinction at two wavelengths is assumed to be equal to the ratio of the wavelengths raised to a power. The resulting SAGE II 780-nm aerosol extinction agrees with those calculated above with less than 10% difference for the events and altitudes studied, and the shapes of the profiles are not affected.

Discussion and Results

Good agreement can be seen between the profiles in Figure 2 for the altitude range of approximately 15 to 25 km. Figure 3 shows mean profiles, calculated by averaging the 73 pairs of profiles in this study. The mean profiles also agree well for the same altitude region.

Figure 4 promotes a more quantitative understanding of the agreement between the SAGE II and ILAS profiles. The solid line is obtained by first interpolating the SAGE II data to the altitudes at which the ILAS data are reported (SAGE II and ILAS data are both reported at one-kilometer increments, but with a half-kilometer offset). The fractional difference between each pair of profiles is then averaged over the 73 pairs. The dashed line in Figure 4 is the root mean square (RMS) difference. Also included is the reported SAGE II one-sigma error (dash-dot line). No error estimate is available for the ILAS Version 3.1 aerosol profiles, but it is likely that the uncertainty is compatible with the SAGE II uncertainty. In Figure 4, the RMS difference is compatible with the measurement uncertainty in the range from about 15 to 25 km, especially if one considers the combined measurement uncertainty of the two instruments.

However, a small systematic bias is evident in Figure 4. The mean fractional difference is zero at about 21 km, but increases in both directions. At lower altitudes, SAGE exceeds ILAS by a maximum of about 10%. At higher altitudes, ILAS exceeds SAGE, crossing 10% around 24 km and continuing to increase above that altitude. It is possible that the process of interpolating the SAGE II aerosol extinction to 780 nm contributes to the observed bias. However, known difficulties with the ILAS altitude registration also provide a likely explanation. An example is solar limb darkening, which may affect the ILAS aerosol extinction at altitudes where atmospheric refraction compresses the apparent solar disk. Ongoing ILAS algorithm development is addressing this issue and should lead to improvements.

Conclusion

It has been shown that the Version 3.1 sunset aerosol extinction data from the Improved Limb Atmospheric Spectrometer agree with the equivalent data from SAGE II, for an altitude range of about 15 km to 25 km. The differences are judged to be compatible with the measurement errors, if the ILAS measurement uncertainty (unreported) is similar to the SAGE II uncertainty. The observed systematic differences in that range may be due to an altitude registration problem with ILAS, a possibility that is still undergoing study.

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