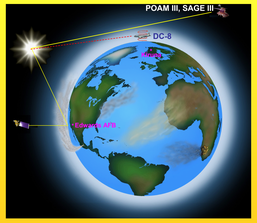

Solar Occultation from Air and Space:

Comparisons of Ozone, Aerosol, and Water Vapor Measurements by Airborne Sun Photometer to Diverse Measurements from Satellites and Aircraft

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We summarize results and future directions for our SOSST task, including results from three journal papers published in this task. The task has focused on integrated analyses of aerosol optical depth (AOD) spectra and ozone and water vapor columns derived from solar-beam transmission measurements by the Ames Airborne Tracking Sunphotometer (AATS-14) on eight DC-8 flights in SOLVE II (January-February 2003). Included are comparisons to many different measurements from satellites and aircraft by solar occultation and other techniques.

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Atmospheric Chemistry and Physics Discussions

Retrieval of ozone column content from airborne Sun photometer measurements during SOLVE II: comparison with coincident satellite and aircraft measurements

J. M. Livingston, B. Schmid, P. B. Russell, J. A. Eilers, R. W. Kolyer, J. Redemann, S. A. Ramirez, J.-H. Yee, W. H. Swartz, C. R. Trepte, L. W. Thomason, M. C. Pitts, M. A. Avery, C. E. Randall, J. D. Lumpe, R. M. Bevilacqua, M. Bittner, T. Erbertseder, R. D. McPeters, R. E. Shetter, E. V. Browell, J. B. Kerr, and K. Lamb

This paper uses a Chappuis-band method (**Fig. L2**) to retrieve ozone from AATS. Before and after SOLVE II, AATS retrievals were tested by comparisons to Dobson and Brewer results (**Fig. L4**), yielding differences of a few DU (~1-2%) for airmass >6 (i.e.; solar zenith angles >~81°, angles typical of the DC-8 Arctic flights).

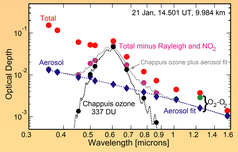

Fig. L2. Ozone retrieval methodology applied to optical depth spectrum measured by AATS-14 on 21 Jan 2003. The optimal least squares fit yields an ozone column content of 337 DU.

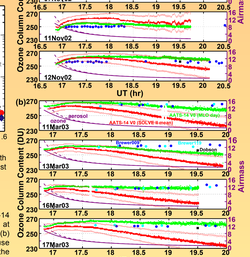

Fig. L4. Ozone column content retrieved from AATS-14 measurements after surface-based instrument calibration at Mauna Loa Observatory, Hawaii in (a) November 2002 and (b) March 2003. Green points show retrievals that use exoatmospheric detector voltages (V_{02}) calculated from the Langley plot analysis for the particular day; thick red points use the mean V_0 values from the November and March data sets, and thin red points give the +-one standard deviation uncertainty returned by the fitting procedure. Coincident Brewer (blue and cyan) and Dobson (black) spectrometer ozone retrievals are also shown. Aerosol and ozone airmass values are plotted in purple.

Comparisons of AATS to satellite solar occultation sensors during SOLVE II (**Fig. L5**) yielded POAM III-AATS differences with mean -2.6% and RMS 3%; SAGE III-AATS differences had mean 3.1% and RMS 7%.

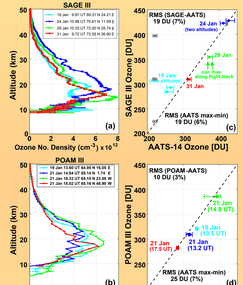

Fig. L5. SAGE III (a) and POAM III (b) ozone profiles; comparison of columnar ozone measured by (c) SAGE III and AATS-14 and (d) POAM III and AATS-14. Bars represent minimum and maximum AATS-14 retrievals along the DC-8 flight track.

Comparisons of AATS line-of-sight (LOS) ozone with the other DC-8 solar occultation sensors (**Fig. L6**) yielded RMS differences of 0.5% for GAMS-AATS and 2.3% for DIAS-AATS.

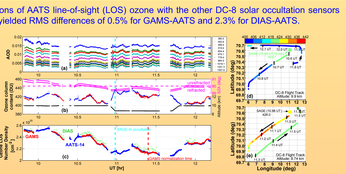

Fig. L6. Frames (a) and (b) show the variation in AOD and columnar ozone, respectively, measured by AATS-14 during the 24 Jan 2003 flight. AATS-14, DIAS, and GAMS retrievals of ozone number density along the line of sight (LOS) are plotted in (c). RMS differences are ~2.1% for AATS and DIAS, and ~0.5% for AATS and GAMS. In (d) and (e), the spatio-temporal variation in AATS-14 columnar ozone along the DC-8 flight track is shown for data acquired at flight altitudes of 9.9 km (10.6-10.9 UT and 11.8-12.2 UT) and 8.74 km (11.0-11.7 UT), respectively. Values are consistent with the integrated 10.98 UT SAGE III retrieval (color coded dot).

AATS retrievals during horizontal transects were compared with ozone columns from the satellite nadir viewers TOMS and GOME by increasing AATS values by the estimated ozone below the DC-8 (using climatology or DC-8 ozone profile measurements). Resultant AATS, TOMS, and GOME columns have RMS differences generally <10-15 DU (3-5%) for two flights (e.g., **Fig. L7**). For the third flight (**Fig. L9**), the AATS column latitudinal gradient was similar to that from TOMS and GOME, but some AATS column values exceed satellite values by up to 30 DU near the subtropical jet, probably because of variability unresolved by the satellite sensors.

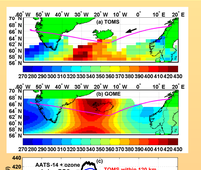

Fig. L7. Comparison of columnar ozone retrieved from AATS-14 measurements during an extended horizontal transect by the DC-8 on 21 January 2003. Contours of ozone column content were retrieved from (a) TOMS and (b) GOME measurements overplotted on the DC-8 flight track (magenta). Comparison of AATS-14 (gray) and DIAS (green) ozone above DC-8 altitude, and AATS-14 (black) with along-track GOME (blue) and near-track TOMS (red) total column ozone in (c). Solar zenith angle (dashed) and DC-8 altitude (solid) are shown in (d).

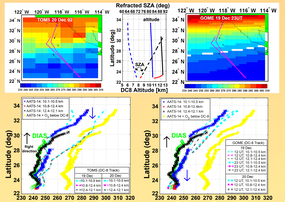

Fig. L9. Comparison of AATS and DIAS columnar ozone retrievals for DC-8 flight of 19-20 December 2002 with corresponding TOMS and GOME retrievals. The actual DC-8 flight track (magenta) is overplotted on contours of TOMS and GOME columnar ozone in the left and right upper frames; the upper middle frame shows the refracted SZA and DC-8 altitude during the southbound transit (blue), the climb from 10.8 km to 12.4 km altitude at the southernmost point (red), and the northbound transit (black). The same color scheme is used for the AATS-14 ozone retrievals shown in the lower frames. The yellow points show AATS ozone retrievals plus an estimated ozone amount below DC-8 altitude.

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Atmospheric Chemistry and Physics

Aerosol optical depth measurements by airborne sun photometer in SOLVE II: Comparisons to SAGE III, POAM III and airborne spectrometer measurements

P. Russell, J. Livingston, B. Schmid, J. Eilers, R. Kolyer, J. Redemann, S. Ramirez, J.-H. Yee,W. Swartz, R. Shetter, C. Trepte, A. Risley Jr., B.Wenny, J. Zawodny,W. Chu, M. Pitts, J. Lumpe, M. Fromm, C. Randall, K. Hoppel, and R. Bevilacqua

This paper presents AATS-14 results for multiwavelength transmission, AOD (vertical) and LOS AOT, including comparisons to SAGE III, POAM III and DIAS. For 6 DC-8 flights, DIAS-AATS differences in LOS AOT at wavelength λ=400 nm had mean -2.3% and RMS 7.7% (**Table R3, Fig. R13**).

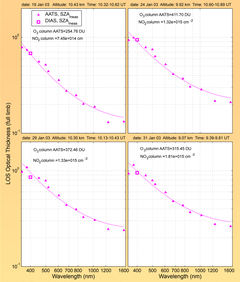


Fig. R13. DIAS LOS aerosol optical thickness (AOT) at SZA_{meas} compared to AATS LOS AOT at SZA_{meas} for 19, 24, 29, and 31 January 2003.

Table R3. DIAS-AATS differences in LOS aerosol OT (AOT) at wavelength 400 nm

UT Start	UT End	% difference (DIAS-AATS)/AATS
19-Jan	9.83	10.13	12.0
19-Jan	10.48	10.62	-4.0
21-Jan	14.61	16.25	-0.4
24-Jan	10.60	10.86	-0.2
24-Jan	11.22	11.49	8.0
29-Jan	10.27	10.43	-7.0
29-Jan	10.87	11.13	-7.0
29-Jan	11.48	11.64	-9.0
31-Jan	9.63	9.81	-5.0
2-Feb	12.46	12.80	-10.0
		mean	-2.3
		rms**	7.7

** $rms = \sqrt{\sum_{i=1}^{n} x_i^2 / n}$

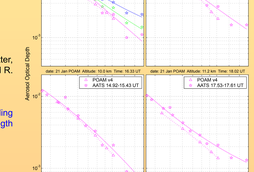


Fig. R15. Comparison of AATS-14 and POAM III/v4 AOD spectra for the 4 POAM III occultations on 19 and 21 January 2003.

AATS-satellite comparisons were possible only for λ >440 nm, because of signal depletion on the satellite full-limb LOS tangent at DC-8 altitudes (~9-11 km). AATS-POAM RMS differences in AOD ((POAM-AATS)/AATS) were ≤31% for wavelengths 440-1020 nm (**Fig. R15**). Corresponding SAGE-AATS RMS differences were ≤33% for λ <~755 nm, but 59% at 1020 nm and 66% at 1545 nm (**Fig. R8**).

The differences between the POAM-AATS and SAGE-AATS comparisons are consistent with differences between POAM III and SAGE III that persisted for several months including the SOLVE II period (**Fig. R17**). The very small stratospheric AOD values (typically <0.004 for λ >1000 nm) during SOLVE II added challenge to the comparisons, but do not explain all the differences.

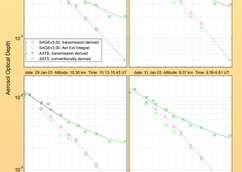


Fig. R8. Comparison of AOD spectra from AATS-14 and SAGE III measurements on 19, 24, 29, and 31 January 2004.

The larger differences (those >33%) are associated with transmission differences, rather than gas subtraction or conversion from LOS to vertical (**Figs. R8, R9, R11**).

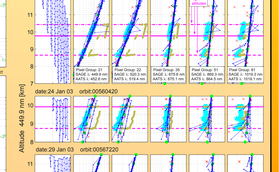


Fig. R9. SAGE III vertical profiles of transmission at representative wavelengths for the occultation events near the DC-8 on 19, 24, 29, and 31 January, with near-coincident AATS transmission values at the AATS measurement SZA_{meas}, and converted to apparent SZA=90°.

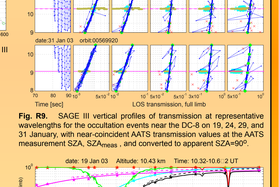


Fig. R11. Comparison of SAGE and AATS transmission, LOSOT, and OD, by components and totals, for 19 January 2003 at 10.43 km. All AATS results for T and LOSOT have been converted from SZA_{meas} to apparent SZA 90°.

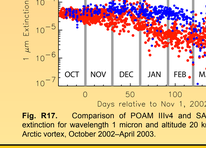
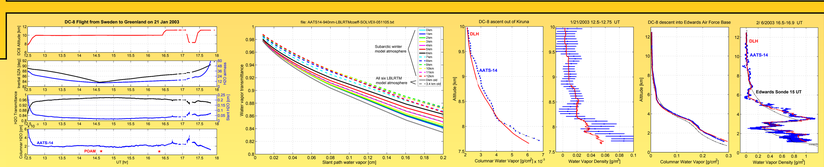


Fig. R17. Comparison of POAM III/v4 and SAGE III/v3.00 extinction for wavelength 1 micron and altitude 20 km inside the Arctic vortex, October 2002–April 2003.



Columnar water vapor is calculated from the AATS measurement in the channel centered at 940.6 nm. In particular, for an instantaneous voltage $V(t)$ measured in this channel at time t,

$$V(t) = \left(\frac{R_0}{R(t)}\right)^2 V_0 \exp\left[-\sum_i m_i(t)\tau_i^{other}(t)\right] T_{H_2O}(t),$$

where the quantity $R_0/R(t)$ is the ratio of the mean earth-sun distance to the instantaneous earth-sun distance, V_0 is the exo-atmospheric calibration voltage, $m_i(t)$ is the airmass factor (ratio of slant path to vertical optical depth or integrated number density) that is a function of vertical distribution of each attenuating species i (where i represents molecular scattering, aerosol extinction, or non-water vapor gas absorption), $\tau_i^{other}(t)$ is the optical depth for the i^{th} attenuating species other than water vapor, and $T_{H_2O}(t)$ is the water vapor transmittance.

For the AATS-14 measurements taken during SOLVE II, the radiative transfer code LBLRTM V9.2 was used to calculate water vapor transmittance as a function of water vapor slant path by assuming a subarctic winter model atmosphere and then varying the solar zenith angle and the altitude of the observed platform.

The calculated water vapor transmittance values were then modeled using a fitting function of the form,

$$T_{H_2O} = \exp[-aU^b],$$

where U is the slant path water vapor and the a and b are fitting coefficients. Columnar water vapor is calculated from the slant amount by dividing by an appropriate water vapor airmass factor. Water vapor density is derived by taking the derivative of a spline fit to the columnar water vapor profile retrieved during aircraft ascent or descent. Results are shown in the accompanying figures.

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Atmospheric Chemistry and Physics

Column ozone and aerosol optical properties retrieved from direct solar irradiance measurements during SOLVE II

W. H. Swartz, J.-H. Yee, R. E. Shetter, S. R. Hall, B. L. Lefer, J. M. Livingston, P. B. Russell, E. V. Browell, and M. A. Avery

This paper includes a scatter plot (**Fig. S6**) comparing DIAS and AATS LOS ozone retrievals for six DC-8 flights, yielding differences with mean -1.6% and RMS 2.1%.

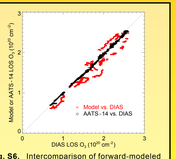
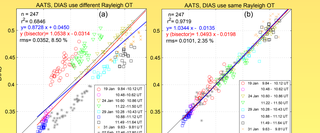


Fig. S6. Intercomparison of forward-modeled and AATS-14 retrieved LOS ozone with DIAS retrieved ozone for six flights, 19 January 2003 - 2 February 2003. Model LOS O_3 is computed from O_3 vertical profiles assembled from DC-8 DIAL, DC-8 in situ, and POAM III results.

Current and Future SOSST Work



Further analyses of the AATS-DIAS comparisons summarized in **Table R3** above produced the scatter plots at left. They show that a large fraction of the DIAS-AATS differences in LOS AOT in Table R3 and frame (a) is caused by DIAS and AATS using different ways to estimate Rayleigh LOS OT. When DIAS and AATS use the same Rayleigh LOS OT (frame (b) at left), the RMS difference in LOS AOT [(DIAS-AATS)/AATS] is reduced from 8.5% to 2.4 %.

Pitts et al. (2005, in preparation) provide detailed analyses of GAMS data, including further comparisons to AATS.

Not included in the above papers are AATS SOLVE II water vapor results and comparisons; examples are shown at right. Future SOSST work includes further AATS-DIAS aerosol comparisons, publication of water vapor results, and possible studies of satellite and aircraft retrieval algorithms and aerosol radiative effects.

ACRONYMS

AOD	Aerosol Optical Depth (vertical)	LOS	Line of Sight
AOT	Aerosol Optical Thickness	LOSOT	Line of Sight Optical Thickness
DIAL	Differential Absorption Lidar	POAM	Polar Ozone and Aerosol Measurement III
DIAS	Direct-beam Irradiance Airborne Spectrometer	RMS	Root-mean-square
DLH	Diode Laser Hygrometer	SAGE	Stratospheric Aerosol and Gas Experiment
GAMS	Gas and Aerosol Monitoring System	SOLVE II	SAGE III Ozone Loss and Validation Experiment
GOME	Global Ozone Monitoring Experiment	TOMS	Total Ozone Mapping Spectrometer