Solar Spectral Flux, Optical Depth, Water Vapor, and Ozone Measurements and Analyses in the ACE-Asia Spring 2001 Intensive Experiment

Peter Pilewskie, Co-PI
Atmospheric Physics Branch
Earth Science Division
NASA Ames Research Center
Moffett Field, CA 94035-1000
phone: 650-604-0746. fax: 650-604-3625
email: ppilewskie@mail.arc.nasa.gov

Philip B. Russell, Co-PI
Atmospheric Chemistry and Dynamics Branch
Earth Science Division
NASA Ames Research Center
Moffett Field, CA 94035-1000
phone: 650-604-5404. fax: 650-604-6779
email: prussell@mail.arc.nasa.gov

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LONG-TERM GOALS

This research was conducted as part of the Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia). ACE-Asia's goals are to determine and understand the properties and controlling factors of the aerosol in the anthropogenically modified atmosphere of Eastern Asia and the Northwest Pacific and to assess their relevance for radiative forcing of climate. ACE-Asia is one of a series of experiments devoted to the longer-term goal of reducing the overall uncertainty regarding aerosol effects on global and regional climates. Aerosol effects are currently the largest source of uncertainty in understanding past and present climates and in predicting the future climate.

OBJECTIVES

The objectives of this effort are to

1. Improve understanding of dust, other aerosol, and water vapor effects on radiative transfer, radiation budgets and climate in the East Asian/West Pacific region,

2. Test and improve the ability of satellite remote sensors to measure these constituents and their radiative effects,

3. Provide tests of closure with in situ measurements.

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14. ABSTRACT
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APPROACH

The research included two coordinated tasks. Task 1, SSFR Measurements and Analyses, was led by Co-PI Peter Pilewskie. In Task 1 the NASA Ames Radiation Group deployed a Solar Spectral Flux Radiometer (SSFR) on a Twin Otter aircraft during the ACE-Asia intensive experiment of Spring 2001. The SSFR has zenith and nadir viewing light collectors for measuring solar spectral upwelling and downwelling irradiance from 300 to 1700 nm at 10 nm resolution. SSFR data were used to determine the net solar radiative forcing of dust and other aerosols, to quantify the solar spectral radiative energy budget in the presence of elevated aerosol loading, and to support satellite algorithm validation.

Task 2, AATS Measurements and Analyses, was led by Co-PI Philip Russell. In Task 2, the NASA Ames Sunphotometer/Satellite Group deployed the 14-channel Ames Airborne Tracking Sunphotometer (AATS-14) on the Twin Otter and the 6-channel version, AATS-6, on the NCAR C-130. Each AATS measures transmission of the direct solar beam in narrow spectral channels. These transmissions are used to derive aerosol optical depth spectra, water vapor column amounts, and, when aerosol optical depth is small enough (<~0.03), ozone column amounts. Data from suitable vertical profiles can be differentiated vertically to yield aerosol extinction spectra and water vapor concentrations.

The SSFR and AATS measurements provide complementary information on atmospheric radiation and radiatively active constituents. This complementary information can be combined in integrated analyses to derive results not obtainable from either sensor alone. For example, combining SSFR-measured absorption (radiative flux divergence) with AATS-measured optical depth can yield the wavelength-dependent aerosol single-scattering albedo (ratio of scattering to extinction--see below).

WORK COMPLETED

SSFR and AATS-14 made measurements on 19 flights of the Twin Otter in the ACE-Asia Spring 2001 experiment. AATS-6 made measurements on 15 flights of the C-130. All flights were based at the Marine Corps Air Station in Iwakuni, Japan. The flights sampled a variety of aerosol conditions over the Yellow Sea, Sea of Japan, East China Sea, Japan, and Korea, including outflows from dust storms, urban-industrial pollution, biomass burning, and seasalt aerosols. The SSFR and AATS measurements were made in conjunction with in situ measurements by a wide variety of aerosol and trace gas sensors on each aircraft. Flights were coordinated with overpasses by a variety of satellites.

SSFR was calibrated for wavelength, absolute power, and angular response at NASA Ames before and after the ACE-Asia deployment. Some of this work was done in conjunction with the Ames Airborne Sensors Facility, which takes part in round robin calibration comparisons with NIST and the University of Arizona, and which also calibrates airborne simulators of satellite sensors, such as the MODIS Airborne Simulator (MAS). SSFR calibration was also checked repeatedly between flights using a LI-COR Field Calibrator.

AATS-6 and AATS-14 were calibrated at the Mauna Loa Observatory before and after the ACE-Asia deployment. Cross-checks of their relative calibration were made on the ground between flights and also in flight on two occasions.

The SSFR and AATS data sets are being analyzed and used in a variety of studies, some of which are illustrated by the results described below. The AATS ACE-Asia data have been archived and made available at http://geo.arc.nasa.gov/sgg/ACE-Asia/data_plots_login_page.html . Although ONR support for this effort was primarily for measurements and ends in FY02, analyses are being continued with non-ONR support, e.g., from NASA and NOAA.

RESULTS

Figure 1 shows an example of vertical profiles of multiwavelength aerosol optical depth (AOD) and extinction derived from AATS-14 measurements on the Twin Otter flight of April 17 2001. Measuring solar beam attenuation by an AATS on the same aircraft as in situ sensors allows an exact match in the aerosol layers described by the attenuation and in situ measurements. Such a match allows the best-defined comparison between attenuation and in situ results. One type of comparison is between AATS-measured layer AODs and those calculated from the combination of scattering measured by nephelometer and absorption measured by Particle Soot Absorption Photometer (PSAP). Preliminary ACE-Asia results obtained from a partial data set from both airborne platforms (Twin Otter and C-130) indicate that total layer AODs calculated from the nephelometer-PSAP combination are 20% - 40% less than those from AATS-6 or -14 measurements. These preliminary results are being further investigated by more extensive analyses of the complete Twin Otter and C-130 data sets. Results are described in papers being prepared for the special *J. Geophys. Res.* section on ACE-Asia.

Figure 2 shows an example result from a different type of ACE-Asia closure study, which compared aerosol extinction from AATS-14 with values calculated from Mie theory using measured size distributions and composition (used to determine the complex refractive indices). That study (Wang et al., 2002) analyzed data from four Twin Otter flights. It found that in the boundary layer, pollution layers, and free troposphere with no significant mineral dust present, aerosol extinction closure was achieved within the estimated uncertainties over the full range of wavelengths of AATS-14. Aerosol extinctions predicted from measured size distributions also reproduced the wavelength dependence derived from AATS-14 data. Considering all four flights, the best-fit lines yielded Predicted/Observed ratios in boundary and pollution layers of 0.97 ±0.24 and 1.07 ±0.08 at wavelength 525 nm, and 0.96 ±0.21 and 1.08 ±0.08 at wavelength 1059 nm, respectively. In free troposphere dust layers, aerosol extinctions predicted from the measured size distributions were generally less than those derived from the AATS-14 data; the Predicted/Observed ratios are 0.65 ±0.06 and 0.66 ±0 .05 at 525 nm and 1059 nm, respectively. A detailed analysis suggests that the discrepancy is likely a result of the lack of the knowledge of mineral dust shape, as well as variations in aerosol extinction derived from AATS-14 data when viewing through horizontally inhomogeneous layers. A more extensive study incorporating results from all 19 Twin Otter flights is described in a paper being prepared for the ACE-Asia special section of *J. Geophys. Res.*

Figures 3 and 4 show examples of results that combine SSFR and AATS measurements. Figure 3 shows spectra of absorption measured by SSFR, along with AOD measured simultaneously by AATS-14 on an ACE-Asia flight. Also shown are model calculations of absorption. The model calculations shown in Figure 3 assumed a wavelength-independent single scattering albedo (SSA), which clearly underestimates absorption for wavelengths <600 nm. Adjusting model SSA to produce a match between modeled and measured absorption yields the SSA values shown in Figure 4. A paper being prepared for the ACE-Asia section of *J. Geophys. Res.* includes the case shown here and others from ACE-Asia, along with comparisons to previous results for the wavelength-dependent SSA of various mineral dusts.

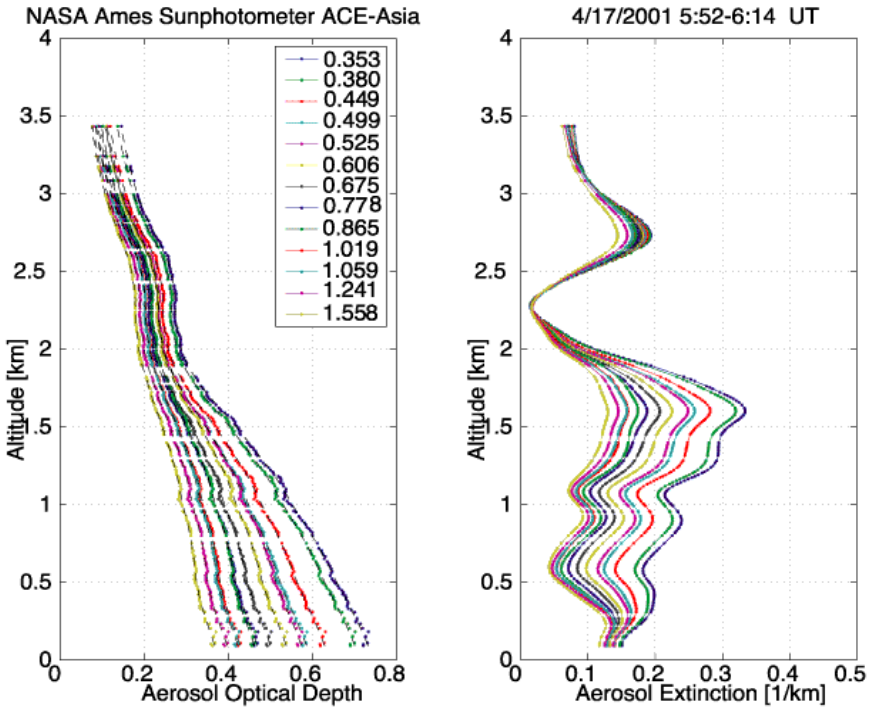

Figure 1. Left panel: Aerosol optical depth profiles at 13 wavelengths from 354 to 1558 nm calculated from AATS-14 measurements acquired during an aircraft ascent south of Korea on 17 April 2001 during ACE-Asia. Right panel: Corresponding aerosol extinction profiles derived by differentiating spline fits (dashed lines in left panel) to the optical depth profiles.

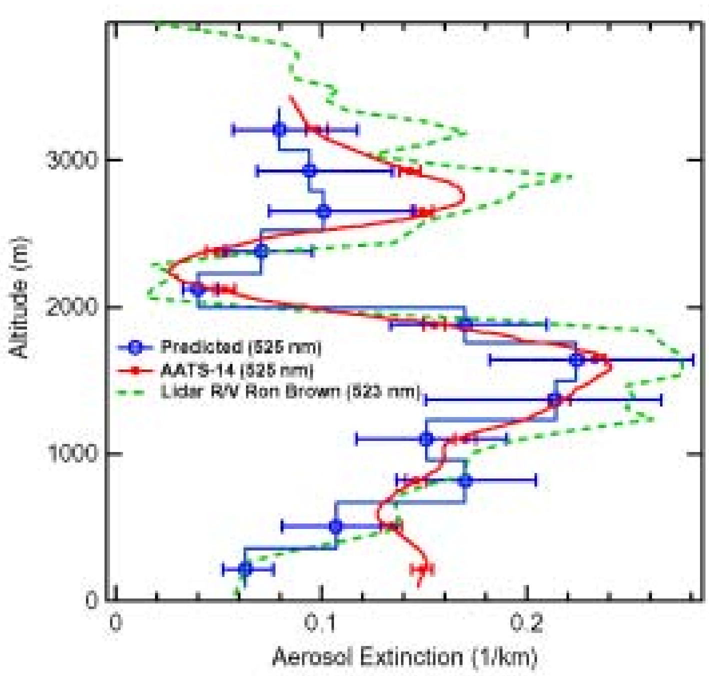

Figure 2. Comparison of aerosol extinction derived from AATS-14 measurement, aerosol size distributions, and lidar measurements on R/V Ron Brown during the ascent shown in Figure 1 (Wang et al., 2002a).

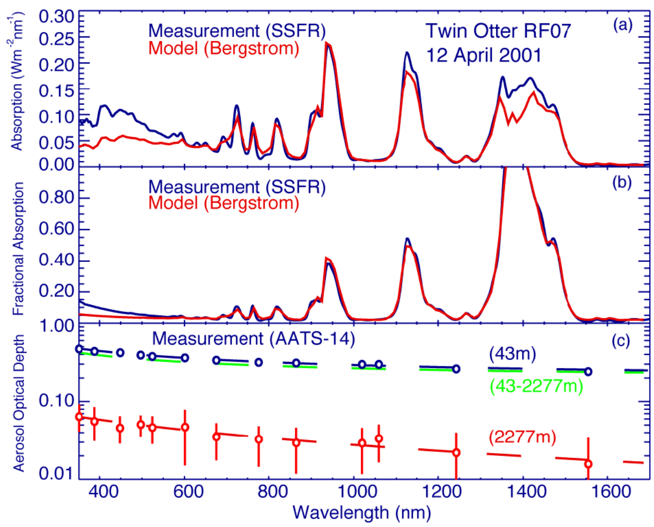

Figure 3. (a) Measured (blue) and modeled (red) absorption spectra for the ACE-Asia profile flown on Twin Otter Flight RF07, 12 April 2001. (b) Corresponding spectra of fractional absorption. (c) AOD spectra measured simultaneously on the same aircraft.

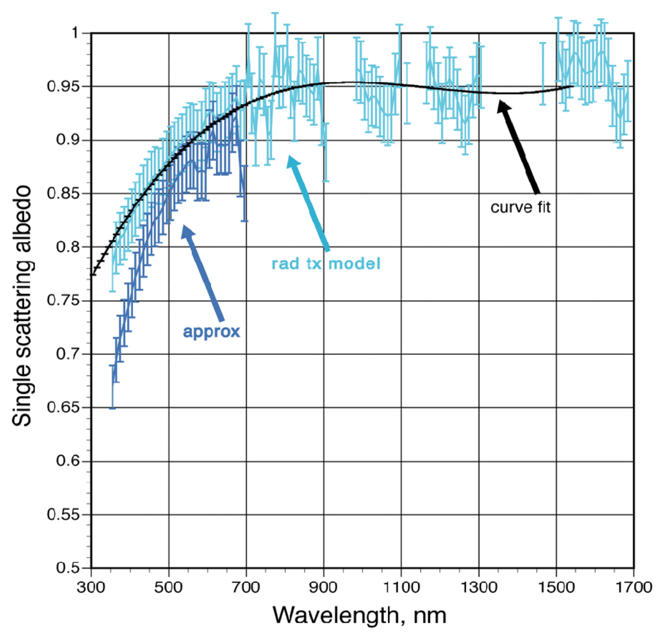

Figure 4. Aerosol single scattering albedo spectra derived from the measured flux and AOD spectra in Figure 3.

IMPACT/APPLICATIONS

As mentioned above, analyses of the ACE-Asia SSFR and AATS measurements are continuing, and the results shown in the preceding section are part of larger bodies of work described in papers being prepared for publications such as the ACE-Asia special section of *J. Geophys. Res*. These studies are helping to answer major outstanding questions about the properties and effects of Asian aerosols. Their current and future use is helping to reduce uncertainties about the role of aerosols in determining the climate.

TRANSITIONS

The AATS ACE-Asia data, archived at http://geo.arc.nasa.gov/sgg/ACE-Asia/data_plots_login_page.html , are being accessed by many users and applied in a variety of studies, including validation of optical depths predicted by chemical transport models and retrieved from satellite sensors.

RELATED PROJECTS

Dr. Mian Chin of Georgia Tech and NASA Goddard uses the GOCART model (http://code916.gsfc.nasa.gov/People/Chin/results/aot.html) to predict aerosol fields from data on sources, transport, and chemical transformations. She is using the archived AATS data to test GOCART predictions of aerosol optical depth.

Dr. Ralph Kahn of Jet Propulsion Laboratory is responsible for aerosol data products derived from the Multi-angle Imaging Spectro-Radiometer (MISR, http://www-misr.jpl.nasa.gov/mission/valid.html). He is using AATS archived data to validate MISR aerosol retrievals.

Dr. Christina Hsu of NASA/Goddard Space Flight Center has developed a new algorithm to retrieve 4-wavelength aerosol optical depth from the SeaWiFS satellite sensor (http://seawifs.gsfc.nasa.gov/SEAWIFS/BACKGROUND/). She is using ACE-Asia AATS data to validate these retrievals.

PUBLICATIONS

Wang, J., R.C.Flagan, J.H.Seinfeld, H.H.Jonsson, D.R.Collins, P.B.Russell, B.Schmid, J.Redemann, J.M.Livingston, S.Gao, D.A.Hegg, E.J.Welton, and D.Bates, Clear-column radiative closure during ACE-Asia: Comparison of multiwavelength extinction derived from particle size and composition with results from sunphotometry, *J. Geophys. Res.,* in press, 2002.