SRI International

Final Report • 31 December 1997

MEASUREMENT AND ANALYSIS OF ATMOSPHERIC SPECTRAL OPTICAL DEPTHS WITH NASA AMES AIRBORNE SUNPHOTOMETERS DURING TARFOX AND ACE-2

SRI Project 7325

Prepared by:

John M. Livingston, Principal Investigator
Senior Research Meteorologist
Applied Physical Sciences Laboratory

Phillip B. Russell, Technical Officer
NASA Ames Research Center

Prepared for:

NASA Ames Research Center
P.O. Box 1000
Moffett Field, California 94035-1000

NASA Ames Cooperative Agreement NCC 2-938

Approved:

Eric M. Pearson, Co-Director
Applied Physical Sciences Laboratory

333 Ravenswood Avenue • Menlo Park, CA 94025-3493 • (415) 326-6200 • FAX: (415) 326-5512 • Telex: 334486

1 INTRODUCTION

Aerosol particles emitted into the atmosphere either by natural processes or by man are widely recognized as having the potential to affect significantly the radiation balance of the earth-atmosphere system in either of two ways: directly, by interacting with solar and terrestrial radiation, or indirectly, by altering cloud microphysics, albedo, and precipitation. Recent estimates of the global, annually averaged direct and indirect radiative forcing by anthropogenic aerosols have been comparable in magnitude but opposite in sign to corresponding estimates of the forcing due to the increase in greenhouse gases during the past century. However, the uncertainties associated with these estimates are large, and they have constituted one of the largest sources of uncertainty in validating current climate models and in predicting future climate.

In an attempt to reduce the uncertainties associated with quantifying the magnitude of the aerosol net radiative forcing effect, during the past two years the International Global Atmospheric Chemistry (IGAC) Project endorsed three separate field projects to measure simultaneously the radiative effects of anthropogenic and natural atmospheric aerosol particles and their associated physical and chemical properties. Government and contractor scientists from the NASA Ames Research Center participated in the final two of these three field projects: the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) and the North Atlantic Regional Aerosol Characterization Experiment (ACE-2).

TARFOX was conducted out of Wallops Island, Virginia, during summer 1996. Its focus was on characterizing the chemical and physical properties and radiative effects of anthropogenic aerosols transported from the eastern seaboard of the United States over the western North Atlantic Ocean. During TARFOX, NASA Ames operated its six-channel airborne automatic tracking sunphotometer (AATS-6) aboard the University of Washington C-131A aircraft for the entire field campaign. During the final week of the project NASA Ames operated its newly developed 14-channel airborne tracking sunphotometer (AATS-14) aboard the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) modified Cessna aircraft (the Pelican).

ACE-2 took place during summer 1997, with aircraft based on the Canary Island of Tenerife. Separate ground-based instruments were located on the island of Madeira, on the European mainland in Portugal, and on a Ukrainian research ship, the R/V Vodyanitsky, that sailed from the port of Sagres, Portugal. The focus of ACE-2 was on characterizing the chemical and physical properties and radiative effects of anthropogenic aerosols transported from the European continent and mineral dust transported from the African continent over the subtropical Northeastern Atlantic Ocean. During ACE-2, the NASA Ames AATS-14 was flown aboard the Pelican, and the NASA Ames AATS-6 and two Ames handheld Microtops sunphotometers manufactured by Solar Light Company, Inc., were operated onboard the R/V Vodyanitsky.

2 SUMMARY OF ACCOMPLISHMENTS

This cooperative agreement provided support for John Livingston of SRI International to contribute to the research activities undertaken by the NASA Ames sunphotometer science team both in the development of a new multiwavelength airborne sunphotometer (AATS-14) and in the acquisition and analysis of measurements during TARFOX and ACE-2. A list of the conference presentations and journal publications supported by this contract is presented in Section 3. In accordance with the scope of work of this contract, the following tasks were undertaken and completed during the course of the contract:

- Participation in the design and development of the 14-channel Ames Airborne Tracking Sunphotometer (AATS-14), including the development and implementation of Visual Basic software for real-time data processing and display and post-acquisition data reduction and analysis.
- Operation of the six-channel Ames Airborne Tracking Sunphotometer (AATS-6) aboard the University of Washington C-131A during TARFOX and in-field analysis and presentation of data acquired with the AATS-6.
- Post-mission analysis of data acquired during TARFOX with the AATS-6 and the AATS-14. Preliminary optical depth results were presented at the 1997 American Geophysical Union Spring Meeting (Livingston and Russell, 1997). Final results will appear in a TARFOX Special Section of the *Journal of Geophysical Research—Climate and Atmospheric Physics* in an article by Russell et al. (1998). Optical depths derived from the AATS-6 measurements were used in a chemical apportionment study by Hegg et al. (1997). Additionally, the AATS-6 optical depth data are being used by other investigators in a variety of TARFOX-related studies, and the results are expected to appear in several articles now in preparation for submittal to one or more TARFOX Special Sections of the *Journal of Geophysical Research.* (e.g., Durkee et al., 1998).
- Pre-TARFOX calibration of the AATS-6 at Mauna Loa Observatory in May 1996, and post-TARFOX calibration of the AATS-6 and AATS-14 at Zugspitze, Germany in October 1996, including analyses of all data sets. Results of the analyses are presented in Tables 1 and 2, including the results for the May 1996 calibration that were listed previously in the SRI Interim Technical Report No. 1 (October 1996).
- Analysis of AATS-14 airborne calibration data acquired on 17 November 1996 during a late afternoon Pelican flight over the central California coast. These results are also shown in Table 2.

- Operator training, instrument preparation, field coordination, and analysis of shipboard measurements of aerosol optical depth with the AATS-6 during ACE-2. Preliminary results were presented at the 1997 American Geophysical Union Fall Meeting (Livingston et al., 1997).
- Coordination of data acquisition with the AATS-14 aboard the Pelican during ACE-2 and in-field preliminary data analysis and presentation.
- Calibration of the AATS-6 and AATS-14 in April/May 1997 at Mauna Loa prior to ACE-2, and post-mission calibration of the AATS-6 at Mauna Loa in August 1997. Results for the AATS-6 are included in Table 1.

TABLE 1

ZERO-AIRMASS INTERCEPT VOLTAGES FOR THE SIX-CHANNEL NASA AMES AIRBORNE TRACKING SUNPHOTOMETER (AATS-6)

	CENTER WAVELENGTH (nm)				
DATE	**380.1**	**450.7**	**525.3**	**863.9 / 862.0***	**1020.7**
April 1994[A1]	6.219 ± 0.3%	5.290 ± 0.7%	7.984 ± 0.7%	*7.924 ± 0.8%	7.027 ± 0.8%
November 1994[H1]	5.888 ± 0.5%	5.235 ± 0.4%	7.900 ± 0.3%	*7.945 ± 0.7%	7.018 ± 0.8%
October 1995[A2]	5.663 ± 0.5%	5.137 ± 0.5%	7.751 ± 0.2%	*8.225 ± 0.3%	7.004 ± 0.3%
May 1996[H2]	5.556 ± 0.5%	5.213 ± 0.2%	7.689 ± 0.3%	6.681 ± 0.1%	6.967 ± 0.4%
October 1996[G]	5.402 ± 0.2%	5.227 ± 0.2%	7.567 ± 0.4%	6.595 ± 0.5%	6.987 ± 0.3%
April/May 1997[H3]	5.380 ± 0.8%	5.211 ± 0.2%	7.533 ± 0.6%	6.552 ± 0.2%	6.988 ± 0.3%
August 1997[H4]	5.311 ± 0.4%	5.179 ± 0.5%	7.374 ± 0.3%	6.467 ± 0.2%	6.972 ± 0.2%

[A1] Mt. Lemmon Steward Observatory, Tucson, Arizona. Includes data from three days: 25, 28, 29 April 1994.

[H1] Mauna Loa Observatory, Hawaii. Includes data from seven days: 3, 6, 7, 8, 9, 14, 19 November 1994.

[A2] Mt. Lemmon Steward Observatory, Tucson, Arizona. Includes data from five days: 17–21 October 1995.

[H2] Mauna Loa Observatory, Hawaii. Includes data from six days: 21–26 May 1996.

[G] Schneefernerhaus (Zugspitze), Germany. Includes data from two events: 24 October sunrise and sunset, 1996.

[H3] Mauna Loa Observatory, Hawaii. Includes data from five days: 25, 27–29 April, 1 May 1997.

[H4] Mauna Loa Observatory, Hawaii. Includes data from five days: 27–31 August 1997.

TABLE 2

NASA AMES 14-CHANNEL AIRBORNE TRACKING SUNPHOTOMETER (AATS-14) CALIBRATION VOLTAGES FROM GERMANY (ZUGSPITZE, OCTOBER 1996) AND FROM CALIFORNIA (PELICAN FLIGHT, NOVEMBER 1996)

	WAVELENGTH (nm)													
	380.3	448.3	453.0	499.4	524.7	605.4	666.8	711.8	778.5	864.4	1018.7	1557.5	AIRMASS	OZONE
24 Oct sunrise	8.089	6.778	7.981	7.773	7.751	8.086	7.611	7.599	7.327	7.420	7.177	4.152	2.5 – 6.5	250
24 Oct sunset	8.028	6.725	7.928	7.717	7.687	8.002	7.553	7.571	7.308	7.363	7.194	4.103	2.2 – 6.3	250
7 Nov sunset	8.008	6.742	7.801	7.615	7.549	7.766	7.412	7.473	7.203	7.382	7.091	4.163	2.2 – 6.5	270
mean (10/24)	8.058	6.752	7.955	7.745	7.719	8.044	7.582	7.585	7.318	7.391	7.186	4.127		
sd/mean	0.54%	0.56%	0.47%	0.51%	0.58%	0.75%	0.54%	0.27%	0.18%	0.54%	0.16%	0.85%		
mean (all)	8.042	6.748	7.903	7.702	7.662	7.951	7.525	7.548	7.279	7.388	7.154	4.139		
sd/mean	0.52%	0.40%	1.17%	1.04%	1.34%	2.09%	1.36%	0.88%	0.92%	0.39%	0.77%	0.78%		

Rayleigh scattering (i.e., uniformly mixed gas) airmass values were calculated assuming mid-latitude winter and mid-latitude summer molecular density profiles (MODTRAN 3) for Germany and for California data, respectively. For Germany measurements, the lidar aerosol backscatter profile measured at Garmisch 1914–1953 local time on 24 October (Jaeger, personal communication) was used to calculate aerosol airmasses; for California data, the aerosol airmasses were assumed equal to the uniformly distributed gas values. Ozone airmass values were calculated using the 1976 U. S. Standard Atmosphere ozone vertical distribution. Nitrogen dioxide airmass values were assumed equal to the uniformly mixed gas values.

3 CONFERENCE PRESENTATIONS AND JOURNAL PUBLICATIONS

Durkee, P. A., B. B. Brown, K. E. Nielsen, P. B. Russell, and J. Livingston, Aerosol optical properties from NOAA AVHRR and GOES-9 measurements during TARFOX, Invited Paper A42D-03, 1997 Spring Meeting of the American Geophysical Union, Baltimore, MD, May 27–30, 1997, *EOS Trans. Amer. Geophys. Union*, **78**, S87, 1997.

Durkee, P. A. B. B. Brown, K. E. Nielsen, P. B. Russell, J. Livingston, P. Hobbs, and P. Hignett, Aerosol optical properties from NOAA AVHRR and GOES-9 measurements during TARFOX, Manuscript to be submitted to TARFOX Special Issue of *J. Geophys. Res.*, 1998.

Hegg, D. A., J. Livingston, P. V. Hobbs, T. Novakov, and P. B. Russell, Chemical apportionment of aerosol column optical depth off the Mid-Atlantic coast of the United States, Invited Paper A41C-08, 1997 Spring Meeting of the American Geophysical Union, Baltimore, MD, May 27–30, 1997, *EOS Trans. Amer. Geophys. Union*, **78**, S82, 1997.

Hegg., D. A., J. Livingston, P. V. Hobbs, T. Novakov, P. Russell, Chemical apportionment of aerosol column optical depth off the mid-Atlantic Coast of the United States, *J. Geophys. Res.*, **101**, 25,293-25,303, 1997.

Livingston, J. M., and P. B. Russell, Aerosol optical depth spectra, vertical profiles, and horizontal transects derived from TARFOX airborne sunphotometer measurements, Poster A51B-08, 1997 Spring Meeting of the American Geophysical Union, Baltimore, MD, May 27–30, 1997, *EOS Trans. Amer. Geophys. Union*, **78**, S92, 1997.

Livingston, J. M., V. Kapustin, B. Schmid, P. B. Russell, P. A. Durkee, T. S. Bates, P. K. Quinn, and V. Freudenthaler, Shipboard sunphotometer measurements of aerosol optical depth spectra obtained during ACE-2, Paper A31D-09, 1997 Fall Meeting of the American Geophysical Union, San Francisco, CA, December 8-12, 1997, *EOS Trans. Amer. Geophys. Union*, **78**, F97–98, 1997.

Russell, P., J. Livingston, D. Hegg, P. Hobbs, T. Novakov, and J. Wong, Direct aerosol radiative forcing off the U.S. Mid-Atlantic coast: Calculations from sunphotometer and in situ measurements in TARFOX, Paper A42D-04, 1997 Spring Meeting of the American Geophysical Union, Baltimore, MD, May 27-30, 1997, *EOS Trans. Amer. Geophys. Union*, **78**, S87–88, 1997.

Russell, P. B., J. M. Livingston, P. Hignett, S. Kinne, J. Wong, P. Durkee, and P. V. Hobbs, Direct aerosol radiative forcing off the US Mid-Atlantic coast: Comparison of values calculated from sunphotometer and in situ data with those measured by airborne pyranometer, Manuscript to be submitted to TARFOX Special Issue of *J. Geophys. Res.*, 1998.

Russell, P. B., P. Hignett, L. L. Stowe, J. M. Livingston, S. Kinne, and J. Wong, Direct aerosol radiative forcing: Calculations and measurements from the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX), Proceedings of the Air and Waste Management Association & American Geophysical Union Specialty Conference on Visual Air Quality, Aerosols, and Global Radiation Balance, September 9–12, 1997, Bartlett, New Hampshire.

Russell, P. B., P. V. Hobbs, and L. L. Stowe, An overview of the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX), Proceedings of the Air and Waste Management Association & American Geophysical Union Specialty Conference on Visual Air Quality, Aerosols, and Global Radiation Balance, September 9–12, 1997, Bartlett, New Hampshire.

Schmid, B., J. M. Livingston, P. B. Russell, and P. A. Durkee, Three dimensional measurements of lower tropospheric aerosol optical depth spectra and water vapor amounts during ACE-2 by means of airborne sunphotometry, Paper A31D-08, 1997 Fall Meeting of the American Geophysical Union, San Francisco, CA, December 8–12, 1997, *EOS Trans. Amer. Geophys. Union*, **78**, F97, 1997.