

Clear Column Closure Studies of Urban-Marine and Mineral-Dust Aerosols Using Aircraft, Ship, Satellite, and Ground-Based Measurements in ACE-2

B. Schmid

*Bay Area Environmental Research Institute
San Francisco, California*

P. B. Russell

*National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California*

J. M. Livingston

*SRI International
Menlo Park, California*

S. Gasso and D. A. Hegg

*University of Washington
Seattle, Washington*

D. R. Collins, R. C. Flanagan, and J. H. Seinfeld

*California Institute of Technology
Pasadena, California*

E. Ostrom and K. J. Noone

*Stockholm University
Stockholm, Sweden*

P. A. Durkee and H. H. Jonsson

*Naval Postgraduate School
Monterey, California*

E. J. Welton, K. J. Voss, and H. R. Gordon

*University of Miami
Miami, Florida*

P. Formenti and M. O. Andreae

*Max Planck Institute for Chemistry
Mainz, Germany*

V. N. Kapustin

*University of Hawaii
Honolulu, Hawaii*

T. S. Bates and P. K. Quinn

*National Oceanic and Atmospheric
Administration-Pacific Marine
Environmental Laboratory
Seattle, Washington*

Introduction

As part of the second Aerosol Characterization Experiment (ACE-2), European urban-marine and African mineral-dust aerosols were measured aboard the Pelican aircraft, the Research Vessel (R/V) Vodyanitskiy, from the ground and from satellites (Heintzenberg and Russell 1999).

Measurements

Among other quantities, the Pelican measured aerosol optical depth and extinction spectra, water vapor column contents and vertical profiles using a 14-channel sunphotometer (Schmid et al. 1999); aerosol absorption coefficient and 3-wavelength scattering coefficients using an absorption photometer and

nephelometer (Öström and Noone 1999); aerosol scattering humidification factors using a passive humidigraph (Gassó et al. 1999); and aerosol size distributions using a differential mobility analyzer and two optical particle sizers (Collins et al. 1999).

The R/V Vodyanitskiy measured various atmospheric parameters, including aerosol optical depth spectra and water vapor column contents using a six-channel tracking sunphotometer (Livingston et al. 1999), plus aerosol size distributions and chemical compositions using the National Oceanic and Atmospheric Administration-Pacific Marine Environmental Laboratory (NOAA-PMEL) shipboard suite (Quinn et al. 1996; 1999), and aerosol extinction profiles using a lidar. Ground-based measurements included aerosol optical depth spectra (Smirnov et al. 1998, Formenti et al. 1999) and aerosol extinction profiles from a lidar (Welton et al. 1999).

The advanced very high resolution radiometer (AVHRR) instruments aboard the NOAA-12 and NOAA-14 satellites measured upward-scattered radiances from which 2-wavelength aerosol optical depths have been derived (Durkee et al. 1999).

Results

A variety of comparisons between properties measured by different techniques or derived from other measurements using models have been carried out (items denoted by * are comparisons where results are not available yet):

- Optical depth spectra
 - Measured by sunphotometer (Figure 1, Figure 2),
 - Derived by integrating vertical profiles of humidified scattering coefficient and absorption coefficient
 - Derived by integrating vertical profiles of size distribution using hygroscopic growth factors and model refractive index spectra (combined according to internal and external mixing models)
 - Derived from AVHRR radiances (Figure 2)
- Extinction spectra
 - Derived by vertically differentiating sunphotometer optical depth spectra (Figure 1),
 - Derived from in situ measurements of scattering coefficient, absorption coefficient, and humidification factor,
 - Derived from in situ measurements of size distribution, hygroscopic growth factors, and model refractive index spectra
- Particle size distributions
 - Measured in situ,
 - Derived by inverting optical depth or extinction spectra,
 - Derived from AVHRR spectral radiance ratios using the bimodal model employed in retrieving optical depths*
- Single-scatter albedo spectra
 - Calculated from measured size distributions and model refractive index spectra, using various internal and external mixing models
 - Derived from measured aerosol absorption and scattering coefficients
 - Used in retrieving optical depths from AVHRR spectral radiances

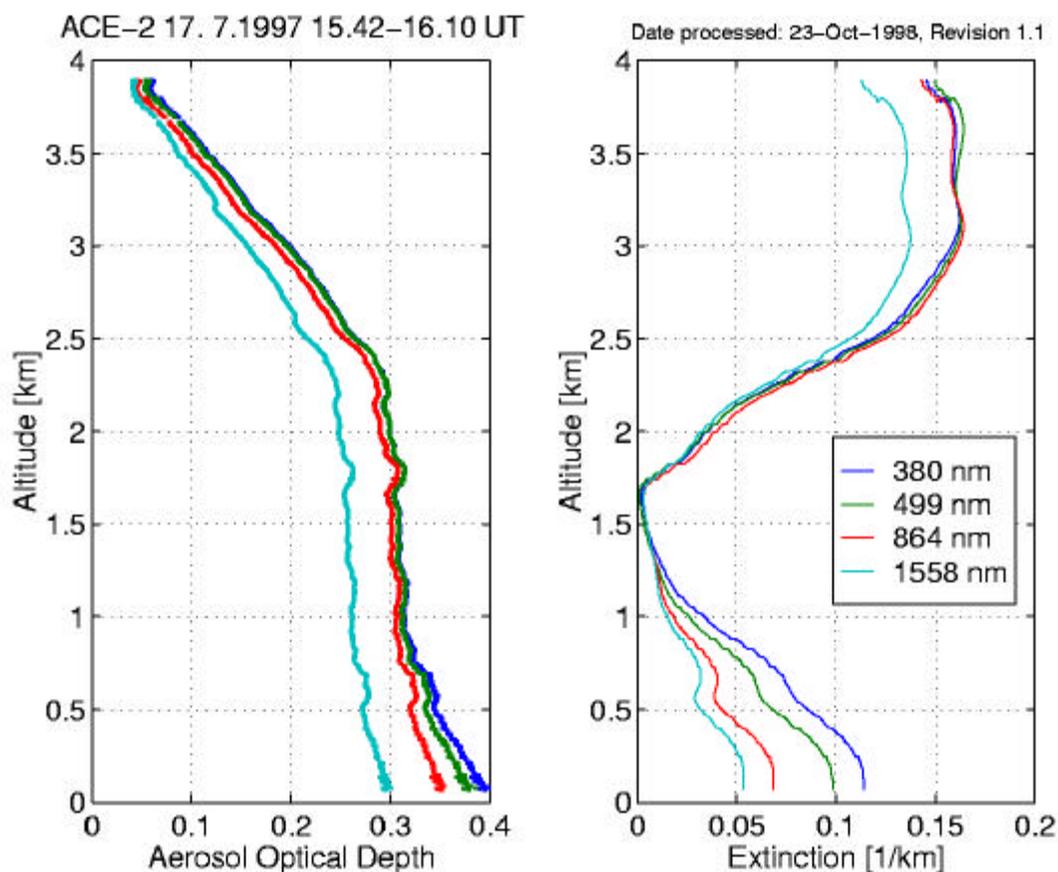


Figure 1. Left panel: Profiles of aerosol optical depth at four selected AATS-14 wavelengths measured in ACE-2 south of the coast of Tenerife. Right panel: Aerosol extinction profiles derived by differentiating the profiles in the left panel. The marine boundary layer and an elevated Sahara dust layer can be characterized.

- Scattering phase functions
 - Calculated from measured size distributions and model refractive index spectra, using various internal and external mixing models, including possible shape effects
 - Calculated as above, but using size distributions retrieved from optical depth or extinction spectra*
 - Used in retrieving optical depths from AVHRR spectral radiances*
- Water vapor column contents
 - Derived from sunphotometer transmission spectra
 - Derived from satellite-measured radiances*
 - Derived by integrating in situ water vapor profiles

Initial comparisons have shown that achieving closure, or mutual consistency, depends critically on the methods used to account for aerosol hygroscopic growth, scattering humidification factors, and the particle-size cutoffs of different sampling instruments.

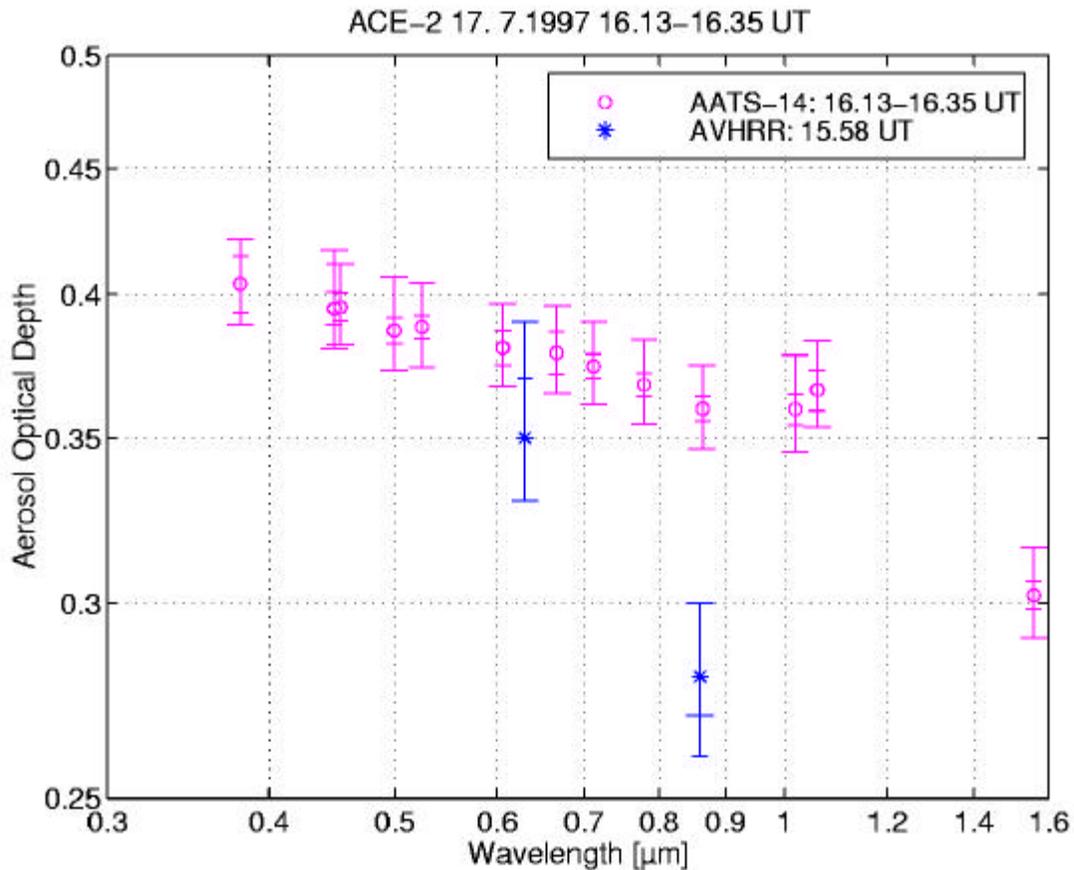


Figure 2. Comparison of aerosol optical depth as retrieved from AVHRR radiances (Durkee et al. 1999) and measured by Ames Airborne Tracking Sunphotometer (AATS)-14. The elevated dust layer shown in Figure 1 is responsible for the disagreement, especially in the AVHRR 860-nm channel. In the absence of such dust layers, AVHRR and AATS-14 values typically agree within error bars (Durkee et al. 1999; Livingston et al. 1999).

References

Collins, D. R., H. H. Jonsson, R. C. Flagan, J. H. Seinfeld, K. J. Noone, E. Öström, D. A. Hegg, S. Gassó, P. B. Russell, J. M. Livingston, B. Schmid, and L. M. Russell, 1999: In situ aerosol size distributions and clear column radiative closure during ACE-2. *Tellus*. Submitted

Durkee, P. A., K. E. Nielsen, P. B. Russell, B. Schmid, J. M. Livingston, D. Collins, R. D. Flagan, J. H. Seinfeld, K. J. Noone, E. Ostrom, S. Gassó, D. Hegg, T. S. Bates, and P. K. Quinn, 1999: Regional aerosol properties from satellite observations: ACE-1, TARFOX and ACE-2 results. *Tellus*. Submitted.

Formenti, P., M. O. Andreae, and J. Lelieveld, 1999: Measurements of aerosol optical depth in the North Atlantic free troposphere: results from ACE-2. *Tellus*. Submitted.

Gassó, S., D. A. Hegg, K. Noone, D. S. Covert, B. Schmid, P. B. Russell, J. M. Livingston, P. A. Durkee, and H. Jonsson, 1999: Influence of humidity on the aerosol scattering coefficient and its effect on the upwelling radiance during ACE2. *Tellus*. Submitted.

Heintzenberg J., and P. B. Russell, 1999: An Overview of the ACE 2 Clear Sky Column Closure Experiment (CLEARCOLUMN). *Tellus*. Submitted.

Livingston, J. M., V. Kapustin, B. Schmid, P. B. Russell, P. A. Durkee, T. Bates, and P. K. Quinn, 1999: Shipboard sunphotometer measurements of aerosol optical depth spectra during ACE-2. *Tellus*. Submitted.

Öström, E., and K. J. Noone, 1999: Vertical profiles of aerosol scattering and absorption measured in situ during the North Atlantic Aerosol Characterization Experiment. *Tellus*. Submitted.

Quinn, P. K., D. J. Coffman, T. S. Bates, and D. S. Covert, 1999: Chemical and optical properties of ACE 2 aerosol. *Tellus*. Submitted.

Quinn, P. K., V. N. Kapustin, T. S. Bates, and D. S. Covert, 1996: Chemical and optical properties of marine boundary layer aerosol particles of the mid-Pacific in relation to sources and meteorological transport. *J. Geophys. Res.*, **101**, 6931-6951.

Schmid, B., J. M. Livingston, P. B. Russell, P. A. Durkee, H. H. Jonsson, D. R. Collins, R. C. Flagan, J. H. Seinfeld, S. Gassó, D. A. Hegg, E. Öström, K. J. Noone, E. J. Welton, K. Voss, H. R. Gordon, P. Formenti, and M. O. Andreae, 1999: Clear sky closure studies of lower tropospheric aerosol and water vapor during ACE-2 using airborne sunphotometer, airborne in-situ, space-borne, and ground-based measurements. *Tellus*. Submitted.

Smirnov, A., B. N. Holben, I. Slutsker, E. J. Welton, and P. Formenti, 1998: Optical properties of Saharan dust during ACE-2. *J. Geophys. Res.*, **103**, 28,079-28,092.

Welton, E. J., K. J. Voss, H. R. Gordon, H. Maring, A. Smirnov, B. Holben, B. Schmid, J. M. Livingston, P. B. Russell, P. A. Durkee, P. Formenti, and M. O. Andreae, 1999: Ground-based lidar measurements of aerosols during ACE-2: Instrument description, results, and comparisons with other ground-based and airborne measurements. *Tellus*. Submitted.