THIRD ANNUAL PROGRESS REPORT FOR NASA GRANT TO UNIVERSITY OF WASHINGTON ENTITLED "UTILIZATION OF THE UNIVERSITY OF WASHINGTON'S AIRBORNE MEASUREMENTS FOR STUDIES OF THE RADIATIVE EFFECTS OF AEROSOLS ON THE EARTH'S CLIMATE" (NAS5-7675) FOR THE PERIOD 9/1/00-8/31/01.

PRINCIPAL INVESTIGATOR: PROFESSOR PETER V. HOBBS

1. Progress Report for 3rd Year

During the past year work under this grant has focussed on the following:

a) Continuing analyses of the large quantities of airborne data on atmospheric aerosol collected by our group over the past several years.

b) Preparation and submission for publication of six manuscripts, including three for the special GACP issue of *J. Atmos. Sci.* (see Section 3 for listing). These papers described the results of airborne aerosol studies carried out in the Arctic, over the Pacific and Atlantic Oceans, in the USA, and in Africa.

c) Initial reduction and analysis of aerosol measurements collected in thirty-one research flights in Southern Africa in support of SAFARI-2000.

2. Highlights of Results Obtained over Entire Three-Year Period of GACP Award*

- Comprehensive measurements on the physical and chemical properties of aerosols from biomass burning in the Amazon, including use of these data to derive the effects of biomass aerosol on radiation budgets in the Amazon and globally (see, for example, Ross et al., 1998; Reid and Hobbs, 1998, Reid et al., 1998; Martins et al., 1998; Kotchenruther and Hobbs, 1998).

- Documentation of the effects of smoke aerosol on cloud droplet concentrations and cloud droplet effective radius (see Reid et al., 1999a).
- Comparison of aerosol optical depths measured with a sunphotometer on the UW research aircraft on the U.S. East Coast with those derived from satellite measurements. A good correlation was found for AVHRR channel 1 (640 nm), but the satellite values were 0.05-0.15 below those measured by the sunphotometer (see Veefkind et al., 1999).
- Testing of the algorithm used for retrieving aerosol optical depths (AOD) from MODIS against sunphotometer measurements obtained aboard the UW research aircraft on the U.S. East Coast. The AODs at 550 nm, and their spectral dependencies, were in good agreement (see Tanre et al., 1999).
- Comparison of measurements with calculations of downward and upward radiant fluxes showed that for the U.S. East Coast in summer the aerosol have a single-scattering albedo in the mid-visible of 0.89-0.93. The calculated value for the instantaneous daytime upwelling flux changes due to aerosol are 14 to 48 W m^{-2} for mid-visible AODs between 0.2 and 0.55. These values are 30-100 times greater than the globally-averaged direct forcing expected for the global-average sulfate AOD on 0.04 (see Russell et al., 1999b).

---

[*] See Section 3 for references.

- Derivation of the effective aerosol complex index of refraction of aerosols from backscatter measurements and airborne measurements of aerosol size spectra. For the U.S. East Coast, the derived values of the real and imaginary parts of the complex index of refraction were 1.34-1.45 and 0.001-0.008, respectively (see Redemann et al., 2000a).
- Use of aerosol properties measured aboard the UW research aircraft on the U.S. East Coast to derive the first estimates of the vertical structure of aerosol radiative forcing. Aerosol single scattering at 450 nm were 0.9-0.985 and the asymmetry factor 0.6-0.8. Instantaneous shortwave aerosol radiative forcings were –36 W m^{-2} at the TOA and 56 W m^{-2} at the surface (see Redemann et al., 2000b).
- Use of UW airborne measurements to derive an optically equivalent model for ambient aerosol on the U.S. East Coast in summer. The model was validated and used to derive values for the single-scattering albedo and asymmetry factor (g) of the aerosol. A pronounced increase in g with relative humidity was observed. The model was used to derive the mean instantaneous change in the local albedo induced by the aerosol (0.027 ± 0.018 at 550 nm) (see Hartley and Hobbs 2001).
- Measurements aboard the UW research aircraft around convective clouds over the remote tropical Pacific Ocean showed enhanced concentrations of small (Aitken) particles, internally mixed particles with diameters around 0.3 μm containing acidic sulfate and nitrate. The enhancements in the larger-sized particles produced smoother (more Junge-type) particle size spectra (see Kaneyasu et al., 2001).[*]

[*] Work done in part during the third year of this grant.

- Utilization of measurements on emissions from a biomass fire, collected aboard the UW research aircraft in the Pacific Northwest, for inputs and evaluation of outputs of a physical and chemical model for the evolution of smoke plumes (see Trentmann et al., 2001).
- Surface albedo affects the retrieval of aerosol optical properties from satellites. Airborne measurements from the UW research aircraft and surface-based measurements were used to describe the seasonal evolution of the albedo of arctic sea ice (see Perovich et al., 2000). *
- Airborne measurements from the UW research aircraft in the Arctic show large enhancements in the concentrations of small particles just above the tops of stratus clouds. This could be a widespread source of aerosol in the Arctic (see Garrett et al., 2001a). *
- Increases in anthropogenic aerosol can increase the longwave emissivities of thin clouds, thereby warming the Earth's surface. It is shown that the effect can be particularly important in the Arctic in winter and early spring, and may add to the warming produced by increases in greenhouse gases (see Garrett et al., 2001b).*

3. Papers Published or Submitted Under this Three-Year Grant

(a) "Radiative Characteristics of Regional Haze Dominated by Smoke from Biomass Burning in Brazil: Closure Tests and Direct Radiative Forcing" by J. L. Ross, P. V. Hobbs and B. Holben (*J. Geophys. Res., 103,* 31,925-31,941, 1998).

(b) "Physical and Optical Properties of Young Smoke from Individual Biomass Fires in Brazil" by J. S. Reid and P. V. Hobbs (*J. Geophys. Res., 103,* 32,013-32,030, 1998).

(c) "Comparison of Techniques for Measuring Shortwave Absorption and Black Carbon Content of Aerosols from Biomass Burning in Brazil" by J. S. Reid, P. V.

Hobbs, C. Liousse, J. V. Martins, R. E. Weiss, and T. E. Eck (*J. Geophys. Res., 103,* 32,031-32,040, 1998).

(d) "Effects of Black Carbon Content, Particle Size, and Mixing on Light Absorption by Aerosols from Biomass Burning in Brazil" by J. V. Martins, P. Artaxo, C. Liousse, J. S. Reid, P. V. Hobbs, and Y. J. Kaufman (*J. Geophys. Res., 103,* 32,043-32,050, 1998).

(e) "Sphericity and Morphology of Smoke Particles from Biomass Burning in Brazil" by J. V. Martins, P. V. Hobbs, R. E. Weiss and P. Artaxo (*J. Geophys. Res., 103*, 32,051-32,047, 1998).

(f) "Physical, Chemical and Optical Properties of Regional Hazes Dominated by Smoke in Brazil" by J. S. Reid, P. V. Hobbs, R. J. Ferek, D. R. Blake, J. V. Martins, M. R. Dunlap and C. Liousse (*J. Geophys. Res., 103,* 32,059-32,080, 1998).

(g) "Humidification Factors of Aerosols from Biomass Burning in Brazil" by R. A. Kotchenruther and P. V. Hobbs (*J. Geophys. Res., 103,* 32,081-32,089, 1998).

(h) "Emission Factors of Hydrocarbons, Halocarbons, Trace Gases and Particles from Biomass Burning in Brazil" by R. J. Ferek, J. S. Reid, P. V. Hobbs, D. B. Blake and C. Liousse (*J. Geophys. Res., 103,* 32,107-32,118, 1998).

(i) "Relationships Between Cloud Droplet Effective Radius, Liquid Water Content, and Droplet Concentration for Warm Clouds in Brazil Embedded in Biomass Smoke" by J. S. Reid, P. V. Hobbs, A. L. Rangno and D. A. Hegg (*J. Geophys. Res., 104,* 6145-6153, 1999a).

(j) "Aerosol Properties and Radiative Effects in the United States East Coast Haze Plume: An Overview of the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX)" by P. B. Russell, P. V. Hobbs and L. S. Stowe (*J. Geophys. Res., 104,* 2213-2222, 1999a).

(k) "An Overview of the University of Washington Airborne Measurements and Results from the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX)" by P. V. Hobbs (*J. Geophys. Res., 104,* 2233-2238, 1999).

(l) "Humidification Factors for Atmospheric Aerosols off the Mid-Atlantic Coast of the United States" by R. A. Kotchenruther, P. V. Hobbs and D. A. Hegg (*J. Geophys. Res., 104,* 2239-2251, 1999).

(m) "Aerosol Optical Depth Retrieval Using ATSR-2 and AVHRR Data During TARFOX" by J. P. Veefkind, G. de Leeuw, P. D. Durkee, P. B. Russell, P. V. Hobbs and J. M. Livingston (*J. Geophys. Res., 104,* 2253-2260, 1999).

(n) "Retrieval of Aerosol Optical Thickness and Size Distribution Over Ocean from the MODIS Airborne Simulator During TARFOX" by D. Tanre, L. A. Remer, Y. J. Kaufman, S. Mattoo, P. V. Hobbs, J. M. Livingston, P. B. Russell, and A. Smirnov (*J. Geophys. Res., 104,* 2261-2278, 1999).

(o) "Aerosol-Induced Radiative Flux Changes off the United States Mid-Atlantic Coast: Comparison of Values Calculated from Sunphotometer and In Situ Data with those Measured by Pyranometer" by P. B. Russell, J. M. Livingston, P. Hignett, S. Kinne, J. Wong, A. Chien, R. Bergstrom, P. Durkee and P. V. Hobbs (*J. Geophys. Res., 104,* 2289-2307, 1999b).

(p) "Use of the Angstrom Exponent to Estimate the Variability of Optical and Physical Properties of Aging Smoke Particles in Brazil" by J. S. Reid, T. F. Eck, S. A. Christopher, P. V. Hobbs, and B. Holben (*J. Geophys. Res., 104,* 27,473-27,489, 1999b).

(q) "Estimation of Surface and Top-of-Atmosphere Shortwave Irradiance in Biomass Burning Regions During SCAR-B" by S. A. Christopher, X. Li, R. M. Welch, J. S. Reid, P. V. Hobbs, T. F. Eck and B. Holben (*J. Appl. Meteor., 39,* 1742-1753, 2000.

(r) "Properties of Aerosols Aloft Relevant to Direct Radiative Forcing off the Mid-Atlantic Coast of the United States" by W. S. Hartley, P. V. Hobbs, J. L. Ross, P. B. Russell, and J. M. Livingston. *J. Geophys. Res., 105*, 9859-9885, 2000.

(s) "Comparison of Aerosol Optical Properties and Water Vapor Among Ground and Airborne Lidars and Sun Photometers During TARFOX" by R. Ferrare, S. Ismail, E. Browell, V. Brackett, M. Clayton, S. Kooi, S. H. Melfi, D. Whiteman, G. Schwemmer, K. Evans, P. Russell, J. Livingston, B. Schmid, B. Holben, L. Remer, A. Smirnov, and P. V. Hobbs, *J. Geophys. Res., 105*, 9917-9933, 2000.

(t) "Comparison of LASE, Aircraft, and Satellite Measurements of Aerosol Optical Properties and Water Vapor During TARFOX" by R. Ferrare, S. Ismail, E. Browell, V. Brackett, S. Kooi, M. Clayton, P. V. Hobbs, S. Hartley, J. P. Veefkind, P. Russell, J. Livingston, D. Tanré, and P. Hignett, *J. Geophys. Res., 105*, 9935-9947, 2000.

(u) "Retrieving the Vertical Structure of the Effective Aerosol Complex Index of Refraction from a Combination of Aerosol In Situ and Remote Sensing Measurements During TARFOX" by J. Redemann, R. P. Turco, K. N. Liou, P. B. Russell, R. W. Bergstrom, B. Schmid, J. M. Livingston, P. V. Hobbs, W. S. Hartley, S. Ismail, R. A. Ferrare, and E. V. Browell, *J. Geophys. Res., 105,* 9949-9970, 2000a.

(v) "Case Studies of the Vertical Structure of the Direct Shortwave Aerosol Radiative Forcing During TARFOX" by J. Redemann, R. P. Turco, K. N. Liou, P. V. Hobbs, W. S. Hartley, R.W. Bergstrom, E.V. Browell, and P.B. Russell, *J. Geophys. Res.*, *105*, 9971-9979, 2000b.

(w) "FIRE Arctic Clouds Experiment." J. A. Curry, P. V. Hobbs, M. D. King, D. A. Randall, P. Minnis, G. A. Isaac, J. O. Pinto, T. Uttal, A. Bucholtz, D. G. Cripe, H. Gerber, C. W. Fairall, T. J. Garrett, J. Hudson, J. M. Intrieri, C. Jakob, T. Jensen, P. Lawson, D. Marcotte, L. Nguyen, P. Pilewskie, A. Rangno, D. C. Rogers, K. B. Strawbridge, F. P. J. Valero, A. G. Williams, D. Wylie, *Bull. Amer. Meteor. Soc.*, *81*, 5-29, 2000.

(x) "An Aerosol Model and Aerosol-Induced Changes in the Clear-Sky Albedo off the East Coast of the United States." W. S. Hartley, and P. V. Hobbs, *J. Geophys. Res.*, *106*, 9733-9748, 2001.

(y) "Aerosol Properties Around Marine Tropical Cumulus Clouds." N. Kaneyasu, P. V. Hobbs, Y. Ishizaka, and G.-W. Qian, *J. Geophys. Res.*, *106*, 14,435-14,445, 2001.[*]

(z) "Simulation of a Biomass Burning Plume: Comparing Model Results with Observations." Trentmann, J., M. O. Andreae, H.-F. Graf, P. V. Hobbs, R. D. Ottmar, and T. Trautmann, *J. Geophys. Res.* (In press). [*]

(aa) "The Seasonal Evolution of Arctic Sea Ice Albedo," D. K. Perovich, T. C. Grenfell, B. Light, and P. V. Hobbs, *J. Geophys. Res.*, (In press). [*]

(bb) "High Aitken Nucleus Concentrations Above Cloud Tops in the Arctic." T. J. Garrett, T. J., P. V. Hobbs, and L. F. Radke, *J. Atmos. Sci.*, 2001a (Special Issue on Global Aerosol Climatology—in press). [*]

(cc) "Aerosol Effects on Cloud Emissivity and Surface Longwave Heating in the Arctic." T. J. Garrett, L. F. Radke, and P. V. Hobbs, *J. Atmos. Sci.* 2001b (Special Issue on Global Aerosol Climatology—in press). [*]

(dd) "Comparison of Aerosol Single Scattering Albedos Derived by Diverse Techniques in Two North Atlantic Experiments." Russell, P. B., J. Redemann, B. Schmid, R. W. Bergstrom, J. M. Livingston, D. M. McIntosh, P. V. Hobbs, P. K. Quinn, C. M. Carrico, M. J. Rood, E. Öström, K. J. Noone, W. von Hoyningen-Huene, and L. Remer, *J. Atmos. Sci.* (Special Issue on Global Aerosol Climatology—in press). [*]

Report Prepared by
Peter V. Hobbs

[*] Papers published or accepted for publication during the third year of this grant.
[*] Papers published or accepted for publication during the third year of this grant.