SECOND 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 9/1/99-8/31/00.

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1. Progress Report for 2nd Year

During the past year efforts under this grant have focussed on the following:

a) Preparation and submission of manuscripts for the 2nd Special Issue of *Journal of Geophysical Research* devoted to results from the 1996 TARFOX aerosol study on the U.S. East Coast.

b) Reduction and analysis of aerosol measurements obtained in the 1998 FIRE-ACE field study in the Arctic, and submission of manuscripts to the *Journal of Geophysical Research* Special Issue on FIRE-ACE and to other journals.

c) Reduction and analysis of measurements obtained in the 1999 TRMM KWAJEX study in the Marshall Islands.

Brief descriptions follow of each of the above.

a) ***T**ropospheric **A**erosol **R**adiative **F**orcing **O**bservational E**x**periment (TARFOX)*

Five manuscripts were submitted to (and accepted by) the *Journal of Geophysical Research* 2nd Special Issue on TARFOX (*J. Geophys. Res., 105*, D8, April 27, 2000). These manuscripts describe, in part, measurements and results obtained by the University of Washington (UW) research group. Some of the highlights of the results reported in these papers are summarized below.

(i) Sunphotometer measurements of aerosol optical thickening (AOT) at 450 nm were greater than those derived from in situ measurements by (12 ± 5)% (see Harley et al., 2000).

(ii) At 550 nm the mean value of the ambient aerosol single-scattering albedo was (0.95 ± 0.03) (see Hartley et al., 2000).

(iii) Lidar (LASE) profiles of aerosol extinction and AOT had a bias difference of 0.0055 km^{-1} (10%) and a rms difference of 0.026 km^{-1} (42%) compared to profiles derived from the UW airborne in situ measurements. These differences are within the error and estimates of the measurements (see Ferrare et al., 2000).

(iv) Aerosol backscatter measurements from the LASE and in situ aerosol measurements from the UW aircraft were used to derive vertical profiles of the effective aerosol complex index of refraction at 815 nm. The derived values of the complex index of refraction ranged from 1.33 to 1.45 for the real part and 0.001 to

0.008 for the imaginary part. These are the first complete set of vertically resolved aerosol size distribution and refractive index data. They can be used to obtain the vertical distribution of aerosol optical profiles (see Redemann et al., 2000a).

(v) Aerosol optical properties were calculated from the UW in situ airborne measurements. The aerosol single-scattering albedo at 450 nm ranged from 0.9 to 0.985, and the aerosol asymmetry factor from 0.6 to 0.8. The instantaneous shortwave aerosol radiative forcings derived from the aerosol optical properties were –30 W m^{-2} at the TOA and –56 W m^{-2} at the surface (see Redemann et al., 2000b).

b) ***F****irst* ***I****SCCP* ***R****egional* ***E****xperiment-****A****rctic* ***C****loud* ***E****xperiment (FIRE-ACE)*

Fire-ACE was concerned with many aspects of the radiative balance of the Arctic. Here we confine our brief remarks to aerosol effects studied by our group. An overview of the FIRE-ACE field study, including some preliminary data, was published in the *Bulletin of the AMS* (see Curry et al., 2000).

The intergovernmental Panel on Climate Change (IPCC) has concluded that the major uncertainty in predicting anthropogenic effects on climate is the effects of aerosols on cloud radiative properties. Previous studies of these effects have been confined to shortwave radiation, for which aerosol cause cooling (due to increases in the reflection of solar radiation by clouds affected by anthropogenic aerosol). In a recent manuscript submitted to *Nature*, which utilizes data collected in FIRE-ACE, we discuss the effects of aerosols on the longwave radiative properties of thin arctic stratus clouds. In this case, aerosol increase the emissivity of the cloud and produce a warming effect. We estimate that in the Arctic in winter and spring, the surface warming due to this effect is about 0.8˚C. This effect may explain, in part, the warming observed in recent years in the winter (but not summer) in the Arctic (see Garrett et al., 2000a).

Our airborne measurements in the Arctic in spring show large increases in the concentrations and particles with diameter below 0.1 μm above the tops of clouds when the humidity is high in these regions, temperatures are below about 10˚C, and particle surface areas less than about 100 μm^2 cm^{-3}. We attribute these particles to homogeneous, bimolecular nucleation. This may be an important source of small particles in the Arctic. (See Garrett et al., 2000b).

c) ***Kwaj****alein Field* ***Ex****periment (KWAJEX)*

During the course of our participation in the NASA TRMM/KWAJEX study in the Marshall Islands in 1999, we "piggybacked" some aerosol measurements, which we are analyzing under NAS5-7675. As in the Arctic (see previous paragraph), we measured greatly enhanced concentrations of small particles (<0.1 μm) around clouds in the tropics. In addition, however, there were increases in the concentrations of acidic sulfate particles with diameters of about 0.3 μm. We attribute the acidic sulfate to heterogeneous oxidation of SO_2 in cloud droplets. The enhancement in the concentration of 0.3 μm particles produced smoother (more Junge-type) particle size spectra. These observations provide further support for the hypothesis that particles produced in the vicinity of convective clouds in the tropics are an important global source of aerosols.

2. Papers Published or Submitted During Past Year

(i) TARFOX 2nd Special Issue

a. Hartley, W. S., P. V. Hobbs, J. L. Ross, P. B. Russell, and J. M. Livingston. "Properties of aerosols aloft relevant to direct radiative forcing off the mid-Atlantic coast of the United States," *J. Geophys. Res.*, *105*, 9859-9885, 2000.

b. Ferrare, R., 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. "Comparisons of Aerosol Optical Properties and Water Vapor Among Ground and Airborne Lidars and Sun Photometers During TARFOX." *J. Geophys. Res.*, *105*, 9917-9933, 2000.

c. Ferrare, R., 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. "Comparisons of LASE, Aircraft, and Satellite Measurements of Aerosol Optical Properties and Water Vapor During TARFOX." *J. Geophys. Res.*, *105*, 9935-9947, 2000.

d. Redemann, J., 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. "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." *J. Geophys. Res.*, *105*, 9949-9970, 2000.

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

f. Hartley, W. S., and P. V. Hobbs, "An Aerosol Model and Aerosol-Induced Changes in the Clear-Sky Albedo off the East Coast of the United States." *J. Geophys. Res.,* 2000 (submitted).

(ii) FIRE-ACE

a) Curry, J. A., 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. "FIRE Arctic Clouds Experiment." *Bull. Amer. Meteor. Soc.*, *81*, 5-29, 2000.

b) Garrett, T. J., L. F. Radke, and P. V. Hobbs. "Aerosol Effects on Cloud Emissivity and Surface Temperatures in the Arctic." *Nature.*, 2000 (submitted).

c) Garrett, T. J., P. V. Hobbs, and L. F. Radke. "Humidity Effects on Particle Nucleation Above Cloud Tops in the Arctic." *Geophys. Res. Lett.*, 2000 (submitted).

d) Kaneyasu, N., P. V. Hobbs, Y. Ishizaka, G.-W. Qian. "Aerosol Properties Around Marine Tropical Cumulus Clouds." *J. Geophys. Res.*, 2000 (submitted).

3. Plans for 3rd Year of Grant

Our work during the 3rd year of this grant will be concerned with the following three main tasks:

a) Completion of our studies of the aerosol measurements we obtained in FIRE-ACE and KWAJEX

b) In the summer of 2000 our group, with its CV-580 research aircraft, will participate in the NASA SAFARI-2000 project in Southern Africa. One of the main goals of this study is to obtain in situ airborne measurements of the physical and chemical properties of aerosols in this region for comparison with simultaneous remote sensing measurements from the Terra satellite and the ER-2 aircraft. In addition, we expect to obtain an extensive set of measurements on the sources, transport and modification of aerosols over the Southern African sub-continent. With the aid of grant NAS5-7675, we will begin our reduction, archiving and analysis of this new data set on aerosols.

c) One of our ultimate goals is to compare and contrast the many measurements on aerosols that we have collected in various parts of the world (United States, Middle East, North East Atlantic, Brazil, Arctic, Western Pacific and Africa) over the past several years in order to produce a "global" assessment of these unique data sets.

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8/2/00