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Program Element: Aerosol-Climate Interactions Program (ACIP)
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Quantification of aerosol radiative effects by integrated analyses of airborne measurements, satellite retrievals, and radiative transfer models

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Budget requested from NOAA ($K):

Period	Prong A Aerosol Absorption Using Flux Divergence	Prong B Extinction Closure, Including Satellite Validation	Prong C Regional Forcing Using Satellite and Suborbital	Total
March 1, 2003 - February 28, 2004	99.9	100.1	95.3	295.2
March 1, 2004 - February 28, 2005	106.4	102.8	102.0	311.2
March 1, 2005 - February 28, 2006	102.3	111.9	109.8	324.0
Three Year Total	308.6	314.7	309.3	932.6

TABLE OF CONTENTS

ACRONYMS

AATS-6 (14)	6 (14)-channel Ames Airborne Tracking Sunphotometer
ACE	Aerosol Characterization Experiment
ACIP	Aerosol-Climate Interactions Program
AERONET	Aerosol Robotic Network
AOD	Aerosol Optical Depth
ARM	Atmospheric Radiation Measurement
ARESE	ARM Enhanced Shortwave Experiment
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CCRI	Climate Change Research Initiative
CERES	Clouds and the Earth's Radiant Energy System
CFORS	Chemical Weather FORecasting System
CIRPAS	Center for Interdisciplinary Remotely Piloted Aircraft Studies
CRD	Cavity Ring-Down
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment
CTM	Chemical Transport Model
CW	Continuous Wave
CWV	Column Water Vapor
DISORT	DIScrete Ordinates Radiative Transfer
DOE	Department of Energy
EOS	Earth Observing System
ESA	European Space Agency
GMS	Geostationary Meteorological Satellite
GOCART	Global Ozone Chemistry Aerosol Radiation Transport
GOES	Geostationary Operational Environmental Satellite
INDOEX	Indian Ocean Experiment
IOP	Intensive Observation Period
JOSS	Joint Office for Scientific Studies
MATCH	Model of Atmospheric Transport and CHemistry
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate-resolution Imaging Spectroradiometer
NAAPS	Navy Aerosol Analysis and Prediction System
NACIP	National Aerosol-Climate Interactions Program
NAS	National Academy of Sciences
NIR	Near Infra-Red
ONR	Office of Naval Research
PRIDE	Puerto RIco Dust Experiment
SAFARI	Southern African Regional Science Initiative
SeaWiFS	Sea-viewing Wide-Field-of-view Sensor
SGP	Southern Great Plains
SSA	Single Scattering Albedo
SSFR	Solar Spectral Flux Radiometer
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
TOMS	Total Ozone Mapping Spectrometer
UCAR	University Corporation for Atmospheric Research

Quantification of aerosol radiative effects by integrated analyses of airborne measurements, satellite retrievals, and radiative transfer models

Lead Principal Investigator: Philip B. Russell, NASA Ames Research Center

Co-Principal Investigators:
Peter Pilewskie, NASA Ames Research Center
Beat Schmid, Bay Area Environmental Research Institute
Jens Redemann, Bay Area Environmental Research Institute

Proposed Cost: $932,600, March 1, 2003-February 28, 2006

Abstract. Aerosols are potentially important agents of climate change, but their impacts on current and future climate are very uncertain. Three prominent reasons for this uncertainty are: (1) Aerosol effects on radiative fluxes, clouds and hydrology are critically dependent on light absorption by aerosols as a function of wavelength and aerosol type; however, this absorption is currently uncertain, because aerosols are highly variable, different measurement techniques often disagree, and some techniques can change the ambient aerosol. (2) Aerosol effects are equally dependent on the distribution of extinction (solar beam attenuation) in space, time, and wavelength, but extinction derived from in situ measurements and other techniques (including satellite retrievals) often disagrees with measured solar beam attenuation. (3) Satellites have great potential to reduce uncertainties in aerosol effects, but limitations or uncertainties in satellite results require supplementing and/or validating them with other information.

We propose integrated analyses to address the above three problems in a coordinated manner. Our objectives are to: (A) Advance the technique of determining wavelength-dependent aerosol absorption using radiative flux divergence by comparing flux-divergence results for a variety of aerosols to results from other techniques and applying the flux-divergence technique to climatically significant aerosols. (B) Assess the consistency (closure) between solar beam attenuation measured by airborne sunphotometer and derived from in situ, lidar, and satellite methods. (C) Assess regional aerosol radiative forcing by combining satellite and suborbital inputs in state-of-the-art radiative transfer models.

We will analyze data sets from field experiments in which vertically resolved measurements of radiative flux, solar beam attenuation, and aerosol physical-chemical-optical properties are coordinated with satellite measurements of Earth-atmosphere reflected radiation. The data sets are from ACE-Asia (Spring 2001) and the planned DOE SGP Aerosol IOP (May 2003; see list of acronyms on p. ii). We will attack the above problems using three highly coordinated prongs, each led by a Co-PI and focused on one of the above objectives. <u>Prong A (Aerosol Absorption Using Flux Divergence</u>) will use measurements by Solar Spectral Flux Radiometers (SSFRs) to obtain wavelength-dependent aerosol absorption and will combine absorption with simultaneously measured optical depths from an Ames Airborne Tracking Sunphotometer (AATS) to obtain wavelength-dependent single-scattering albedo (SSA). Results from ACE-Asia and SGP Aerosol IOP data sets will be compared to simultaneous measurements of absorption and SSA by other techniques. <u>Prong B (Extinction Closure</u>) will compare extinction from (i) AATS-measured solar beam attenuation, (ii) in situ physical-chemical-optical measurements on the same aircraft, (iii) lidar and (iv) various satellites. <u>Prong C (Regional Forcing Assessments by Combining Satellite and Suborbital Results)</u> will use advanced satellite data sets and address one of the world's most climatically significant aerosols—the Asian Pacific plume of mineral dust, soot, organics, sulfates, and sea salt.

The proposed research will benefit the general public and the scientific community by reducing the uncertainties about aerosol effects on climate cited by the National Academy of Sciences (NAS) analysis of key questions in climate change science and by the White Paper of the National Aerosol-Climate Interactions Program (NACIP).

Quantification of aerosol radiative effects by integrated analyses of airborne measurements, satellite retrievals, and radiative transfer models

1. RESULTS FROM PRIOR RESEARCH

As required by the Instructions for Submitting Proposals (http://www.ogp.noaa.gov/c&gc/ao/2003/propinstruction.htm), this section summarizes, in two pages, results of each relevant research project during the last 3 years. More extensive descriptions of selected results and their relevance to the proposed research are given in Sections 2.2-2.4.

ACE-2 and ACE-Asia Aerosol Radiative Effect Studies Using Airborne Sunphotometer, Satellite and In-Situ Measurements. NOAA Award NA02AANRG0129, NASA RTOP 622-96-00-57-01, 5/2000-4/2003, $466,100. This award supported (a) Acquisition and use of satellite data to plan ACE-Asia approaches, including selection of areas most favorable to measuring aerosol radiative effects with least interference by clouds; (b) Preliminary optical modeling of the complex aerosols expected in ACE-Asia, by building on models developed for sulfate, carbonaceous, and mineral dust aerosols studied in TARFOX, ACE-2, and PRIDE; (c) Comparison of aerosol absorption derived by flux-change and other techniques in TARFOX and ACE-2; (d) Contributions to the Science and Implementation Plan for ACE-Asia 2001; (e) Development and testing of sunphotometric water vapor analysis techniques for ACE-Asia; (f) Mission Scientist duties for ACE-Asia C-130 flights addressing aerosol-radiation interactions; (g) Calibrations, integration, test flights, and measurements using the 6-channel Ames Airborne Tracking Sunphotometer (AATS-6) on the C-130 in ACE-Asia Spring 2001; (h) Intercomparisons, validations, and closure analyses combining the AATS-6 data with satellite and other suborbital data; and (i) Aerosol radiative effect calculations that combine satellite and suborbital inputs. Results are described in four journal publications led by our team (Redemann et al., 2001a; Bergstrom et al., 2002a; Russell et al., 2002; Schmid et al., 2001), plus several others we coauthored (e.g., Ingold et al., 2000; Kiedron et al., 2000; Revercomb et al., 2001; Wang et al., 2002a). Our AATS-6 ACE-Asia data set has been archived and made available to the user community via the Ames web site (http://geo.arc.nasa.gov/sgg/AATS-website/AATS_Data.html) and a link from UCAR-JOSS. These data are being used in many ongoing studies that have been reported at numerous conferences (e.g., Chin et al., 2001; Livingston et al., 2001; Redemann et al., 2001b,c; Russell et al., 2001a,b; Kuzmanoski et al., 2002). Selected results are summarized in Sections 2.2-2.4 of this proposal.

Solar Spectral Flux, Optical Depth, Water Vapor, and Ozone Measurements and Analyses in the ACE-Asia Spring 2001 Intensive Experiment. Office of Naval Research Award N0001401F0183, NASA RTOP 622-96-00-56-79, 11/2000-9/2002, $163,900. This award supported measurements and analyses of solar spectral fluxes and direct beam transmissions in support of the ACE-Asia Spring 2001 Intensive Experiment. Spectral fluxes (300-1700 nm at 10 nm resolution) were measured by zenith and nadir viewing Solar Spectral Flux Radiometers (SSFRs) on the CIRPAS Twin Otter. Simultaneously and on the same aircraft, direct beam transmissions were measured in 14 narrow bands (354-1558 nm) by AATS-14. The AATS-measured beam transmissions were analyzed to derive aerosol and thin-cloud optical depth at 13 wavelengths, plus column water vapor overburden. The data were used to support the overall goals of ACE-Asia, with emphasis on determining the net solar radiative forcing of East Asian/West Pacific aerosols, quantifying the solar spectral radiative energy budget in the presence of elevated aerosol loading, supporting satellite algorithm validation, and providing tests of closure with in situ measurements. Our AATS-14 ACE-Asia data set has been archived and made available to the user community (see above for link). Results are described in Wang et al. (2002a), in numerous ACE-Asia conference presentations, and in many papers being drafted for the ACE-Asia special issue of *J. Geophys. Res*. Selected results are shown in Sections 2.2-2.4.

Improved Exploitation of Field Data Sets to Address Aerosol Radiative-Climatic Effects

and Development of a Global Aerosol Climatology. NASA RTOP 622-44-75-10, 10/98-9/02, $675,000. This award supported tasks on (a) Airborne sunphotometer optical depth data quality checks, (b) Mixed aerosol optical modeling, (c) Automated size distribution retrievals, (d) Size distribution comparisons and closure studies, (e) Water vapor/aerosol interactions and satellite retrievals, and (f) Flux change/radiative forcing studies. These tasks were accomplished primarily by analyses of data sets from TARFOX and ACE-2. Results are described in 10 journal publications led by the Ames sunphotometer-satellite team (Bergstrom and Russell, 1999; Bergstrom et al., 2002a; Livingston et al., 2000; Redemann et al., 2000a,b, 2001; Russell and Heintzenberg, 2000; Russell et al., 2002; Schmid et al., 1999, 2000), plus 9 others we coauthored (Collins et al., 2000; Ferrare et al., 2000a,b; Flamant et al., 2000; Gasso et al., 2000; Hartley et al., 2000; Ismail et al., 2000; Pilewskie et al., 2000; Welton et al., 2000).

Satellite-Sunphotometer Studies of Aerosol, Water Vapor, and Ozone Roles in Climate-Chemistry-Biosphere Interactions. NASA RTOP 291-01-91-45, 2/1999-12/2002, $675,000. This award supported modeling and integrated analyses of suborbital and satellite data to address impacts of biomass smokes, Asian and African soil dust, and other tropospheric aerosols and water vapor on the Earth's radiation budget. Research focused primarily on analysis of data from three international multiplatform field campaigns: PRIDE, SAFARI 2000, and ACE Asia. Data from airborne sunphotometers and other airborne and surface remote and in situ measurements were combined in closure studies to test and improve models of complex multicomponent tropospheric aerosols and their interactions with water vapor and radiation. Pre-campaign modeling and algorithm development focused on providing realtime analysis and display capabilities useful for studies of aerosol evolution and mass budgets, including flight planning and direction. During and after campaigns suborbital data and models were used to validate satellite measurements of aerosols and water vapor. They were then used to supplement the satellite data with other information needed for studies of aerosol physicochemical evolution and radiative-climatic effects. In particular, satellite maps of aerosol properties were combined with suborbital data in radiative transfer models to assess aerosol effects on radiation balance and heating rates, both at the surface and aloft. Thirteen journal manuscripts were submitted, describing results from PRIDE, SAFARI 2000, and ACE Asia (Bergstrom et al., 2002b; Colarco et al., 2002; Gatebe et al., 2002; Levy et al., 2002; Livingston et al., 2002; Magi et al., 2002; McGill et al., 2002; Pilewskie et al., 2002a; Reid et al., 2002; Schmid et al., 2002; Wang et al., 2002a,b; Xu et al., 2002).

Investigation of the Uncertainty and Variability of the Direct Spectral Radiative Forcing by Atmospheric Aerosols. NASA RTOP 622-44-76-10, 10/1998-9/2002, $348,000. This award supported the analysis of hyperspectral solar flux measurements from various flight missions to determine the direct radiative forcing by aerosols. Three journal manuscripts were submitted, describing results from PRIDE and SAFARI 2000 (Bergstrom et al., 2002b; Pilewskie et al., 2002a,c). Selected results are summarized in Section 2.2.

Retrieval of Ice-Water Content Using Near-Infrared Remote Sensing. DOE Atmospheric Radiation Measurement Program, Solicitation Notice 99-16, NASA RTOP 622-43-00-56-33, 10/1999-9/2002, $230,000. This award supported the use Solar Spectral Flux Radiometer (SSFR) data to infer cloud water (ice or liquid) path and effective water content. Results recently submitted for publication (Pilewskie et al., 2002b) show that SSFR flux spectra measured above and below cloud can be used to derive cloud optical and physical properties which are in agreement with in situ microphysical measurements. See also Section 2.2.4.

Measurement of Solar Spectral Irradiance in Support of CRYSTAL. NASA RTOP 622-44-76-10, 10/2001-9/2002, $437,000. This award supported measurements by Solar Spectral Flux Radiometers (SSFRs) and broadband infrared radiometers on two aircraft (ER-2 and Twin Otter) in the Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment (CRYSTAL-FACE, July 2002), including sensor preparation, modification, calibration, integration, flight operation, and initial data reduction. Complete data analysis, presentation, and publication are planned for FY 2003-2004.

2. PROPOSED RESEARCH (STATEMENT OF WORK)

2.1 Problem Identification, Overall Objectives, Relevance, and Methodology

Aerosol effects on atmospheric radiation pose major uncertainties in understanding past and present climates and in predicting the future climate. These uncertainties, and strategies for reducing them, have recently been emphasized by the National Academy of Sciences' analysis of key questions in climate change science (NAS, 2001). Recent experiments designed to reduce these uncertainties (e.g., TARFOX, ACE-2, INDOEX, PRIDE, SAFARI-2000, ACE-Asia) have produced important advances but in the process have posed remaining questions that must be answered (Russell et al., 1999a; Raes et al., 2000; Russell and Heintzenberg, 2000; Ramanathan et al., 2001, 2002; Levy, 2002c). These remaining questions have guided the research priorities and strategies articulated by the National Aerosol-Climate Interaction Program (NACIP) and in turn by NOAA's Aerosol-Climate Interactions Program (ACIP). For example, NACIP and ACIP (Ramanathan et al., 2002; Levy, 2002a,b) emphasize the importance of absorbing aerosol components (including black and organic carbon and mineral dust) both in directly affecting Earth-atmosphere radiation budgets and in determining aerosol-cloud interactions and regional hydrology. Aerosol absorption deposits solar energy that would have warmed Earth's surface into atmospheric layers aloft. There it can shorten cloud lifetimes by causing them to "burn off" (Ackerman et al., 2000). Absorbing aerosols can also inhibit cloud formation in several ways. The reduction in surface heating decreases evapotranspiration, and the combination of increased heating aloft and reduced heating below weakens the convective motions that drive much cloud formation. Thus aerosol absorption can affect regional hydrology in addition to radiative forcing. Quantifying these effects requires a quantitative description of the vertical, regional, and temporal distributions of aerosol absorption across all wavelengths where absorbed energy is significant.

In its White Paper (Ramanathan et al., 2002) NACIP also emphasizes the need to quantify aerosol properties and effects on a region-by-region basis and to represent these properties and effects accurately in models that calculate aerosol radiative and climatic effects. The "new paradigm" of NACIP is to attack the aerosol-climate forcing problem from an observational basis. NACIP stresses that a sound observational basis requires combining satellite observations (the only mode for global observations of aerosols) with multi-platform measurements at the surface and within the atmosphere, including aircraft flights to map the vertical and horizontal variations of key aerosol properties and effects. NACIP also stresses the need to both quantify and reduce the uncertainties in both observations and model calculations.

The current NOAA ACIP call for proposals (Levy, 2002a) has focused the above NACIP priorities into three specific areas in which proposals are solicited. These areas include:

1. Investigations that address limiting factors in current in-situ measurement capabilities by using methods or instruments capable of autonomous operation on light aircraft. Prime examples are methods to measure aerosol light absorption and intercomparisons of different instruments.

2. Spin-up of comprehensive light aircraft field measurements of the most radiatively important aerosols, highly integrated with state-of-the-art modeling.

3. Analyses of ACE-Asia data that stress synergistic use of multi-disciplinary data sets, with emphasis on achieving closure on the radiative impacts of Asian aerosols observed during the campaign.

This proposal addresses all three of the above ACIP-solicited areas in a coordinated fashion. The objectives of the proposed research are:

A. Advance the technique of determining wavelength-dependent aerosol absorption using radiative flux divergence by comparing flux-divergence results for a variety of aerosols to results from other techniques and applying the flux-divergence technique to climatically significant aerosols.

B. Assess the consistency (closure) between solar beam attenuation measured by airborne sunphotometer and derived from in situ, lidar, and satellite methods.

C. Assess regional aerosol radiative forcing by combining satellite and suborbital inputs in state-of-the-art radiative transfer models.

Our proposed approach is to analyze data sets from field experiments in which vertically and horizontally resolved measurements of radiative flux, solar beam attenuation, and aerosol physical-chemical-optical properties are coordinated with satellite measurements of Earth-atmosphere reflected radiation. The data sets, from ACE-Asia (Spring 2001) and the planned DOE SGP Aerosol IOP (May 2003) are described more fully below. First we describe how the work would be organized and the methods employed.

We plan to attack the above problems using three highly coordinated prongs, each led by a Co-PI (as listed on the cover page) and focused on one of the above objectives.

Prong A. Aerosol Absorption Using Flux Divergence. Radiative flux is the flow of radiant energy (diffuse plus direct) across a surface. The net (downwelling minus upwelling) flux at the top of a layer minus the net flux at the bottom (i.e., the net flux divergence across a layer) is the energy absorbed by the layer. Hence, flux divergence measurements are a direct way of determining the absorption by whatever is in an atmospheric layer, in its ambient state. Measuring flux divergence with fine spectral resolution allows the identification and subtraction of gas absorption features, thus isolating the aerosol absorption. Perturbation or loss of aerosol particles by aircraft and instrument inlet and filter effects is avoided. As shown in Section 2.2, early publications from PRIDE and SAFARI illustrate how Dr. Pilewskie's Solar Spectral Flux Radiometers (SSFRs) yield wavelength-dependent aerosol absorption, which, when combined with optical depths from an Ames Airborne Tracking Sunphotometer (AATS) in a radiative transfer model, yields wavelength-dependent single-scattering albedo (SSA). These techniques will be applied to the ACE-Asia and SGP Aerosol IOP data sets, and the results compared to simultaneous measurements of absorption and SSA by other techniques.

Prong B. Extinction Closure, Including Satellite Validation. An important class of extinction closure studies addresses the question: "Can in situ measurements of aerosol properties account for the solar beam attenuation (extinction) by an aerosol layer or column?" 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. As shown in Section 2.3, such comparisons have revealed important insights about aerosol sampling and inadvertent modification in such previous experiments as TARFOX, ACE-2, and SAFARI. We will base the proposed study of extinction closure on the ACE-Asia and SGP Aerosol IOP data sets. In addition to comparisons to airborne in situ measurements we will include comparisons to lidar extinction profiles and total column aerosol optical depth (AOD) from various satellites and models (see Section 2.3).

Prong C. Regional Forcing Assessments by Combining Satellite and Suborbital Results. As amplified in Section 2.4, this prong will use the general approach we applied to North Atlantic aerosols (Bergstrom and Russell, 1999), but will extend it in many ways: by using more advanced satellite and suborbital data sets and by applying it to the Asian-Pacific aerosol. This aerosol is one of the world's most climatically significant because of its great concentration, extent, and expected growth (e.g., Huebert et al., 1999). It is also one of the most difficult to assess, because it is a complicated and varying mixture of many components, including desert dust, a strong soot component, organics, sulfates, and sea salt.

As noted above, these methods will be applied to the following data sets:

Data Set 1. ACE-Asia (Spring 2001). This set includes measurements on the Twin Otter aircraft by SSFRs, AATS-14, and many in situ sensors, plus measurements on the C-130 aircraft by AATS-6 and many other sensors, all made in coordination with satellite overpasses. The satellite data products include multiwavelength aerosol optical depth (AOD) from sensors such as MISR, MODIS, SeaWiFS, AVHRR, and others. Also useful in the analyses will be the fields of AOD and other properties predicted by the chemical-transport models (CTMs) CFORS, GOCART, MATCH, and NAAPS (see list of acronyms on p. iii; see Section 2.3 for references describing models). The ACE-Asia campaign ended about 1 year ago, and early presentations (e.g., Redemann et al., 2001b,c) and journal manuscripts (e.g., Wang et al., 2002a) have demonstrated the outstanding quality and scope of the data set. However, our current ACE-Asia analysis funding will end within a year and will not cover the highly integrated analyses proposed here. The ACE-Asia data set provides a golden opportunity to extend the abovementioned PRIDE and SAFARI flux divergence analyses to one of the world's most climatically significant aerosols—the Asian Pacific plume of desert dust and pollution.

In addition to the satellite sensors mentioned above, we plan to contribute to the validation of CERES data by furnishing ACE-Asia AATS-6 and -14 data, and data-use advice, to Dr. Sundar Christopher of the University of Alabama in Huntsville. Dr. Christopher is proposing to NOAA ACIP an investigation that would, among other things, use biaxial scan mode CERES data to develop angular models for estimating radiative fluxes and thereby reduce uncertainties in aerosol radiative forcing.

Data Set 2. DOE SGP Aerosol IOP (May 2003). Plans for this experiment, which recently received tentative approval from the ARM Science Team Executive Committee, include measurements by SSFR, AATS-14, and many others. A significant advance will be mounting the up-looking SSFR on a stable platform, which will reduce tilt effects and thereby extend the SSFR absorption analyses to smaller aerosol optical depths. This will extend the range of aerosol conditions to which the flux divergence technique can be applied. Dr. Beat Schmid (Co-PI) has been involved in the planning of the May 2003 IOP and has developed an airborne payload based on the CIRPAS Twin Otter aircraft.

2.2 Prong A. Aerosol Absorption Using Flux Divergence

The goals of this prong of the proposed research are to:

- Advance the technique of determining wavelength-dependent aerosol absorption using radiative flux divergence, by comparing flux-divergence results for a variety of aerosols to results from other techniques and applying the flux-divergence technique to climatically significant aerosols.

- Provide results on wavelength-dependent absorption and SSA of significant aerosol types to Prongs B and C and to the community via summary data files, presentations and publications.

Several recent airborne intensive field campaigns conducted to study the radiative forcing of clouds and various types of aerosols have included the measurement of solar spectral irradiance over flight profiles throughout the troposphere and lower stratosphere. These data provided the means to determine the net spectral flux at various atmospheric levels, from which spectral flux divergence and absorption were derived. Further analysis through radiative transfer modeling has been applied to derive aerosol or cloud droplet single scattering albedo. The initial successes of these measurements and analyses provide the basis for expanding our efforts toward the objectives described in this proposal. In this section we describe the measurement and modeling tools used and present some of our results from recent field studies.

2.2.1 The Solar Spectral Flux Radiometer

The Solar Spectral Flux Radiometer (SSFR) is a moderate resolution flux (irradiance) spectrometer covering the wavelength range 300-1700 nm. The SSFR uses an identical pair of Zeiss Monolithic Miniature Spectrometer Modules (MMS-1 and MMS-NIR) for simultaneous zenith and nadir viewing. The MMS-1 has a flat-field, 366 mm^{-1} grating and a Hamamatsu Si linear diode array detector. We control the MMS-1 module temperature to 27±0.3º C. The MMS-NIR has a 179 mm^{-1} flat-field grating with a 128-element InGaAs linear diode array, thermoelectrically cooled to 0º C. Spectral resolution is 9 nm for the MMS-1 and 12 nm for the MMS-NIR. The light collector is a scaled version of the optical collector designed by Crowther (1998). Tests of the design show a high degree of linearity with cosine of incidence angle to values as low as 0.1. A water-free quartz hyperdome protects the light collector in flight. A high-grade custom-made fiber optic bundle transmits incident light to the two spectrometer input slits. Data acquisition and control use a 226 MHz 586 PC. Dynamic resolution is 15 bits full range; sampling resolution is ~3.25 nm. Spectral sampling is at ~1 Hz. Data is recorded on a 220 Mbyte PCMCIA flash memory card.

The SSFR is calibrated for wavelength, angular response, and absolute spectral power. Spectral calibration is referenced to the HeNe laser line at 632.8 nm, a temperature stabilized laser diode line at 1298 nm, and several lines from Hg, Xe, and Ar lamps. Spectral power calibration uses a NIST secondary standard lamp and a LI-COR Field Calibrator. The LI-COR units are fully enclosed devices suitable for field use. In the field we calibrate the SSFR before and after flights using the same portable LI-COR devices to monitor SSFR stability during the experiment.

Over most of the active spectral range the short-term stability, or precision, is <0.1% for the Si detector array and <0.2% for the InGaAs array. The longer term stability shown by pre- and post-deployment comparisons is ~0.5% (~0.75%) for the Si (InGaAs) array, with some falloff at the detection limits. Absolute accuracy of SSFR irradiance spectra depends mostly on the accuracy of the transfer standard. The error over our spectral range for the NIST standard used to calibrate the SSFR was 1-3%. The LI-COR calibrator lists a 3% uncertainty across the spectrum. Aircraft pitch and roll contribute additional error during aircraft operations. Later in this section we quantify this error in terms of error bars on derived aerosol absorption and SSA, showing that the error was acceptable for aerosol optical depths commonly observed in SAFARI, PRIDE, and ACE-Asia. As noted above (see <u>Data Set 2</u>), pitch and roll effects will be reduced in the planned DOE SGP Aerosol IOP by mounting the up-looking SSFR on a stable platform, thus extending the range of aerosol conditions to which the flux divergence technique can be applied

2.2.2 Radiative Transfer Model

We have developed a numerical radiative transfer model specifically for comparison with the SSFR. Major features of the model are: a k-distribution representation for O_2, O_3, CO_2 and H_2O absorption coefficients (Mlawer, et al, 1997); DISORT, a multiple scattering code (Stamnes, et al, 1988); Kurucz representation of the solar spectrum (Kurucz, 1992); and SSFR filter functions (Pilewskie et al, 2002). The 140 model bands (10 nm wide, 300-1700 nm) match the SSFR spectral coverage. Model inputs are vertical profiles of gases, aerosol and clouds, spectral scattering and absorption properties of aerosols and clouds, spectral surface reflectance, and solar zenith angle. Bergstrom et al. (2002b) describe the details of the code and present comparisons with measured spectral irradiance from biomass-burning aerosol layers, plus solutions for wavelength-dependent SSA of aerosol layers.

2.2.3 Flux Divergence in Aerosol Layers

The net flux at any level is defined as the difference between downwelling and upwelling irradiance:

$$F_{net} = F_{\downarrow} - F_{\uparrow} .$$

The flux divergence, or absorption, A, in a layer is defined as the difference between net flux above and below a layer:

$$A = (F_{\downarrow} - F_{\uparrow})_2 - (F_{\downarrow} - F_{\uparrow})_1 ,$$

where 2 and 1 denote upper and lower flight levels, respectively. Finally, we determine fractional absorption, α, by normalizing the layer absorption by the downwelling flux incident at the top of the layer:

$$\alpha = \frac{(F_{\downarrow} - F_{\uparrow})_2 - (F_{\downarrow} - F_{\uparrow})_1}{F_{\downarrow 2}}$$

2.2.3.1 Biomass Burning Aerosol. The SSFRs flew on the University of Washington Convair-580 during the Southern African Regional

Science Initiative (SAFARI 2000), affording the opportunity to apply the flux divergence technique to the biomass burning aerosols that prevailed in that study. Figure 1 shows results from the 6 September flight, which included two stacked level legs over Mongu, Zambia, during an intense haze episode. SSFR downwelling and upwelling irradiance (flux) spectra are shown in Figure 1a; albedo spectra (ratios of upwelling to downwelling flux) are in Figure 1b, and aerosol optical depths measured simultaneously by AATS-14 from the same aircraft are in Figure 1c. Note that the near-infrared albedo aloft (575 mb) is less than that near the surface (878 mb), suggesting very strong absolute absorption by the massive optically thick haze layer present between these two heights. Figure 2a shows the spectral absorption for this layer. The solid curve is total absorption; by interpolating across the various near-infrared gas absorption bands we estimate the aerosol contribution to the absorption as depicted by the dashed curve.

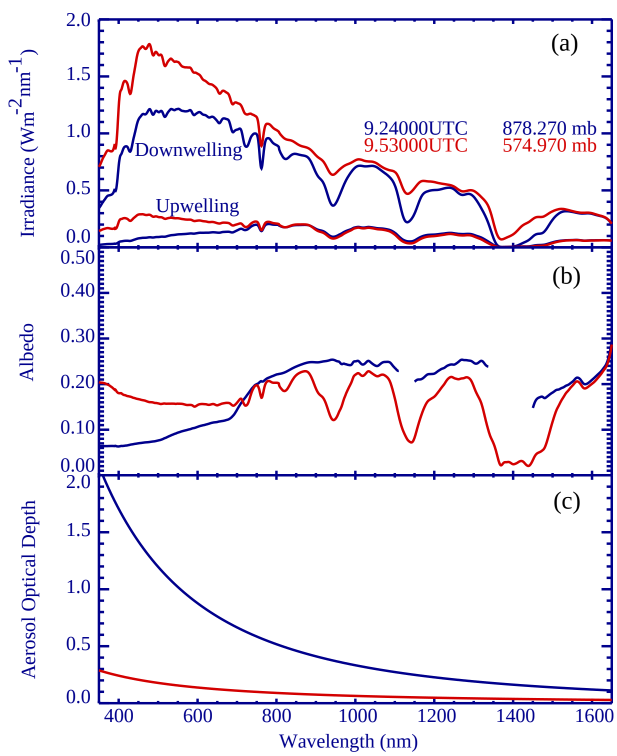

Figure 1. (a) Upwelling and downwelling flux spectra from two SAFARI Convair-580 flight legs on 6 September 2000. (b) Albedo spectra from the same legs. (c) Corresponding aerosol optical depths from AATS-14 measurements.

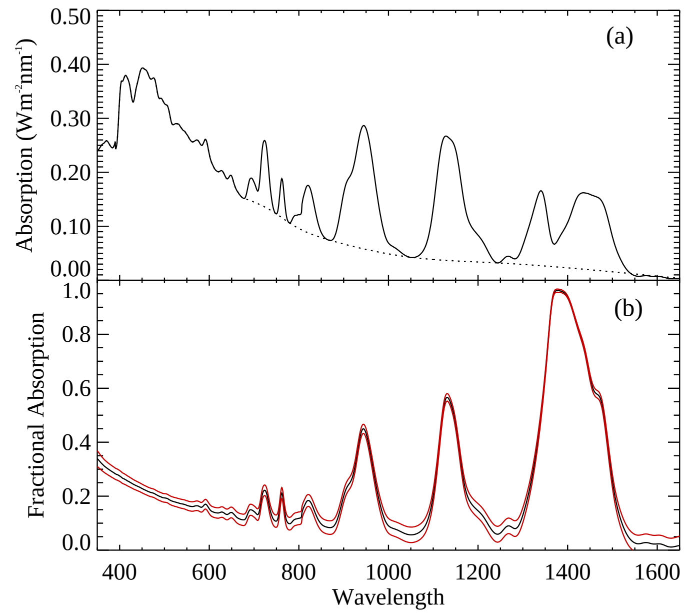

Figure 2. (a) Spectral flux divergence (absorption) between the highest and lowest flight legs in the 6 September flight profile over Mongu, Zambia. The dashed curve represents the aerosol absorption "continuum." (b) Fractional absorption from the same case. Red curves indicate the range of uncertainty.

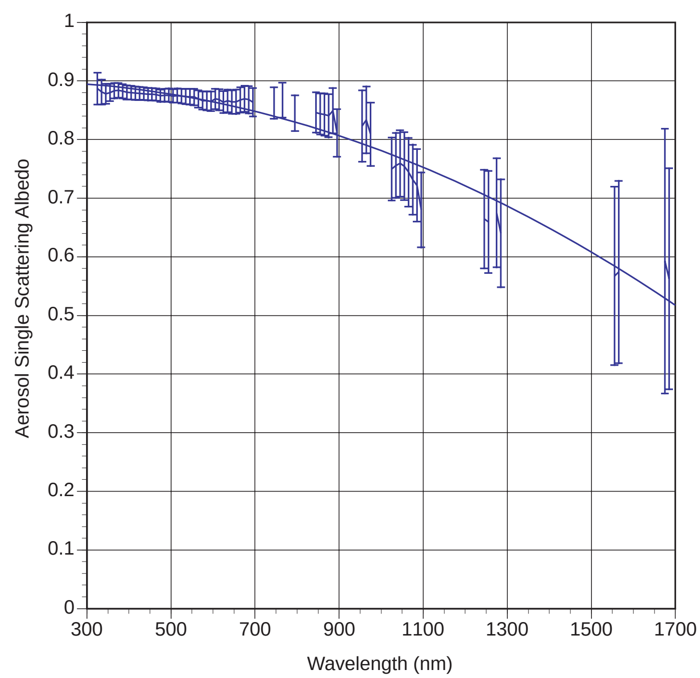

Figure 3. Derived single scattering albedo for the biomass burning aerosol sampled in the 6 September 2000 Mongu, Zambia, case study.

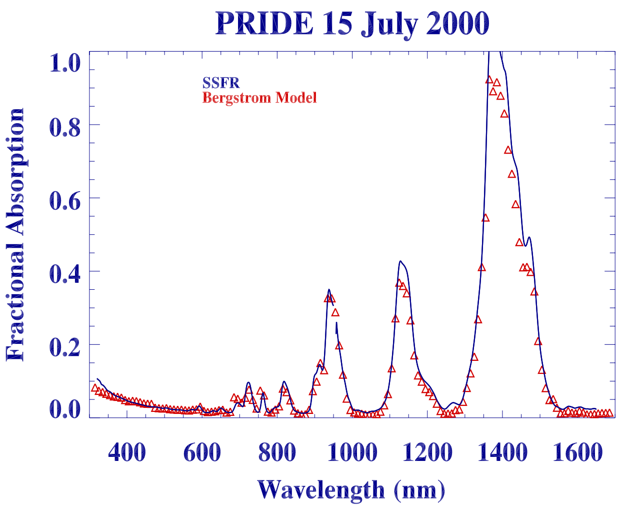

Figure 4. Measured (blue spectrum) and modeled (red triangles) fractional absorption for a dust layer during the PRIDE case study on 15 July 2000.

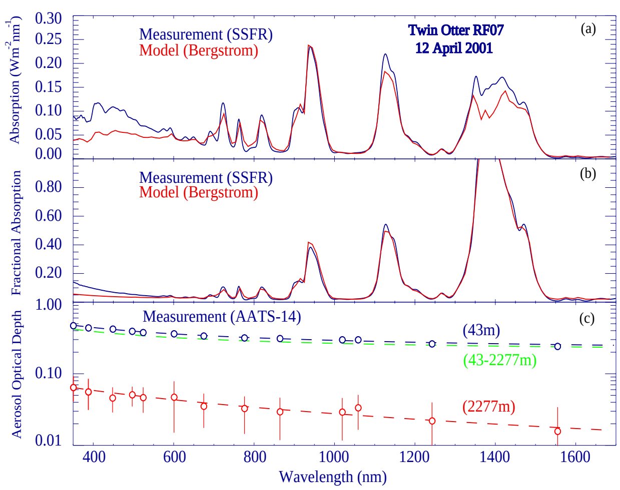

Figure 5. (a) Measured (blue) and modeled (red) absorption spectra for the ACE-Asia profile flown on Twin Otter Flight RF07, 12 April 2001. (b) Corresponding spectra of fractional absorption. (c) AOD spectra measured simultaneously on the same aircraft.

The fractional absorption in Figure 2a can be combined with the AOD in Figure 1c to estimate aerosol single scattering albedo using the radiative transfer model described above. The best-fit single scattering albedo thus obtained is shown in Figure 3 with the wavelength regions dominated by gaseous absorption removed. The error bars for the single scattering albedo are estimated from the error bars in the fractional absorption, shown in Figure 2b. These errors result primarily from uncertainties in SSFR tilt during aircraft pitch and roll (see also below). The spectral slope of the aerosol SSA shows the decrease with wavelength expected for black carbon (Bergstrom et al., 2002a).

2.2.3.2 Dust Aerosol. Radiative profiles in dust layers were acquired during the Puerto Rico Dust Experiment (PRIDE) and the Asian Pacific Aerosol Characterization Experiment (ACE-Asia). Following the methodology described above, we used these to derive the spectral absorption in dust layers from which aerosol radiative parameters could be derived. Figure 4 shows agreement between measured and modeled dust absorption during PRIDE on 15 July 2000.

Figure 5 shows spectra of absorption and AOD measured simultaneously on an ACE-Asia flight. The model calculations shown in Figure 5 assumed a wavelength-independent 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 6. Figure 7 compares the SSA spectra derived for these PRIDE and ACE-Asia cases to published results for

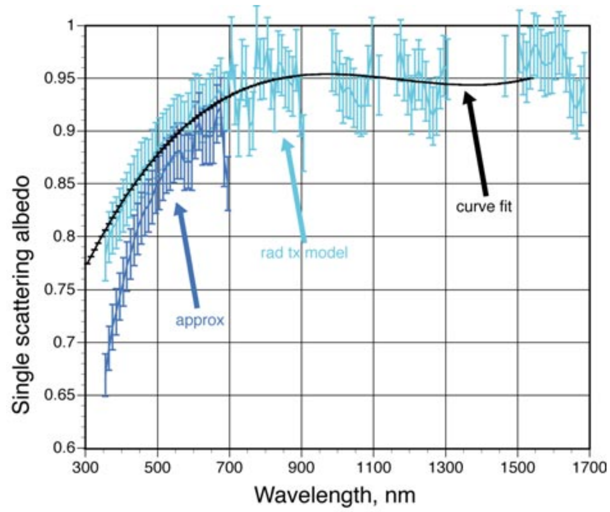

Figure 6. Aerosol single scattering albedo spectra derived from the measured flux and AOD spectra in Figure 5.

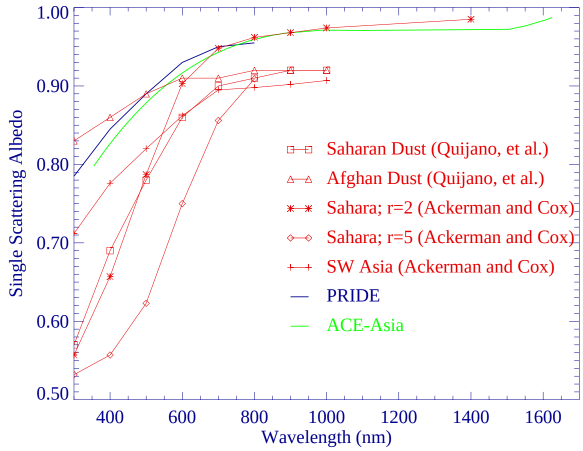

Figure 7. Derived dust single scattering albedo from PRIDE (blue curve) and ACE-Asia (green curve). Five aerosol models are shown for comparison (Quijano et al., 2000; Ackerman and Cox, 1988)

Saharan, Afghan and SW Asian dusts (Quijano et al., 2000; Ackerman and Cox, 1988).

2.2.4 Solar Absorption in Clouds, and Relationship to Aerosols

The NACIP White Paper (Ramanathan et al., 2002) emphasizes the need to elucidate the many aerosol-cloud interactions. As noted in Section 2.1, one such interaction is the "burning off" of clouds by aerosol absorption, and there are others relating to modified surface evapotranspiration and atmospheric dynamics. Hence, there is a need to better understand the relationships between aerosol absorption and cloud properties. In this connection we note that the flux divergence method can be used to measure cloud absorption and other properties as well as aerosol absorption. In fact, SSFR measurements have been used for this purpose in the second ARM Enhanced Shortwave Experiment (ARESE II). Recent results (Pilewskie et al., 2002b) show that SSFR flux spectra measured above and below cloud can be used to derive cloud absorption, mean effective droplet radius, cloud optical depth, and cloud water path values that agree with in situ microphysical measurements within the range of instrumental uncertainty. In the proposed research we plan to explore this capability by selecting and analyzing appropriate cloud-aerosol cases in the ACE-Asia and SGP Aerosol IOP data sets.

2.3 Prong B. Extinction Closure, Including Satellite Validation

The goals of this prong of the proposed research are to:

- Assess the consistency (closure) between solar beam attenuation measured by airborne sunphotometer and derived from in situ, lidar, and satellite methods.

- Provide results, grouped by aerosol condition, to Prongs A and C and to the community via summary data files, presentations and publications.

An important class of extinction closure studies addresses the question: "Can in situ measurements of aerosol properties account for the solar beam attenuation (extinction) by an aerosol layer or column?" Such closure studies have revealed important insights about aerosol sampling and inadvertent modification in such previous experiments as TARFOX (Hegg et al., 1997; Hartley et al. 2000), ACE-2 (Collins et al., 2000, Schmid et al., 2000) and SAFARI 2000 (Magi et al., 2002). We will base the study of extinction closure on the ACE-Asia and SGP Aerosol IOP data sets, and will include lidar extinction profiles and total column AOD from various satellites (as done for SAFARI by Schmid et al., 2002) and models (see below).

Key is the measurement of aerosol optical depth and columnar water vapor with the Ames Airborne Tracking Sunphotometers, AATS-14 and AATS-6 (e.g., Matsumoto et al., 1987). This is because inlet effects (e.g., loss or enhancement of large particles, shrinkage by evaporation of water, organics, or nitrates) and filter effects are avoided. AATS-14 measured the transmission of the direct solar beam at 14

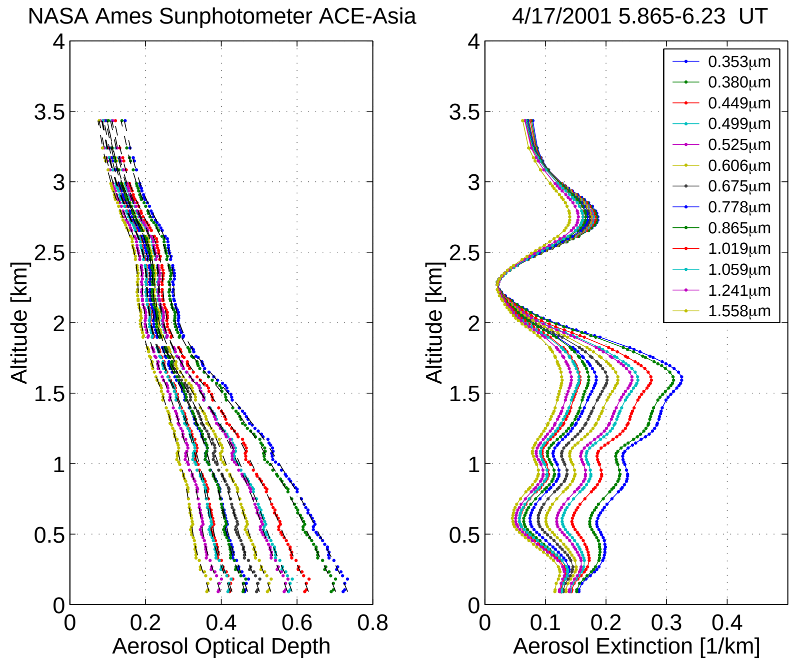

Figure 8. Left panel: Aerosol optical depth profiles at 13 wavelengths from 354 to 1558 nm calculated from AATS-14 measurements acquired during an aircraft ascent south of Korea on 17 April 2001 during ACE-Asia. Right panel: Corresponding aerosol extinction profiles derived by differentiating spline fits (dashed lines in left panel) to the optical depth profiles.

discrete wavelengths λ, from 354 to 1558 nm, during ACE-Asia. For the SGP Aerosol IOP the instrument's wavelength range is currently being extended to 2138 nm. AATS-6 measures at 6 discrete wavelengths between 380 and 1020 nm. From the direct solar beam transmission measurement we derive spectral aerosol optical depths AOD(λ), columnar water vapor, CWV, and columnar ozone. Flying at different altitudes over a fixed location allows derivation of AOD(λ) or CWV in a given layer. Data obtained in vertical profiles allows derivation of spectral aerosol extinction $E_a(\lambda)$ (see Figure) and water vapor density ρ_w.

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. An example from ACE-Asia where the in situ extinction is computed as the sum of scattering (from humidified nephelometry) and absorption (PSAP instrument) is shown in Figure 9. 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 combination of nephelometer and PSAP data are 20% - 40% less than those from AATS-6 or -14 measurements (Redemann et al., 2002). We propose a detailed analysis of all available ACE-Asia profiles including stratification of the closure results with respect to aerosol types, relative humidity, flight pattern during profile and other factors. Figure 10 shows an example result from an ACE-Asia closure study (Wang et al., 2002) that compares aerosol extinction from AATS-14 with values calculated from Mie theory using measured size distributions and composition (used to determine the complex refractive indices). This study, now submitted to *J. Geophys Res.*, is limited to four Twin Otter vertical profiles. We propose to conduct the same type of analysis for as many C-130 and Twin Otter vertical profiles as possible.

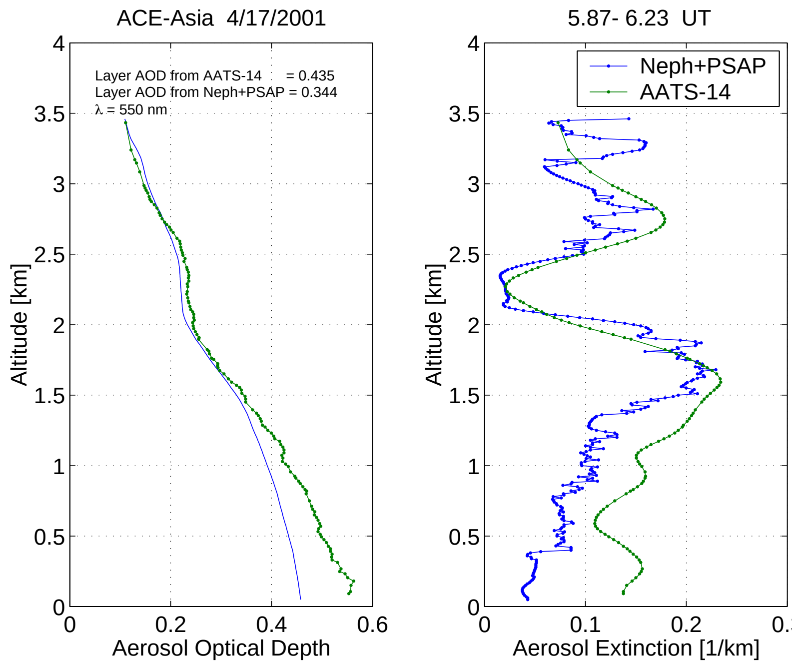

Figure 9. Aerosol optical depth (left) and extinction (right) profile at 550 nm measured by AATS-14 and computed as the sum of scattering (from humidified nephelometry) and absorption (PSAP instrument) during aircraft ascent shown in Figure 8.

We also propose to apply the described closure analysis to the data expected from the May 2003 SGP Aerosol IOP. This IOP will include airborne measurements of extinction using the relatively new Continuous Wave Cavity Ring-Down (CW-CRD) technology (Strawa et al., 2002). Although the CW-CRD instrument does sample aerosol through an inlet it directly measures in situ extinction, whereas typically in situ extinction is derived from the sum of scattering and absorption measured with two separate instruments (usually nephelometer and filter based absorption). Further advantages of the CW-CRD technique are the absence of filter artifacts, no heating of sample, no angular truncation error, and no illumination errors.

We will extend the extinction closure analysis to include comparisons with the numerous ground-based lidars deployed during ACE-Asia (e.g., Figure 10) and with the lidars operated routinely at SGP (e.g. Turner et al., 2002, Welton et al., 2001).

During ACE-Asia considerable effort was devoted to coordinating aircraft measurements with satellite overpasses. The list of sensors includes AVHRR, GMS-5, MISR, MODIS, SeaWiFS, TOMS and ATSR-2. Airborne sunphotometer measurements flown along transects near the land or ocean surface in ACE-Asia provide aerosol optical depth spectra useful for validating products from most of these sensors. At this point we have performed limited comparisons with SeaWiFS (Figure 11) and MISR. These indicate good agreement between SeaWiFS and AATS-14 if the Hsu et al. (2002) algorithm is used. MISR currently tends to overestimate the AOD with respect to AATS-14. Prompted by these early comparisons the MISR team became aware of an instrument stray light problem, which is currently being addressed (R. Kahn, personal communication). In the framework of this proposal we hope to complete comparisons with all sensors listed above.

Finally we propose to use our ACE-Asia AATS measurements to help validate aerosol transport models such as CFORS (e.g., Uno et al., 2001), GOCART (Chin et al., 2001), MATCH (Collins, 2002; Rasch and Collins, 2001), and NAAPS (e.g., Bucholtz et al., 2002) in vertical profiles and along horizontal

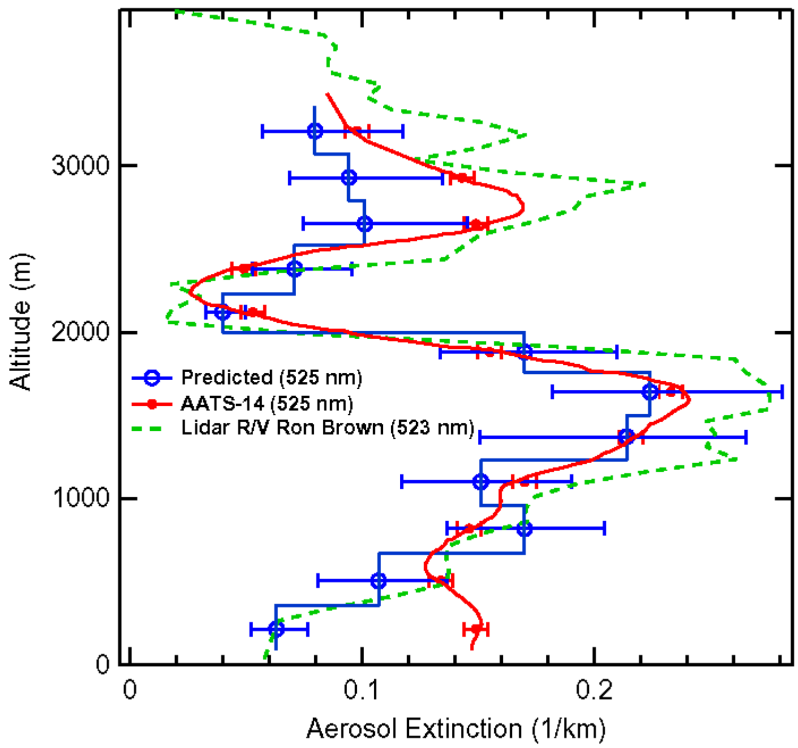

Figure 10. Comparison of aerosol extinction derived from AATS-14 measurement, aerosol size distributions, and lidar measurements on R/V Ron Brown during the ascent shown in Figure 8 (Wang et al., 2002a).

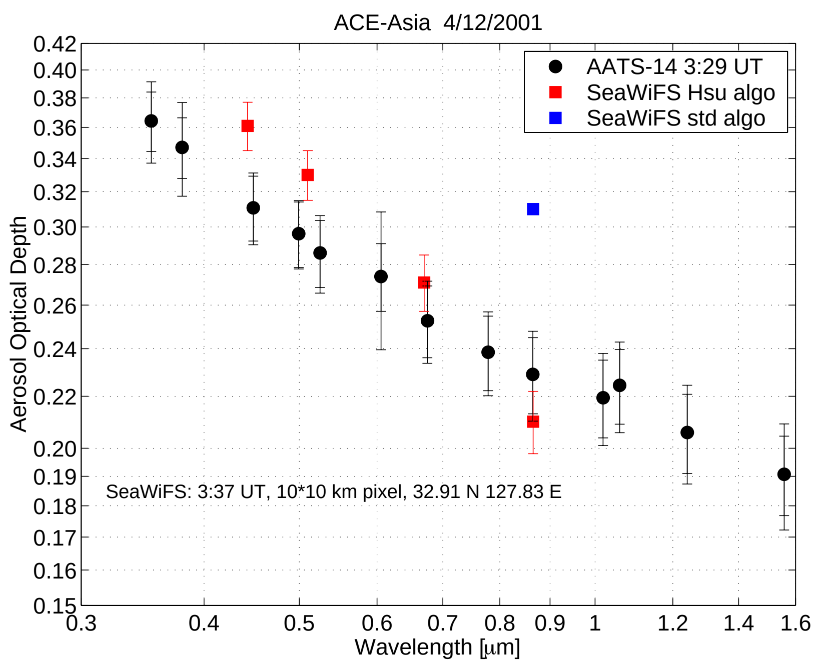

Figure 11. Comparison of spectral aerosol optical depth on April 12, 2001 between AATS-14 and SeaWiFS, using standard and Hsu et al. (2002) algorithms.

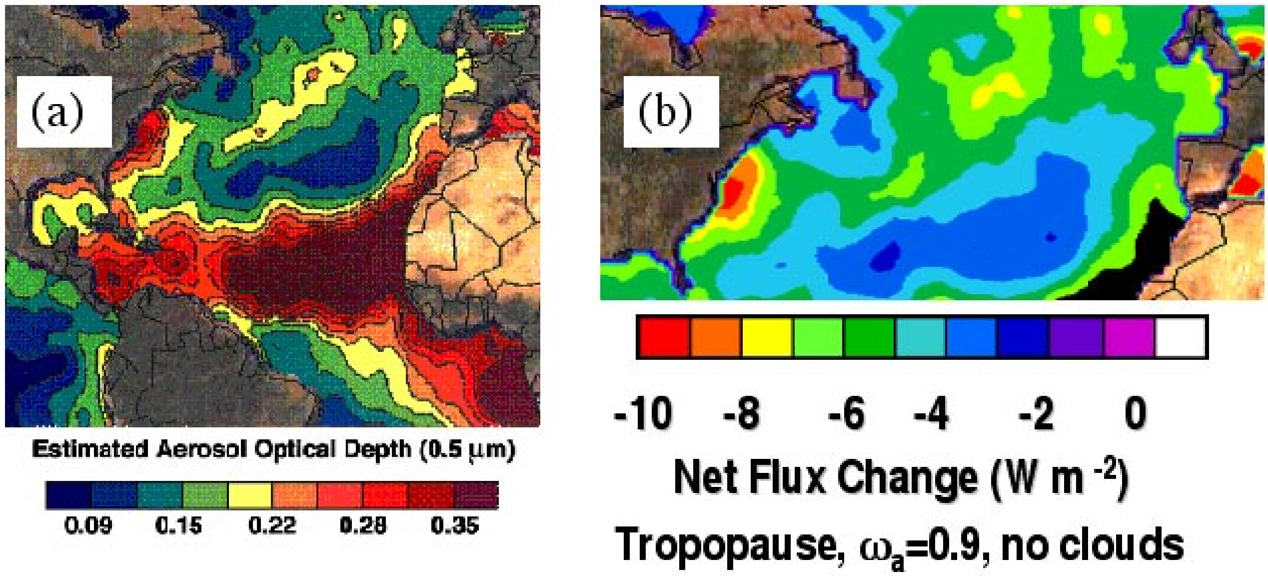

Figure 12. (a) June-August mean AOD at 500 nm derived from AVHRR radiances by Husar et al. (1997). (b) 24h-average, cloud-free direct shortwave aerosol radiative forcing at the tropopause derived from the total aerosol optical depth map in (a). The radiative calculation (Bergstrom and Russell, 1999) assumes an aerosol model based on suborbital measurements in TARFOX and ACE-2. The choice of SSA shown here, ω_a=0.9, is based on radiative flux measurements; other measurements yielded larger SSA (ω_a~0.92 to 0.98) (Russell et al., 2002a). Bergstrom and Russell (1999) show results for ω_a=1 and ω_a=0.9.

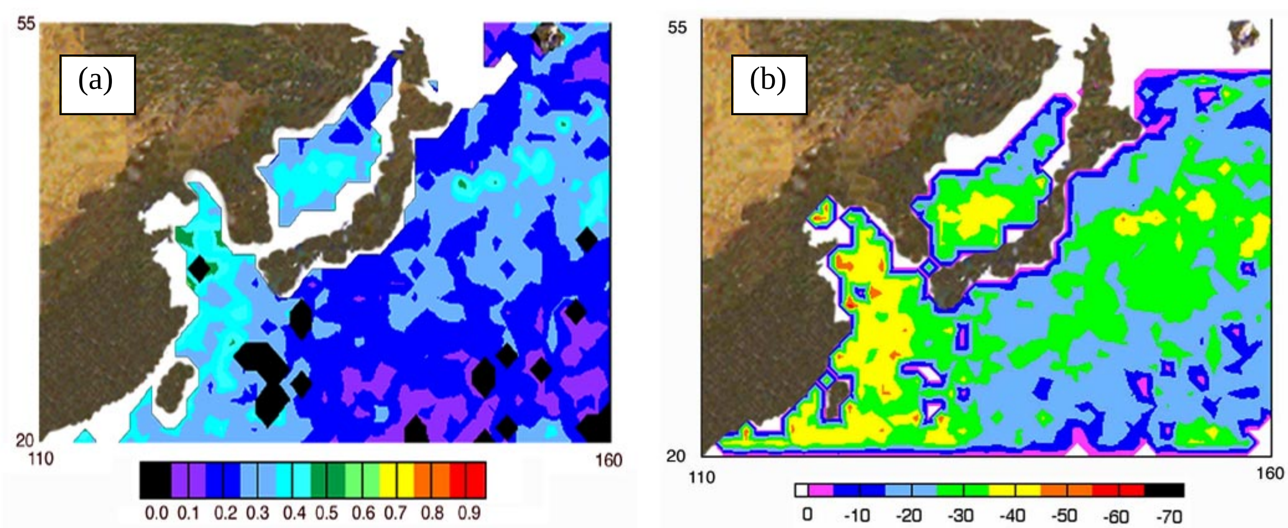

Figure 13. (a) April 2001 monthly mean AOD at 865 nm derived from SeaWiFS radiances using the algorithm of Hsu et al. (2002). (b) 24h-average, cloud-free direct shortwave aerosol radiative forcing at the surface in Wm^{-2}, derived from total aerosol optical depth shown in (a). The radiative calculation assumes an aerosol model of dust over pollution aerosols. The relative amounts of dust and pollution aerosols are adjusted pixel-by-pixel to force model Angstrom exponent to equal the Angstrom exponent derived from the 4-wavelength SeaWiFS radiances by Hsu et al. (2002).

gradients. An initial comparison between GOCART and AATS-14 has been presented by Chin et al. (2001).

2.4 Prong C. Regional Forcing Assessments by Combining Satellite and Suborbital Results

Our first regional assessment of aerosol radiative forcing (Bergstrom and Russell, 1999) combined single-wavelength seasonal AOD maps of the North Atlantic region with aerosol intensive properties derived from the TARFOX and ACE-2 field programs. The AOD maps were derived by Husar et al. (1997) from AVHRR reflectances; an example is shown in Figure 12a. The aerosol intensive properties included optical depth wavelength dependence across the solar spectrum, single scattering albedo, hemispheric upscatter fraction, and relative vertical profile, all synthesized from suborbital measurements by aircraft and ground sites (including lidars). The satellite and suborbital inputs were combined in a radiative transfer model (Bergstrom et al., 2002b) to derive maps of cloud-free and all-sky radiative forcing; an example is shown in Figure 12b.

The goal of Prong C is to provide improved assessments of regional radiative forcing by extending the approach of Bergstrom and Russell (1999) to include the greatly enhanced measurement capabilities of newer satellite sensors (e.g., SeaWiFS, MODIS, MISR, CERES) and new field campaign data. For example, the following satellite-derived aerosol products are available:

1. Maps of aerosol optical depth from AVHRR (ftp://ssa.noaa.gov/patmosa/)

2. Maps of a dust index from GMS-5 (dustnpgs at http://www.joss.ucar.edu/cgi-bin/joss-catalog/ace-asia/products/index)

3. Maps of absorbing aerosol index from TOMS (http://toms.gsfc.nasa.gov/aerosols/aerosols.html)

4. Maps of optical depth mode radius and the ratio of coarse to fine particles from MODIS (http://modis-atmos.gsfc.nasa.gov/MOD04_L2/);

5. Maps of aerosol optical depth and Angstrom exponent from SeaWiFS (Hsu et al. (2002), available at http://code916.gsfc.nasa.gov/Missions/ACEASIA/satellite)

6. Maps of optical depths and the dominant aerosol type (dust, black carbon, sea salt and sulfate) (Higurashi and Nakajima, 2002; Hsu et al., 2002).

A primary focus of Prong C will be the Asian Pacific plume of desert dust and pollution, which is one of the world's most climatically significant aerosols. Initial studies on the radiative impact of Asian aerosols on the basis of SeaWiFS-derived measurements of aerosol optical depth and Angstrom exponent, as well as in situ data obtained during ACE-Asia, have been presented by Russell et al. (2002b). Figure 13a shows a map of the April 2001 monthly mean aerosol optical depth at 865 nm, derived from SeaWiFS-measured radiances using the algorithm of Hsu et al. (2002). Using the map in Figure 13a in conjunction with the satellite retrieved Angstrom parameter and assumptions regarding (i) the aerosol single scattering albedo (and its wavelength dependence); (ii) the asymmetry parameter (and its wavelength dependence) and (iii) the partitioning of the relative contributions of mineral dust and pollution-type aerosol to the total aerosol optical depth enables the computation of corresponding maps of shortwave direct aerosol radiative forcing of climate at the surface or at the top of the atmosphere (TOA). An example for surface radiative forcing is shown in Figure 13b.

In computing the forcing in Figure 13b, we were limited to taking the SeaWiFS-retrieved optical depth and Angstrom exponent and then applying our own radiative transfer model. In this work we propose to utilize the results from Parts A and B above to improve our estimates of the radiative forcing of aerosols in the ACE-Asia region. In particular, the results of the column closure studies (see Section 2.3) carried out in support of ACE-Asia (e.g., Redemann et al., 2002) are expected to yield:

1. Detailed information on the validity of aerosol absorption properties as measured by the PSAP instruments aboard the NCAR C-130 and the CIRPAS Twin-Otter;

2. The vertical distribution of aerosol extinction from comparison of sunphotometer- and in situ- derived aerosol properties (cf. Figures 8-10);

3. Information on the vertical distribution of aerosol species based on the vertical distribution of Angstrom parameters.

This information will be combined with the observed absorption results of Prong A (Section 2.2) to constrain the inputs to the radiative transfer model. For example, the aerosol observed during the ACE Asia campaign was extremely complex mixture of dust and urban pollution. Using the detailed radiative transfer model described in Section 2.2.2, we will compute the effect of the multi-modal aerosol on the observed satellite radiances. (The included multiple scattering code, DISORT, can compute radiances as well as fluxes.)

To avoid the inconsistency in using one model of aerosol radiative properties to convert the satellite-measured radiances into aerosol optical depth and a different model to convert the aerosol optical depth to aerosol radiative forcing, we also propose to collaborate with the teams of A. Higurashi (National Institute of Environmental Studies, Ibaraki, Japan) and T. Nakajima (Univ. of Tokyo, Tokyo, Japan). We will work with them to develop an aerosol model for SeaWiFS measurements that will be used in both the conversion of satellite radiances to AOD and in the conversion of AOD to aerosol radiative forcing of climate. We will also perform sensitivity tests to assess how changing aerosol model parameters affects derived forcing, both when using the same model for both steps, and when using different models in each step. This should enable us to more accurately estimate the aerosol radiative forcing and the associated uncertainties. A major objective will be to quantify and reduce the uncertainties in aerosol radiative-climatic effects cited by NACIP (Ramanathan et al., 2002)

Initial comparisons between various satellite sensors (e.g., MODIS vs. SeaWiFS) indicate considerable differences in temporally-averaged fields of aerosol optical depth. Such differences could be due to the complex interaction of aerosols and clouds in the western Pacific region and the associated complications in satellite cloud screening algorithms, or due to inadequate modeling of the mixtures of various aerosol types in satellite retrieval algorithms. Hence, as a second element of this task, we propose to compare the aerosol optical depth fields derived from various satellite sensors (MODIS, SeaWiFS, MISR, AVHRR) as they are relevant to the calculation of regional mean aerosol radiative forcing of climate. Based on the comparison of instantaneously measured aerosol optical depth between suborbital and satellite sensors proposed in Section 2.3, we expect to aid in explaining any differences found between aerosol products from different satellite sensors.

2.5 Proposed Tasks and Timetable

For the funding requested in Section 3 we will provide the necessary personnel, equipment, and facilities, and will perform the following tasks.

2.5.1 Year One (March 1, 2003 - February 28, 2004)

2.5.1.1 Task A1: Derive aerosol absorption and SSA spectra for a representative variety of aerosol types and conditions using the ACE-Asia Twin Otter SSFR and AATS-14 data sets. Assess uncertainties, taking into account radiometer tilt and all other significant error sources. Compare results to those from other ACE-Asia measurements and the literature for similar aerosols. Begin corresponding analyses for the May 2003 SGP Aerosol IOP data set, to the extent permitted by the state of data reduction for that experiment.

2.5.1.2 Task A2: Provide results of Task A1 to Prongs B and C and to the community in summary data files, presentations and publications.

2.5.1.3 Task B1: Perform extinction closure studies for a representative variety of ACE-Asia aerosols by comparing extinction and optical depth spectra and profiles measured by airborne sunphotometer to results from airborne in situ, lidar, and satellite methods. Synthesize results in terms of uncertainties in key parameters as a function of aerosol and surface condition (e.g., over water vs. land) and measurement or retrieval type.

2.5.1.4 Task B2: Provide results of Task B1 to Prongs A and C and to the community in summary data files and in presentations and publications.

2.5.1.3 Task C1: Assess aerosol radiative forcing for the ACE-Asia region by combining satellite and suborbital results, including those from Prongs A and B. Quantify uncertainties via sensitivity studies that combine uncertainties in input parameters with sensitivities of outputs to inputs. Devote special efforts to cloud effects, both on the satellite retrievals and on radiative flux changes. Quantify the benefit of using a consistent model in satellite retrievals and flux-change calculations.

2.5.1.4 Task C2: Provide results of Task C1 to the community in summary data files and in presentations and publications.

2.5.2 Years Two and Three (March 1, 2004 - February 28, 2006)

2.5.2.1 Task A3: Complete the publication of the ACE-Asia absorption results. Complete the analysis, presentation, and publication of SGP Aerosol IOP absorption results, including an assessment of the accuracy improvement resulting from the stabilized radiometer platform. Synthesize the overall results in terms of aerosol absorption and SSA spectra for major aerosol types. Compare to results of other measurements and previous studies, sorting results by aerosol type.

2.5.2.2 Task B3: Complete the publication of the ACE-Asia extinction closure results. Complete the analysis, presentation, and publication of SGP Aerosol IOP results, including a synthesis of results in terms of uncertainties in key parameters as a function of aerosol and surface condition (e.g., over water vs. land) and measurement type, including absorption results of Prong A.

2.5.2.3 Task C3: Complete the publication of the ACE-Asia regional forcing results, and the analysis, presentation, and publication of SGP Aerosol IOP results. Include a synthesis of results in terms of satellite retrieval type, aerosol type, surface condition (e.g., over water vs. land) and cloud condition. Assess implications for forcing by aerosol type in the major aerosol-influenced regions of the world. Emphasize quantification and reduction of the uncertainties cited by NACIP (Ramanathan et al., 2002).

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3. BUDGET

	FY03							
	$K	Prong A		Prong B		Prong C		Total
	/WY	WY	$K	WY	$K	WY	$K	$K
Civil Service+Contractors								
P. Russell (Lead PI)				0.05		0.10		
P. Pilewskie, Co-PI		0.15						
Secty/Admin (SGG,SG,S,F, etc.)		0.02		0.02		0.02		
Total		**0.17**		**0.07**		**0.12**		
F&A costs* **	48.5	0.17	8.2	0.07	3.4	0.12	5.8	17.5
Co-op								
B. Schmid, Co-PI (BAERI)	142			0.25	35.5	0.03	4.3	39.8
J. Redemann, Co-PI (BAERI)	129			0.07	9.0	0.18	23.2	32.3
S. Ramirez (BAERI)	61			0.10	6.1	0.10	6.1	12.2
S. Howard (BAERI)	92	0.20	18.3					18.3
J. Pommier (BAERI)	102	0.20	20.5					20.5
R. Bergstrom (BAERI)	159	0.15	23.9			0.12	19.1	42.9
J. Livingston (SRI)	235			0.04	9.4			9.4
Total		**0.55**	**62.6**	**0.46**	**60.0**	**0.43**	**52.7**	**175.3**
F&A costs* **	14.5	0.55	8.0	0.46	6.7	0.43	6.2	20.9
Computation & Lab Support								
Network and computer support			3.0		4.0		4.0	11.0
Computer/Peripheral Repairs					2.0		2.0	4.0
Computer Hardware					4.0		4.0	8.0
Bldg 245 Journal Subscriptions			0.3		0.5		0.5	1.3
Travel			8.6		9.4		10.3	28.3
Publications			2.0		3.0		3.0	8.0
Division Reserve (1.5%)			1.4		1.4		1.3	4.2
NASA Reimbursible Taxes (6%)			5.7		5.7		5.4	16.7
Total			**99.9**		**100.1**		**95.3**	**295.2**

***Explanation for Facilities & Administrative (F&A) Costs

For Civil Servants F&A =G&A +ASP+Directorate Reserve (see below)
For Co-op F&A =0.5*ASP

Directorate Reserve of $2.0k per workyear is currently not charged on reimbursable tasks and is excluded from rates above.

General and Administrative (G&A) Costs are those not attributable to any one project, but benefiting the entire organization. G&A is calculated by dividing the ARC Institutional costs by the assigned direct workforce. Functions funded from G&A include Safety, Mail Services, Fire, Security, Environomental, Center Management and Staff, Medical Services, and Administrative ADP.

Allocated Service Pool (ASP) charges are not immediately identified to a project but can be assigned based on usage or comsumption. Functions funded include Computer Security, Network Replacement, ISO 9000, Utilities, Photo & Imaging, Maintenance, Data Communications, and Instrumentation.

BUDGET (cont'd)

	FY04							
	$K	Prong A		Prong B		Prong C		Total
	/WY	WY	$K	WY	$K	WY	$K	$K
Civil Service+Contractors								
P. Russell (Lead PI)				0.05		0.10		
P. Pilewskie, Co-PI		0.15						
Secty/Admin (SGG,SG,S,F, etc.)		0.02		0.02		0.02		
Total		**0.17**		**0.07**		**0.12**		
F&A costs* **	54.5	0.17	9.3	0.07	3.8	0.12	6.5	19.6
Co-op								
B. Schmid, Co-PI (BAERI)	155		0.0	0.25	38.7	0.03	4.6	43.3
J. Redemann, Co-PI (BAERI)	141		0.0	0.07	9.8	0.18	25.3	35.2
S. Ramirez (BAERI)	66		0.0	0.10	6.6	0.10	6.6	13.2
S. Howard (BAERI)	95	0.20	19.0					19.0
J. Pommier (BAERI)	106	0.20	21.2					21.2
R. Bergstrom (BAERI)	169	0.15	25.4			0.12	20.3	45.6
J. Livingston (SRI)	247			0.04	9.9			9.9
Total		**0.55**	**65.5**	**0.46**	**65.0**	**0.43**	**56.8**	**187.3**
F&A costs* **	16.5	0.55	9.1	0.46	7.6	0.43	7.1	23.8
Computation & Lab Support								
Network and computer support			3.2		3.3		4.4	10.9
Computer/Peripheral Repairs					2.0		2.0	4.0
Computer Hardware					4.0		4.0	8.0
Bldg 245 Journal Subscriptions			0.3		0.5		0.5	1.3
Travel			7.6		5.3		9.4	22.3
Publications			4.0		4.0		4	12.0
Division Reserve (1.5%)			1.5		1.5		1.4	4.4
NASA Reimbursible Taxes (6%)			6.0		5.8		5.8	17.6
Total			**106.4**		**102.8**		**102.0**	**311.2**

***Explanation for Facilities & Administrative (F&A) Costs

For Civil Servants F&A =G&A +ASP+Directorate Reserve (see below)
For Co-op F&A =0.5*ASP

Directorate Reserve of $2.0k per workyear is currently not charged on reimbursable tasks and is excluded from rates above.

General and Administrative (G&A) Costs are those not attributable to any one project, but benefiting the entire organization. G&A is calculated by dividing the ARC Institutional costs by the assigned direct workforce. Functions funded from G&A include Safety, Mail Services, Fire, Security, Environomental, Center Management and Staff, Medical Services, and Administrative ADP.

Allocated Service Pool (ASP) charges are not immediately identified to a project but can be assigned based on usage or comsumption. Functions funded include Computer Security, Network Replacement, ISO 9000, Utilities, Photo & Imaging, Maintenance, Data Communications, and Instrumentation.

BUDGET (cont'd)

	FY05							
	$K	Prong A		Prong B		Prong C		Total
	/WY	WY	$K	WY	$K	WY	$K	$K
Civil Service+Contractors								
P. Russell (Lead PI)				0.05		0.10		
P. Pilewskie, Co-PI		0.15						
Secty/Admin (SGG,SG,S,F, etc.)		0.02		0.02		0.02		
Total		**0.17**		**0.07**		**0.12**		
F&A costs* **	64.5	0.17	11.0	0.07	4.5	0.12	7.7	23.2
Co-op								
B. Schmid, Co-PI (BAERI)	169			0.25	42.2	0.03	5.1	47.2
J. Redemann, Co-PI (BAERI)	153			0.07	10.7	0.18	27.6	38.3
S. Ramirez (BAERI)	72			0.10	7.2	0.10	7.2	14.4
S. Howard (BAERI)	98	0.20	19.6					19.6
J. Pommier (BAERI)	109	0.20	21.9					21.9
R. Bergstrom (BAERI)	179	0.10	17.9			0.12	21.5	39.4
J. Livingston (SRI)	259			0.04	10.4			10.4
Total		**0.50**	**59.4**	**0.46**	**70.5**	**0.43**	**61.3**	**191.2**
F&A costs* **	18.0	0.50	9.0	0.46	8.3	0.43	7.7	25.0
Computation & Lab Support								
Network and computer support			3.3		3.6		4.8	11.7
Computer/Peripheral Repairs					2.0		2.0	4.0
Computer Hardware					4.0		4.0	8.0
Bldg 245 Journal Subscriptions			0.3		0.5		0.5	1.3
Travel			8.1		5.6		8.9	22.6
Publications			4.0		5.0		5.0	14.0
Division Reserve (1.5%)			1.4		1.6		1.6	4.6
NASA Reimbursible Taxes (6%)			5.8		6.3		6.2	18.3
Total			**102.3**		**111.9**		**109.8**	**324.0**

***Explanation for Facilities & Administrative (F&A) Costs

For Civil Servants F&A =G&A +ASP+Directorate Reserve (see below)
For Co-op F&A =0.5*ASP

Directorate Reserve of $2.0k per workyear is currently not charged on reimbursable tasks and is excluded from rates above.

General and Administrative (G&A) Costs are those not attributable to any one project, but benefiting the entire organization. G&A is calculated by dividing the ARC Institutional costs by the assigned direct workforce. Functions funded from G&A include Safety, Mail Services, Fire, Security, Environomental, Center Management and Staff, Medical Services, and Administrative ADP.

Allocated Service Pool (ASP) charges are not immediately identified to a project but can be assigned based on usage or comsumption. Functions funded include Computer Security, Network Replacement, ISO 9000, Utilities, Photo & Imaging, Maintenance, Data Communications, and Instrumentation.

BUDGET (cont'd. FY03, FY04, FY05 and Total)

	FY03								FY04								FY05								TOTAL			
	$K	Prong A		Prong B		Prong C		Total	$K	Prong A		Prong B		Prong C		Total	$K	Prong A		Prong B		Prong C		Total	Prong			Total
	/WY	WY	$K	WY	$K	WY	$K	$K	/WY	WY	$K	WY	$K	WY	$K	$K	/WY	WY	$K	WY	$K	WY	$K	$K	A, $K	B, $K	C, $K	$K
Civil Service+Contractors																												
P. Russell (Lead PI)				0.05		0.10						0.05		0.10						0.05		0.10						
P. Pilewskie, Co-PI		0.15								0.15								0.15										
Secty/Admin (SGG,SG,S,F, etc.)		0.02		0.02		0.02				0.02		0.02		0.02				0.02		0.02		0.02						
Total		**0.17**		**0.07**		**0.12**				**0.17**		**0.07**		**0.12**				**0.17**		**0.07**		**0.12**						
F&A costs* **	48.5	0.17	8.2	0.07	3.4	0.12	5.8	17.5	54.5	0.17	9.3	0.07	3.8	0.12	6.5	19.6	64.5	0.17	11.0	0.07	4.5	0.12	7.7	23.2	28.5	11.7	20.1	60.3
Co-op																												
B. Schmid, Co-PI (BAERI)	142			0.25	35.5	0.03	4.3	39.8	155		0.0	0.25	38.7	0.03	4.6	43.3	169			0.25	42.2	0.03	5.1	47.2	0.0	116.4	14.0	130.3
J. Redemann, Co-PI (BAERI)	129			0.07	9.0	0.18	23.2	32.3	141		0.0	0.07	9.8	0.18	25.3	35.2	153			0.07	10.7	0.18	27.6	38.3	0.0	29.6	76.1	105.7
S. Ramirez (BAERI)	61			0.10	6.1	0.10	6.1	12.2	66		0.0	0.10	6.6	0.10	6.6	13.2	72			0.10	7.2	0.10	7.2	14.4	0.0	19.9	19.9	39.8
S. Howard (BAERI)	92	0.20	18.3					18.3	95	0.20	19.0					19.0	98	0.20	19.6					19.6	56.9			56.9
J. Pommier (BAERI)	102	0.20	20.5					20.5	106	0.20	21.2					21.2	109	0.20	21.9					21.9	63.5			63.5
R. Bergstrom (BAERI)	159	0.15	23.9			0.12	19.1	42.9	169	0.15	25.4			0.12	20.3	45.6	179	0.10	17.9			0.12	21.5	39.4	67.1		60.8	127.9
J. Livingston (SRI)	235			0.04	9.4			9.4	247			0.04	9.9			9.9	259			0.04	10.4			10.4		29.6		29.6
Total		**0.55**	**62.6**	**0.46**	**60.0**	**0.43**	**52.7**	**175.3**		**0.55**	**65.5**	**0.46**	**65.0**	**0.43**	**56.8**	**187.3**		**0.50**	**59.4**	**0.46**	**70.5**	**0.43**	**61.3**	**191.2**	**187.5**	**195.5**	**170.8**	**553.8**
F&A costs* **	14.5	0.55	8.0	0.46	6.7	0.43	6.2	20.9	16.5	0.55	9.1	0.46	7.6	0.43	7.1	23.8	18.0	0.50	9.0	0.46	8.3	0.43	7.7	25.0	26.1	22.5	23.3	71.9
Computation & Lab Support																												
Network and computer support			3.0		4.0		4.0	11.0			3.2		3.3		4.4	10.9			3.3		3.6		4.8	11.7	9.5	10.9	13.2	33.6
Computer/Peripheral Repairs					2.0		2.0	4.0					2.0		2.0	4.0					2.0		2.0	4.0		6.0	6.0	12.0
Computer Hardware					4.0		4.0	8.0					4.0		4.0	8.0					4.0		4.0	8.0		12.0	12.0	24.0
Bldg 245 Journal Subscriptions			0.3		0.5		0.5	1.3			0.3		0.5		0.5	1.3			0.3		0.5		0.5	1.3	0.9	1.5	1.5	3.9
Travel			8.6		9.4		10.3	28.3			7.6		5.3		9.4	22.3			8.1		5.6		8.9	22.6	24.4	20.3	28.6	73.2
Publications			2.0		3.0		3.0	8.0			4.0		4.0		4	12.0			4.0		5.0		5.0	14.0	10.0	12.0	12.0	34.0
Division Reserve (1.5%)			1.4		1.4		1.3	4.2			1.5		1.5		1.4	4.4			1.4		1.6		1.6	4.6	4.4	4.5	4.3	13.2
NASA Reimbursible Taxes (6%)			5.7		5.7		5.4	16.7			6.0		5.8		5.8	17.6			5.8		6.3		6.2	18.3	17.5	17.8	17.4	52.7
Total			**99.9**		**100.1**		**95.3**	**295.2**			**106.4**		**102.8**		**102.0**	**311.2**			**102.3**		**111.9**		**109.8**	**324.0**	**308.6**	**314.7**	**309.3**	**932.6**

***Explanation for Facilities & Administrative (F&A) Costs

For Civil Servants F&A =G&A +ASP+Directorate Reserve (see below)
For Co-op F&A =0.5*ASP

Directorate Reserve of $2.0k per workyear is currently not charged on reimbursable tasks and is excluded from rates above.

General and Administrative (G&A) Costs are those not attributable to any one project, but benefiting the entire organization. G&A is calculated by dividing the ARC Institutional costs by the assigned direct workforce. Functions funded from G&A include Safety, Mail Services, Fire, Security, Environomental, Center Management and Staff, Medical Services, and Administrative ADP.

Allocated Service Pool (ASP) charges are not immediately identified to a project but can be assigned based on usage or comsumption. Functions funded include Computer Security, Network Replacement, ISO 9000, Utilities, Photo & Imaging, Maintenance, Data Communications, and Instrumentation.

Travel

	Airfare			Per Diem			Car					Total incl. co-op agreement travel burden
	Trips	$/trip	Total	Days	$/day	Total	Days	$/day	Total	Misc	Total	
FY2003												
Prong A												
Science Meeting, assumed New York												
Pilewskie	1	600	600	5	254	1,270			0	400	$2,270	$2,270
IUGG,Sapporo, JAPAN, 30 June - 11 July 2003												
Pilewskie	1	1,300	1,300	5	259	1,295			0	300	$2,895	$2,895
Science Meeting, assumed Europe												
Bergstrom	1	1,300	1,300	5	250	1,250			0	400	$2,950	$3,466
												$8,631
Prong B												
AGU, San Francisco, 6 - 10 December 2002												
Schmid										300	$300	$353
2003 EGS - AGU - EUG Joint Assembly,7 – 11 April 2003, Nice, FRANCE												
Schmid	1	1,000	1,000	5	186	930			0	400	$2,330	$2,738
IUGG,Sapporo, JAPAN, 30 June – 11 July 2003												
Schmid	1	1,300	1,300	5	259	1,295			0	300	$2,895	$3,402
Russell	1	1,300	1,300	5	259	1,295			0	300	$2,895	$2,895
												$9,387
Prong C												
AGU, San Francisco, 6 - 10 December 2002												
Redemann	1	300	300	5	205	1,025				300	$1,625	$1,909
Bergstrom										300	$300	$353
Science Meeting, assumed Chicago												
Russell	1	900	900	5	201	1,005			0	400	$2,305	$2,305
Bergstrom	1	900	900	5	201	1,005			0	400	$2,305	$2,708
Science Meeting, assumed Europe												
Redemann	1	1,300	1,300	5	200	1,000			0	300	$2,600	$3,055
												$10,330
FY2004												
Prong A												
Science Meeting, assumed Miami												
Piewskie	1	1,400	1,400	5	160	800	5	50	250	200	$2,650	$2,650
Bergstrom	1	1,400	1,400	5	160	800	5	50	250	200	$2,650	$3,114
Science Meeting assumed Boston												
Pilewskie	1	600	600	5	205	1,025			0	200	$1,825	$1,825
												$7,589
Prong B												
AGU, San Francisco, December 8 – 12 December 2003												
Schmid										300	$300	$353
Western Pacific Geophysics Meeting, 16 – 20 August 2004, Honolulu, HI												
Schmid	1	1,300	1,300	5	184	920	5	50	250	200	$2,670	$3,137
Science Meeting assumed Boston												
Russell	1	600	600	5	205	1,025			0	200	$1,825	$1,825
												$5,315
Prong C												
AGU, San Francisco, December 8 – 12 December 2003												
Redemann	1	300	300	5	205	1,025				300	$1,625	$1,909
Bergstrom										300	$300	$353
Western Pacific Geophysics Meeting, 16 – 20 August 2004, Honolulu, HI												
Redemann	1	1,300	1,300	5	184	920	5	50	250	200	$2,670	$3,137
Science Meeting assumed Boston												
Redemann	1	600	600	5	205	1,025			0	200	$1,825	$2,144
Russell	1	600	600	5	205	1,025			0	200	$1,825	$1,825
												$9,369

Travel (cont'd)

FY2005

Prong A										
Science Meeting assumed Asia										
Pilewskie	1	1,500	1,500	5	220	1,100	0	300	$2,900	$2,900
Bergstrom	1	1,500	1,500	5	220	1,100	0	300	$2,900	$3,408
Science Meeting assumed Boston										
Pilewskie	1	600	600	5	205	1,025	0	200	$1,825	$1,825
										$8,133
Prong B										
AGU, San Francisco, 13 – 17 December 2004										
Schmid								300	$300	$353
European Geophysical Society (EGS) XXX General Assembly, 25 – 29 April 2005, Nice, FRANCE										
Schmid	1	1,300	1,300	5	259	1,295	0	300	$2,895	$3,402
Science Meeting assumed Boston										
Russell	1	600	600	5	205	1,025	0	200	$1,825	$1,825
										$5,579
Prong C										
AGU, San Francisco, 13 – 17 December 2004										
Redemann	1	300	300	5	205	1,025		300	$1,625	$1,909
Bergstrom								300	$300	$353
Science Meeting assumed San Diego										
Russell	1	1,300	1,300	5	145	725	0	300	$2,325	$2,325
Science Meeting assumed Boston										
Redemann	1	600	600	5	205	1,025	0	200	$1,825	$2,144
Bergstrom	1	600	600	5	205	1,025	0	200	$1,825	$2,144
										$8,876

4. STAFFING, RESPONSIBILITIES, AND VITAE

Dr. Philip Russell will be Lead Principal Investigator. As such, he will supervise the work, lead the planning, and participate in the analyses, as well as selected presentations and publications. He will be responsible for the completion of the work within budget and schedule. Drs. Peter Pilewskie, Beat Schmid and Jens Redemann will be Co-PIs for Prongs A, B, and C, respectively, each responsible for leading his respective prong and coordinating it with the others. Dr. Robert Bergstrom will play key roles in Prongs A and C, including leading and facilitating the use of his radiative transfer model to (i) derive single scattering albedos from SSFR and AATS measurements and (ii) calculate regional radiative forcings. Ames will furnish additional personnel necessary to accomplish the research.

(a) Philip B. Russell
Abbreviated Curriculum Vitae

B.A., Physics, Wesleyan University (1965, Magna cum Laude; Highest Honors). M.S. and Ph.D., Physics, Stanford University (1967 and 1971, Atomic Energy Commission Fellow). M.S., Management, Stanford University (1990, NASA Sloan Fellow).

Postdoctoral Appointee, National Center for Atmospheric Research (1971-72, at University of Chicago and NCAR). Physicist to Senior Physicist, Atmospheric Science Center, SRI International (1972-82). Chief, Atmospheric Experiments Branch (1982-89), Acting Chief, Earth System Science Division (1988-89), Chief, Atmospheric Chemistry and Dynamics Branch (1989-95), Research Scientist (1995-present), NASA Ames Research Center.

Currently, Member, Science Teams for NASA's Earth Observing System Inter-Disciplinary Science (EOS-IDS) and the Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia) of the International Global Atmospheric Chemistry (IGAC) Project.

Previously, NASA Ames Associate Fellow (1995-96, awarded for excellence in atmospheric research).

Previously, Mission Scientist for ACE-Asia C-130 flights addressing aerosol-radiation interactions. Co-coordinator for the CLEARCOLUMN component of IGAC's Second Aerosol Characterization Experiment (ACE-2). Coordinator for IGAC's Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX). Member, Science Teams for SAGE II and SAGE III (satellite sensors of stratospheric aerosols, ozone, nitrogen dioxide, and water vapor). Member, Science Team for Global Aerosol Climatology Project (GACP).

Previously, Editor-in-Chief (1994-95) and Editor (1993, 1996), *Geophysical Research Letters*. Chair, American Meteorological Society Committee on Laser Atmospheric Studies (1979-82). Member, AMS Committee on Radiation Energy (1979-81). Member, National Research Council Committee on Army Basic Research (1979-81).

Previously, Project Scientist, Small High-Altitude Science Aircraft (SHASA) Project to develop the Perseus A Remotely Piloted Aircraft (RPA, 1992-94). Member, NASA Red Team on Remote Sensing and Environmental Monitoring of Planet Earth (1992-3). Leader, NASA Ames Earth Science Advanced Aircraft (ESAA) Team (1990-94).

NASA Exceptional Service Medal (1988, for managing Stratosphere-Troposphere Exchange Project). NASA Space Act Award (1989, for invention of Airborne Autotracking Sunphotometer). Member, Phi Beta Kappa and Sigma Xi.

SELECTED PUBLICATIONS (from 94 peer-reviewed papers)

Russell, P. B., et al., Comparison of aerosol single scattering albedos derived by diverse techniques in two North Atlantic experiments, *J. Atmos. Sci., 59*, 609-619, 2002.

Russell, P. B., and J. Heintzenberg, An overview of the ACE-2 Clear Sky Column Closure Experiment (CLEARCOLUMN), *Tellus B 52*, 463-483, 2000.

Bergstrom, R. W., and P. B. Russell, Estimation of aerosol radiative effects over the mid-latitude North Atlantic region from satellite and in situ measurements. *Geophys. Res. Lett., 26*, 1731-1734, 1999.

Russell, P. B., P. V. Hobbs, and L. L. Stowe, Aerosol properties and radiative effects in the United States Mid-Atlantic haze plume: An overview of the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX), *J. Geophys. Res*., *104*, 2213-2222, 1999.

Russell, P. B., S. Kinne and R. Bergstrom, Aerosol climate effects: Local radiative forcing and column closure experiments, *J. Geophys. Res.*, *102*, 9397-9407, 1997.

Russell, P. B., et al. Global to microscale evolution of the Pinatubo volcanic aerosol, derived from diverse measurements and analyses, *J. Geophys. Res.*, *101*, 18,745-18,763, 1996.

Russell, P.B., et al. Post-Pinatubo optical depth spectra vs. latitude and vortex structure: airborne tracking sunphotometer measurements in AASE II, *Geophys. Res. Lett.*, *20*, 2571-2574, 1993.

Russell, P.B., L. Pfister, and H.B. Selkirk, "The tropical experiment of the Stratosphere-Troposphere Exchange Project (STEP): Science objectives, operations, and summary findings, *J. Geophys. Res.*, *98*, 8563-8589, 1993.

Russell, P.B., and M.P. McCormick., SAGE II aerosol data validation and initial data use: an introduction and overview, *J. Geophys. Res.*, *94*, 8335-8338, 1989.

Russell, P.B., et al., Satellite and correlative measurements of the stratospheric aerosol: III. Comparison of measurements by SAM II, SAGE, dustsondes, filters, impactors, and lidar, *J. Atmos. Sci.*, *41*, 1791-1800, 1984.

(b) Peter Pilewskie
Abbreviated Curriculum Vitae

NASA Ames Research Center
MS 245-4, Moffett Field CA 94035-1000

Education:

B.S., Meteorology, Pennsylvania State University, 1983
M.S., Atmospheric Science, University of Arizona, 1986
Ph.D., Atmospheric Science, University of Arizona, 1989

Professional Experience:

Radiation Group Leader, Atmospheric Physics Branch, NASA Ames Research Center, 1994-present
Research Scientist, Atmospheric Physics Branch, NASA Ames Research Center, 1989-1994
Research Assistant, Institute of Atmospheric Physics, University of Arizona, 1983-1989

Professional Activities:

Member, Atmospheric Radiation Measurement (ARM) Enhanced Shortwave Experiment (ARESE) II Science Team
Member, Solar Radiation and Climate Experiment (SORCE), 1999-present
Member, Triana Science Team, 1998-present
Member, Global Aerosol Climatology Program (GACP), 1998-present
Member, Atmospheric Radiation Measurement Program (ARM) Science Team, 1997-present
Member, International Global Atmospheric Chemistry (IGAC), Focus on Atmospheric Aerosols, Direct Aerosol Radiative Forcing Activity, 1995-1999
Member, First International Satellite Cloud Climatology Program (ISCCP) Regional Experiment,

Phase III (FIRE III) Science Team, 1994-present
Science Team Leader, International Global Aerosol Program (IGAP), Radiative Effects of Aerosols, 1993

Professional Honors:

NASA Exceptional Scientific Achievement Medal, 1997
NASA Group Achievement Award, FIRE Phase II Science and Operations Team, 1997
NASA Ames Honor Award, Scientist, 1995

Selected Recent Publications:

Pilewskie, P., J. Pommier, R. Bergstrom, W. Gore, S. Howard, M. Rabbette, B. Schmid, P.V. Hobbs, and S.C. Tsay, Solar spectral radiative forcing during the South African Regional Science Initiative. *J. Geophys. Res*. accepted, 2002.
Pilewskie, P., R. Bergstrom, M. Rabbette, J.Pommier, and S. Howard, Cloud solar spectral spectral irradiance during ARESEII. *J. Geophys. Res*. submitted, 2002.
Pilewskie, P., R. Bergstrom, J. Reid, H. Jonsson, S. Howard, and J.Pommier, J. Livingston, and P. Russell. Solar radiative forcing by Saharan dust during the Puero Rico Dust Experiment. *J. Geophys. Res*. submitted, 2002.
Reid, J. S., D. L. Westphal, J. Livingston, D. S. Savoie, H. B. Maring, P. Pilewskie, and D. Eleuterio, The vertical distribution of dust transported into the Caribbean during the Puerto Rico Dust Experiment, *Geophys. Res. Lett.*, in press, 2002.
Rabbette , M. and P. Pilewskie, Multivariate analysis of solar spectral irradiance measurements. *J. Geophys. Res*., 106, D9, 9685-9696, 2001.
Rabbette , M. and P. Pilewskie, Principal component analysis of Arctic solar irradiance spectra. *J. Geophys. Res*. in press, 2002.
Pilewskie, P., M. Rabbette, R. Bergstrom, J. Marquez, B. Schmid, and P.B. Russell, The discrepancy between measured and modeled downwelling solar irradiance at the ground: Dependence on water vapor. *Geophys. Res. Lett.* **25**, 137, 2000.

(c) Beat Schmid
Abbreviated Curriculum Vitae

Bay Area Environmental Research Institute
560 Third Street West, Sonoma, CA 95476

Education

M.S.	1991	Institute of Applied Physics, University of Bern, Switzerland
Ph.D.	1995	Institute of Applied Physics, University of Bern, Switzerland

Professional Experience

Bay Area Environmental Research Institute, Sonoma, CA (1997-Present): Senior Research Scientist
University of Arizona, Tucson, AZ (Oct. 1995 -Jan. 1996): Visiting Scientist
University of Bern, Switzerland (1989-1997): Postdoctoral Researcher (1995-1997)

Scientific Contributions

- 9 years of leading studies in ground-based and airborne sun photometry: instrument design and calibration, development and validation of algorithms to retrieve aerosol optical depth and size distribution, H_2O and O_3.
- Participated with the NASA Ames Airborne Sun photometers in ACE-2 (North Atlantic Regional Aerosol Characterization Experiment, 1997), SAFARI 2000 (Southern African Regional Science Initiative; 2000), and ACE-Asia (Asian Pacific Regional Aerosol

Characterization Experiment; 2001). Extensive comparison of results (closure studies) with other techniques: lidar, optical particle counters, nephelometers, and satellites.

- Participated with the NASA Ames Airborne Sun photometers in the US Dept. of Energy, Atmospheric Radiation Measurement (ARM) program integrated Fall 1997 and Fall 2000 intensive observation periods in Oklahoma. Led sun photometer intercomparison. Extensive comparison of water vapor results with radiosondes, microwave radiometers, lidar, and Global Positioning System.
- Participated with NASA Ames Cavity Ringdown instrument in Reno Aerosol Optics Study (June, 2002).

Scientific Societies/Editorships

- Associate Editor, *Journal of Geophysical Research* (2002-)
- Member, American Geophysical Union and American Meteorological Society

Selected Publications (from 20 published or in press, plus 8 recently submitted)

Schmid B., et al., Coordinated airborne, spaceborne, and ground-based measurements of massive, thick aerosol layers during the dry season in Southern Africa, *J. Geophys. Res.*, accepted, 2002.

Livingston, J. M., et al., incl, B. Schmid, Airborne sunphotometer measurements of aerosol optical depth and columnar water vapor during the Puerto Rico Dust Experiment, and comparison with land, aircraft, and satellite measurements, *J. Geophys. Res.*, submitted, 2002.

Wang, J., et al., incl, B. Schmid, Clear-column radiative closure during ACE-Asia: Comparison of multiwavelength extinction derived from particle size and composition with results from sunphotometry J. Geophys. Res., submitted, 2002.

Pilewskie, P., et al., incl, B. Schmid, Solar Spectral Radiative Forcing During the South African Regional Science Initiative, *J. Geophys. Res.*, submitted, 2002.

Schmid B., et al., Comparison of columnar water-vapor measurements from solar transmittance methods. *Applied Optics*, Vol. 40, No. 12, 1886-1896, 2001.

Schmid, B., et al., 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*, B 52, 568-593, 2000.

Schmid B., et al., Comparison of Aerosol Optical Depth from Four Solar Radiometers During the Fall 1997 ARM Intensive Observation Period, *Geophys. Res. Lett.*, *26*(17), 2725-2728, 1999.

Schmid, B., C. Mätzler, A. Heimo, and N. Kämpfer, Retrieval of Optical Depth and Size Distribution of Tropospheric and Stratospheric Aerosols by Means of Sun Photometry. *IEEE Geosci. Remote. Sens.*, 35(1), 172-182, 1997.

Schmid, B., K. J. Thome, P. Demoulin, R. Peter, C. Mätzler, and J. Sekler, Comparison of Modeled and Empirical Approaches for Retrieving Columnar Water Vapor from Solar Transmittance Measurements in the 0.94 Micron Region. *J. Geophys. Res., 101*(D5), 9345-9358, 1996.

Schmid, B., and C. Wehrli, Comparison of Sun Photometer Calibration by Langley Technique and Standard Lamp. *Appl. Opt.*, *34*(21), 4500-4512, 1995.

(d) Jens Redemann
Abbreviated Curriculum Vitae

Bay Area Environmental Research Institute, 560 Third Street West, Sonoma, CA 95476

PROFESSIONAL EXPERIENCE

Senior Research Scientist	**BAERI, Sonoma, CA**	April 1999 to present
Research Assistant	**UCLA, CA**	May 1995 to March 1999
Lecturer	**UCLA, CA**	Jan. 1999 to present
Research Assistant	**FU Berlin, Germany**	June 1994 to April 1995

EDUCATION

Ph.D. in Atmospheric Sciences, UCLA.	1999
M.S. in Atmospheric Sciences, UCLA.	1997
M.S. in Physics, FU Berlin, Germany.	1995

RELEVANT RESEARCH EXPERIENCE

- Principal Investigator for the participation of AATS-14 in the CLAMS (Chesapeake Lighthouse Aerosol Measurements for Satellites) satellite validation study (July 2001). Responsible for proposal writing, experiment design and instrument integration. Member of CLAMS Science Team.
- Participated in the SAFARI-2000, ACE-Asia field experiments, investigating aerosol-climate interactions.
- Developed a coupled aerosol microphysics and chemistry model to study the dependence of aerosol absorption and single scattering albedo on ambient relative humidity.
- Related airborne measurements using sunphotometers, lidar (light detection and ranging) systems and flux radiometers to in situ measurements of atmospheric (mineral dust) aerosols and gases and modeled the local radiative transfer in Earth’s atmosphere.
- Specialized course work in atmospheric sciences, geophysical fluid dynamics, cloud physics, radiative transfer and remote sensing.

HONORS / ORGANIZATIONS

Invited Speaker at the Atmospheric Chemistry Colloquium for Emerging Senior Scientists (ACCESS V)	June 1999
Outstanding Student Paper Award, American Geophysical Union - fall meeting	1998
NASA Global Change Research Fellowship Awards	1996-1998
UCLA Neiburger Award for excellence in the teaching of the atmospheric sciences	1997
American Association for Aerosol Research, American Geophysical Union	since 1997

SUMMARY OF BIBLIOGRAPHY (selection is appended)

8 peer-reviewed (6 senior-authored + 2 junior-authored), + 4 submitted junior-authored journal articles. 21 senior-authored (33 total) conference presentations.

BIBLIOGRAPHY (Selection)

Russell, P.B., J. Redemann, et al., Comparison of aerosol single scattering albedos derived by diverse techniques in two North Atlantic experiments, *J. Atmos. Sci.*, *59*, 609-619, 2002.

Redemann, J., P.B. Russell, and P. Hamill, Dependence of aerosol light absorption and single scattering albedo on ambient relative humidity for sulfate aerosols with black carbon cores, *J. Geophys. Res.*, *106*, 27,485-27,495, 2001.

Redemann, J., et al., 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.

Redemann, J., et al., Case studies of the vertical structure of the direct shortwave aerosol radiative forcing during TARFOX, *J. Geophys. Res., 105*, 9971-9979, 2000.
Redemann, J., R.P. Turco, R.F. Pueschel, M.A. Fenn, E.V. Browell and W.B. Grant. A Multi-Instrument Approach for Characterizing the Vertical Structure of Aerosol Properties: Case Studies in the Pacific Basin Troposphere, *J. Geophys. Res., 103*, 23,287 - 23,298, 1998.

(e) Robert W. Bergstrom
Abbreviated Currriculum Vitae

Bay Area Environmental Research Institute
560 Third Street West, Sonoma, CA 95476

Education:

B.S., Mechanical Engineering, Oregon State University (1968).
M.S. and Ph.D., Mechanical Engineering, Purdue University (1969 and 1972).
J.D., Law, Stanford University (1983). Member of the California Bar (1983-present).

Professional Experience:

Post-Doctoral fellow, Mainz University, Germany (1972-1973). National Research Associate, NASA Ames Research Center (1974-1977). Senior Scientist, Systems Application Inc., San Rafael CA (1997 – 1980). Associate, Law Firm of McCutchen, Doyle, Brown and Enersen, San Francisco (1983-1984). Co-Founder Legisoft (Software Company, 1984-1992). Assistant Regional Counsel, U.S. EPA, Region IX, San Francisco (1984-1992).

Founder of the Bay Area Environmental Research Institute, San Francisco, CA (1992). Currently, Director of Research. Principal Investigator on several Cooperative Agreements with NASA Ames Research Center.

Selected Recent Publications

Bergstrom, R.W., P. Pilewskie, B. Schmid, P.B. Russell, Comparision of measured and predicted aerosol radiative effects during SAFARI 2000, accepted, *J. Geophys. Res.*, 2002.
Bergstrom, R. W., P. B. Russell, and P. Hignett, Wavelength dependence of the absorption of black carbon particles: Predictions and results from the TARFOX experiment and implications for the aerosol single scattering albedo, *J. Atmos. Sci.*, *59*, 568-578, 2002.
Pilewskie, P. et al. (including R.W. Bergstrom), The Discrepancy between measured and modeled downwelling solar irradiance at the ground: Dependence on water vapor. *Geophys. Res. Lett.*, *25*, 137-14, 2000.
Bergstrom, R.W. and P.B. Russell, Estimation of aerosol direct radiative effects over the mid-latitude North Atlantic from satellite and in situ measurements, *Geophys. Res. Lett.*, *26*, 1731-1734, 1999.
Sokolik, I., O.B. Toon and R.W. Bergstrom, Modeling the radiative characteristics of airborne mineral aerosols at infrared wavelengths, *J. Geophys. Res.*, *103*, 8813-8826, 1998.
Pilewskie, P. et al. (including R.W. Bergstrom), Observations of the spectral distribution of solar irradiance at the ground During SUCCESS," *Geophys. Res. Lett.*, *25*, 1141-1144, 1998.
Russell, P.B. S. Kinne and R.W. Bergstrom: Aerosol climate effects: Local radiative forcing and column closure experiments, *J. Geophys.Res, 102*, 9397, 1997.

5. CURRENT AND PENDING SUPPORT

5.1 Lead Principal Investigator, P. Russell

Short Title	Agency/Task No.	Investigator Months per Year	Dollar Value	Duration	Status
Global Aerosol Climatology (GACP)	NASA RTOP 622-44-75-10	3	$175,000 in FY02	10/1998-9/2002	Funded
ACE-2 & ACE-Asia Aerosol Radiative Effect Studies	NOAA Interagency Transfer of Funds NA02AANRG0129	2	$151,000 in FY02	5/2000-4/2003	Funded
Solar Spectral Flux & Optical Depth in ACE-Asia	Office of Naval Research Award N0001401F0183	1	$58,000 in FY02	11/2000-9/2002	Funded
Composite Data Analyses for Pinatubo Volcanic Aerosols for SAGE II	NASA RTOP 621-45-51-10	1	$20,000 in FY02	10/1995-9/2002	Funded. FY03 renewal proposed
SAGE III Science Team	NASA RTOP 229-10-32-00	1	$105,000 in FY02	11/1990-9/2000	Funded. FY03-05 renewal proposed
Satellite-Sunphotometer Studies of Aerosol,…	NASA RTOP 291-01-91-45	4	$236,000 in FY02	2/2000-12/2002	Funded

5.2 Co-PIs and Co-I

Short Title	Agency/Task No.*	End Date	Investigator-Months per Year/ Level of Effort			
			P. Pilewskie	B. Schmid	J. Redemann	R. Bergstrom
Global Aerosol Climatology (GACP, 2 tasks, Russell, Pilewskie PI of 1 task each)	NASA RTOPs 622-44-75-10, 622-44-76-10	9/02	5/42%	3/25%	3/25%	4/33%
Solar Spectral Irradiance in CRYSTAL	NASA RTOP 622-44-76-10	9/02	6/50%			
Ice-Water Content Using Near-IR	DOE Solicitation 99-16, NASA RTOP 622-43-00-56-33	12/02	1/8%			
ACE-2 and ACE-Asia Aerosol Radiative Effect Studies	NOAA Interagency Transfer of Funds NA02AANRG0129	4/03		2/17%	2/17%	3/25%
Solar Spectral Flux & Optical Depth Measurements & Analyses in ACE-Asia	Office of Naval Research Award N0001401F0183	9/02		1/8%		
SAGE III Science Team	NASA RTOP 229-10-32-00	9/02		2/17%	1/8%	
Satellite-Sunphotometer Studies of Aerosol, Water Vapor and Ozone	NASA RTOP 291-01-91-45	12/02		4/33%	6/50%	3/25%