PROPOSAL TO THE DEPARTMENT OF ENERGY
ATMOSPHERIC RADIATION MEASUREMENT PROGRAM

TO:

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US Department of Energy
Office of Science
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ATTN: Program Notice 02-07

TITLE OF PROPOSAL: Vertically resolved aerosol optical properties over the ARM SGP site

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List of Acronyms

AATS-6	Ames Airborne Tracking 6-channel Sun photometer
AATS-14	Ames Airborne Tracking 14-channel Sun photometer
ACE-2	North Atlantic Regional Aerosol Characterization Experiment
ACE-Asia	Asian Pacific Regional Aerosol Characterization Experiment
AOD	Aerosol Optical Depth
AWG	Aerosol Working Group
ARM	Atmospheric Radiation Measurement Program
BBHR VAP	Broad Band Heating Rate Profile Value Added Product
CIRPAS	Center for Interdisciplinary Remotely-Piloted Aircraft Studies
CLAMS	Chesapeake Lighthouse Aerosol Measurements for Satellites
CSPHOT	Cimel Sun/sky photometer
CW-CRD	Continuous Wave Cavity Ring-Down
CWV	Columnar Water Vapor
IAP	in situ Aerosol Profiles
IOP	Intensive Observation Period
NASA	National Aeronautics and Space Administration
MFRSR	Multifilter Rotating Shadowband Radiometer
OEC	Optical Extinction Cell
OPC	Optical Particle Counter
PI	Principal Investigator
PRIDE	Puerto Rico Dust Experiment
PSAP	Particle Soot Absorption Photometer
RH	Relative Humidity
RSS	Rotating Shadowband Spectrometer
SAFARI-2000	Southern African Regional Science Initiative
SGP	Southern Great Plains
SSFR	Solar Spectral Flux Radiometer
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
WVIOP	Water Vapor Intensive Observation Period

Vertically resolved aerosol optical properties over the ARM SGP site

Abstract

We are submitting a multi-year proposal addressing the question: *What are the vertically resolved optical properties of the ambient unperturbed aerosol over the ARM SGP site?*

In order to meet one of its goals – to relate observations of radiative fluxes and radiances to the atmospheric composition – the ARM program has pursued measurements and modeling activities that attempt to determine how aerosols impact atmospheric radiative transfer, both directly and indirectly. However, significant discrepancies between aerosol properties measured in situ or remotely remain. Therefore, the ARM Aerosol Working Group (AWG), of which the PI is an unfunded member, recommends additional measurements and modeling studies to accurately address the impact of aerosols on atmospheric radiative transfer. To this end, the ARM AWG is currently proposing two Aerosol Intensive Observation Periods (IOPs): A mini-IOP focusing on aerosol absorption under controlled conditions and an IOP with an airborne and ground-based component at the SGP site in May 2003.

The PI has been involved in the planning of the May 2003 IOP and has developed a proposed airborne payload based on the CIRPAS Twin Otter aircraft. However, the budget for the May 2003 IOP does not include funding for integrated analysis.

Hence, we propose integrated analyses of the expected May 2003 IOP airborne dataset aimed at the direct impact of aerosols on atmospheric radiative transfer. Our analysis will focus on two areas. a) Aerosol extinction closure: Extinction closure studies can be viewed as addressing the question: "Can in situ measurements of aerosol properties account for the solar beam attenuation by an aerosol layer or column." b) Aerosol absorption closure.

The investigators have considerable experience in such closure experiments and analysis of in situ and remote-sensing absorption measurements. We will initially focus on May 2003 IOP data expected from three instruments to be flown on the CIRPAS Twin Otter aircraft. All three instruments have been developed and will be operated by NASA Ames scientists. These instruments are the Ames Airborne Tracking 14-channel Sun photometer (AATS-14), the Solar Spectral Flux Radiometer (SSFR), and a newly developed Continuous Wave Cavity-Ring Down (CW-CRD) aerosol extinction instrument. Key for the aerosol extinction closure task is the measurement of aerosol optical depth and extinction with AATS-14. This is because inlet effects (e.g., loss or enhancement of large particles, shrinkage by evaporation of water, organics, or nitrates) and filter effects associated with in situ measurements are avoided. Equally important for this task is the CW-CRD instrument although it does sample aerosol through an inlet. However, the CW-CRD instrument directly measures in situ extinction, whereas typically in situ extinction is derived from the sum of scattering and absorption measured with two separate instruments. For the aerosol absorption closure task, the SSFR will measure flux divergence across an aerosol layer and using the spectral aerosol optical depth below and above that layer measured with AATS-14. This will allow to determine wavelength dependent single scatter albedo of the ambient aerosol (inlet effects are again avoided). The CW-CRD instrument will also determine absorption by subtracting from the extinction measurement the scattering measured with a light detector in the same instrument. Initially we will focus our analysis on these three instruments but will then extend it to include comparisons with other in situ instruments on the same platform and with ground-based lidars and radiometers.

1. Introduction

Two of the primary objectives of ARM are: 1) relate observations of radiative fluxes and radiances to the atmospheric composition and, 2) use these relations to develop and test parametrizations to accurately predict the atmospheric radiative properties. Consequently, ARM has pursued measurements and modeling activities that attempt to determine how aerosols impact atmospheric radiative transfer, both directly and indirectly. However, significant discrepancies remain. We would like to give two examples:

i) Since March 2000, ARM has been measuring in situ aerosol profiles (IAP) by performing routine flights with a light aircraft (Cessna C-172N) over the SGP site and utilizing a similar aerosol instrument package to the one at the SGP ground site. However the IAP plane has a limited ceiling, measures the aerosol at a relative humidity of 40% rather than at ambient RH, and the inlet allows particles to pass only if their aerodynamic diameter is <1μm. Even after attempting (altitude-independent) corrections for all these limitations (using information from ground-based nephelometers and raman lidar) an analysis performed by *Andrews et al*. (2001) shows that those measurements do not account for all of the aerosol extinction: The IAP-derived aerosol optical depths are consistently less (0.05 or ~30%) than the aerosol optical depths (AOD) measured on the ground by sunphotometers. We have assessed the accuracy of ground-based AOD measurements made by ARM sunphotometers (CSPHOT, MFRSR, and RSS) during WVIOP2 and WVIOP3 by comparing to an instrument (AATS-6) that was calibrated immediately before or after the IOPs at Mauna Loa, Hawaii. In both IOPs, we find that the AODs agree within 0.02 (rms, absolute AOD value) (*Schmid et al*., 1999, *Schmid et al*, 2001). Hence, the mean AOD difference of 0.05 found between light aircraft and ground-based sunphotometers is significant. In other words, extinction closure has not been achieved. A similar discrepancy was found when comparing the IAP extinction with extinction from the ground-based Raman lidar at the SGP site (i.e. IAP extinction 30% lower than Raman, *Ferrare et al*., 2002). It should be mentioned that the light aircraft package was aimed at studying vertical aerosol variability and was not optimized for extinction closure (*J. Ogren, personal communication*).

ii) *Mlawer et al*. (2000) successfully modeled ground-based measurements of direct and diffuse solar irradiance from the Rotating Shadowband Spectroradiometer (RSS, *Harrison et al*., 1999) at the SGP site. They used well-validated AOD (*Schmid et al*., 1999) and water vapor measurements (*Revercomb et al*., 2001) as input. However in order to minimize the residuals between measurements and model, *Mlawer et al*. (2000) had to assume aerosol single scattering albedos ω_0 that are “much lower than usually assumed in the aerosol community for this location, and [which] present an intriguing puzzle for this community to consider”. *Mlawer et al.* (2000) analyzed three cases for September/October 1997 and found ω_0=0.89,0.9, and 0.67 (assumed spectrally-invariant). More recently, *Sheridan et al*. (2001) published their 4-year record (1996-2000) of ground-based aerosol measurements at the SGP site. They find a median value of ω_0=0.95 (λ=550 nm, ambient RH), but in September/October 1997 values as low as ω_0=0.87 occur on occasion (but not 0.67 as needed for one case by *Mlawer et al*., 2000).

Based on results like the ones just mentioned, the ARM Aerosol Working Group (of which the PI is an un-funded member) recommends additional measurements and modeling studies to accurately address the impact of aerosols on atmospheric radiative transfer. To this end, the ARM AWG is currently proposing two Aerosol IOPs: A mini-IOP focusing on aerosol absorption under controlled conditions (Desert Research Institute, Reno, NV, Summer 2002) and an IOP with an airborne and ground-based component at the SGP site in May 2003 (*Schwartz et al*., 2002). The PI of this proposal has been heavily involved in the planning of the May 2003 IOP and has developed a proposal for a potential airborne payload based on the CIRPAS Twin Otter aircraft. However, the budget for the May 2003 IOP does not include funding for the type of integrated analysis proposed here.

2. Proposed Research

We propose integrated analyses of the expected May 2003 IOP airborne dataset aimed at the direct impact of aerosols on atmospheric radiative transfer. The currently proposed airborne payload is detailed in Table 1. Our analysis will focus on two areas:

a) Aerosol extinction closure

Extinction closure studies can be viewed as addressing the question: "Can in situ measurements of aerosol properties account for the solar beam attenuation by an aerosol layer or column."

Key is the measurement of aerosol optical depth and extinction with the Ames Airborne Tracking 14-channel Sunphotometer, AATS-14 (*Schmid et al*, 2000). 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 measures the transmission of the direct solar beam at 14 discrete wavelengths from 354 to 1558 nm (currently being expanded to 2138 nm) from which spectral aerosol optical depths AOD(λ), columnar water vapor, CWV, and columnar ozone can be derived. 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 $E_a(\lambda)$ and water vapor density ρ_w. A description of AATS-14 can be found in Apendix A.

Table 1: Twin Otter Aircraft measurements for ARM Aerosol IOP May 4 - May 31, 2003 (tentative).

Available Measurement	**Instrument**	**PI/Organization**
Aerosol size distribution 10 nm-1μm at 2 RH (one can be ambient)	TDMA System (cabin)	Caltech
Aerosol/cloud size distribution d=0.1-2.5 μm d>0.3 μm	PCASP probe CAPS probe	CIRPAS
Aerosol/cloud size distribution d>0.5 μm	FSSP probe	CIRPAS
Aerosol size distribution d>0.5 μm	TSI Aerodynamic Particle Sizer (wing)	CIRPAS
Total aerosol number concentration	Condensation Nucleus Counters (CNCs)	CIRPAS
Cloud liquid water content	Gerber PVM Johnson probe on CAPS	CIRPAS
Meteorological state parameters: Dry-bulb temperature Dew point temperature Pressure Wind vector (mean)	Gust probe	CIRPAS
Aircraft state parameters: Position Airspeed Pressure altitude Attitude (pitch, roll, yaw)		CIRPAS
Cloud condensation nuclei supersaturation spectrum	New Caltech CCN instrument. Will fly for the first time in CRYSTAL-FACE	Caltech
Turbulence Updraft velocity	Analysis	Irivine or NPS

Table 1 (continued): Twin Otter Aircraft measurements for ARM Aerosol IOP May 4 - May 31, 2003 (tentative).

Available Measurement	**Instrument**	**PI/Organization**
Aerosol optical properties	TSI Nephelometer 3 wavelengths Soot Photometer (PSAP 550 nm) (cabin)	D. Covert/ U. Wash.
Aerosol hygroscopic properties	Humidigraph (cabin) 550 nm, RH=20,60,85%	D. Covert/ U. Wash
Aerosol optical depth (354-1560 or 2140 nm, 14 channels), water vapor, extinction and water vapor density in feasible profiles	NASA Ames Airborne Tracking Sunphotometer (AATS-14)	B. Schmid/NASA Ames
Aerosol light extinction coefficient (690 and 1550 nm)	Cavity ring-down extinction cell	A. Strawa/NASA Ames
Downwelling and Upwelling Solar Irradiance (broadband)	Kipp and Zonen CM-22 pyranometers	McCoy/SANDIA A. Buchholz/NRL
Downwelling and Upwelling Solar Spectral Irradiance, 1320 channels (300-1700 nm)	NASA Ames Solar Spectral Flux Radiometer (cabin)	P. Pilewskie/NASA Ames
Aerosol absorption	Photoacoustic Instrument	Pat Arnott/DRI

This proposal also addresses the use of the relatively new Continuous Wave Cavity Ring-Down (CW-CRD) technology to measure the aerosol extinction coefficient. A CW-CRD instrument recently developed by Dr. Strawa at NASA Ames (Co-I of this proposal) is expected to be part of the Twin Otter payload for the May 2003 IOP. The IOP will mark the first major field campaign where the CW-CRD technique will be used on an airborne platform. The CW-CRD instrument is described in Appendix B. A detailed instrument description including ground-based measurements and validations has been submitted for publication (*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 compare the AATS-14 measurements with the CW-CRD results and also with the airborne in situ measurements of scattering from humidified nephelometry and absorption (see section 2b). Also we will calculate extinction from Mie theory, using measured size distributions and complex refractive indices estimated from the (usually mixed) composition. Comparisons will also be made with the aerosol profiles from the routine light-airplane IAP, and the SGP Raman and Micro Pulse lidars (*Ferrare et al*., 2001; *Turner et al*., 2001; *Turner et al*., 2002; *Welton et al*., 2002).

The community has learned a great deal from extinction closure studies (e.g. *Fouquart et al*., 1987; *Clarke et al*., 1996; *Remer et al*., 1997; *Hegg et al*., 1997, *Hartley et al*., 2000, *Kato et al*., 2000, *Collins et al*., 2000; *Schmid et al*., 2000, *Andrews et al*., 2001, *Magi et al*., 2002), and such studies continue to be a good way to test whether in situ measurements of scattering, absorption, size, and chemistry are consistent with solar beam attenuation. It is noteworthy, that extinction or AOD closure between in situ and sunphotometer measurements has been achieved only in those studies (*Clarke et al*., 1996; *Hegg et al*., 1999; *Hartley et al*. 2000; *Collins et al*., 2000, *Schmid et al.* 2000, and *Magi et al*., 2002) where both measurements were taken from the same airplane.

Therefore, the discrepancy (mentioned in the introduction) found between the ARM light-airplane IAP data and ground-based AOD data is rather typical. However, the AATS-14 extinction and AOD profiles can be exactly matched in altitude to the airborne in situ results – a match that is not possible when comparing airborne in situ to ground AOD results.

The profiles measured by AATS-14 will be of considerable value to the ARM radiation community as they represent the effect of the ambient aerosol unperturbed by sampling effects. In fact the ARM program is currently implementing a broad band heating rate profile value added product (BBHR VAP, *Mlawer et al.*, 2002). In this BBHR VAP aerosol is currently implemented in a very simplistic manner. The authors of the BBHR VAP are therefore asking the AWG for an aerosol best estimate (i.e. averaged over 3-h). Most likely such an estimate will have to be a combination of lidar, IAP and groundbased in situ and radiometer data acquired routinely at the SGP site. Coordinating flights between the IAP light-weight aircraft and the Twin Otter during the May 2003 IOP will allow to asses at what altitudes the current correction scheme for the IAP data fails, and it can help in designing a package for the IAP better suited to measure ambient aerosol. Furthermore the AATS-14 data can be used to assess uncertainties of the lidar aerosol extinction profiles. It should be noted that the shortest wavelength of AATS-14 (354 nm) is an almost perfect match of the Raman Lidar wavelength (355 nm), hence eliminating the need for spectral interpolation.

For purposes of illustration we show selected AATS-6 and AATS-14 aerosol vertical profiles obtained in recent large field campaigns such as PRIDE (Figure 1), ACE-Asia (Figure 2), and SAFARI-2000 (Figure 3). As mentioned above we plan to compare the airborne extinction profiles with the ground-based lidars at SGP. An example of such a comparison performed during SAFARI-2000 is shown in (Figure 4).

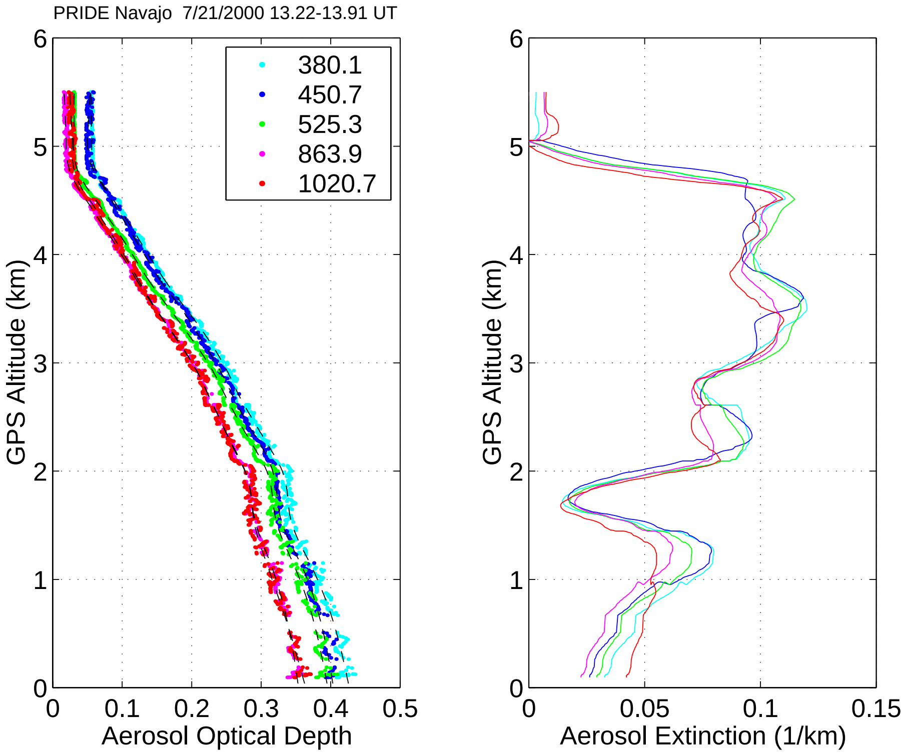

Figure 1: Left panel: Aerosol optical depth profiles at 5 wavelengths from 380 to 1021 nm calculated from AATS-6 measurements acquired during an aircraft ascent off the east coast of Puerto Rico on 21 July 2000 during PRIDE. Right panel: Corresponding aerosol extinction profiles derived by differentiating spline fits (dashed lines in left panel) to the optical depth profiles. From *Livingston et al.*, 2002.

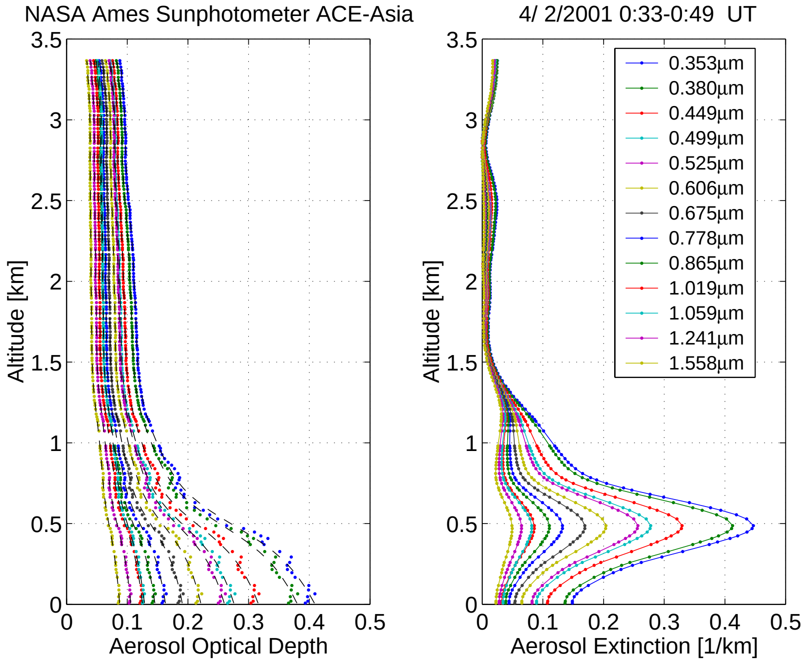

Figure 2: Left panel: Aerosol optical depth profiles at 13 wavelengths from 354 to 1558 nm calculated from AATS-14 measurements acquired during an aircraft ascent south of Hiroshima, Japan on 2 April 2001 during ACE-Asia. Right panel: Corresponding aerosol extinction profiles derived by differentiating spline fits (dashed lines in left panel) to the optical depth profiles. Unpublished data.

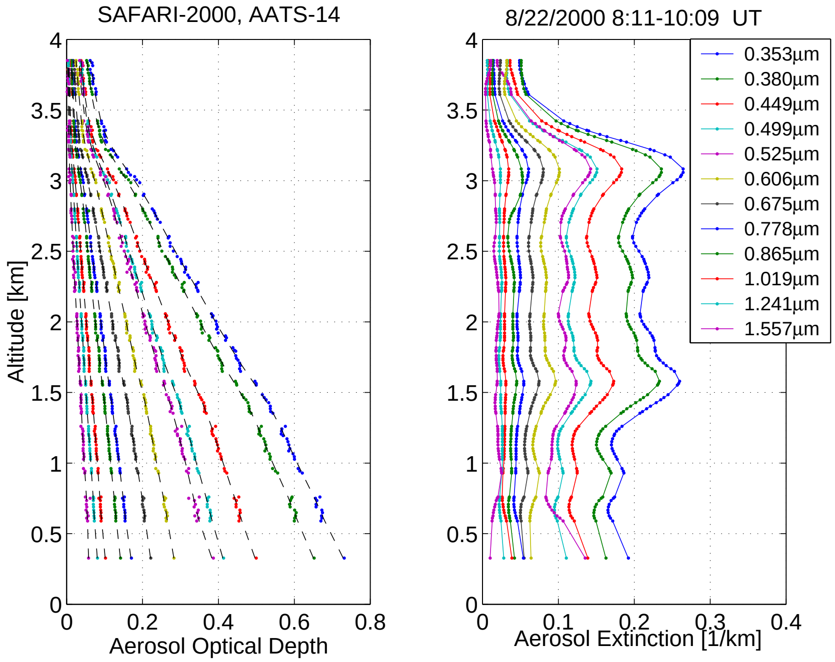

Figure 3: Left panel: Aerosol optical depth profiles at 12 wavelengths from 354 to 1558 nm calculated from AATS-14 measurements acquired during an aircraft descent in Kruger National Park, South Africa on 22 August 2000 during SAFARI-2000. Right panel: Corresponding aerosol extinction profiles derived by differentiating spline fits (dashed lines in left panel) to the optical depth profiles. From *Schmid et al*., 2002.

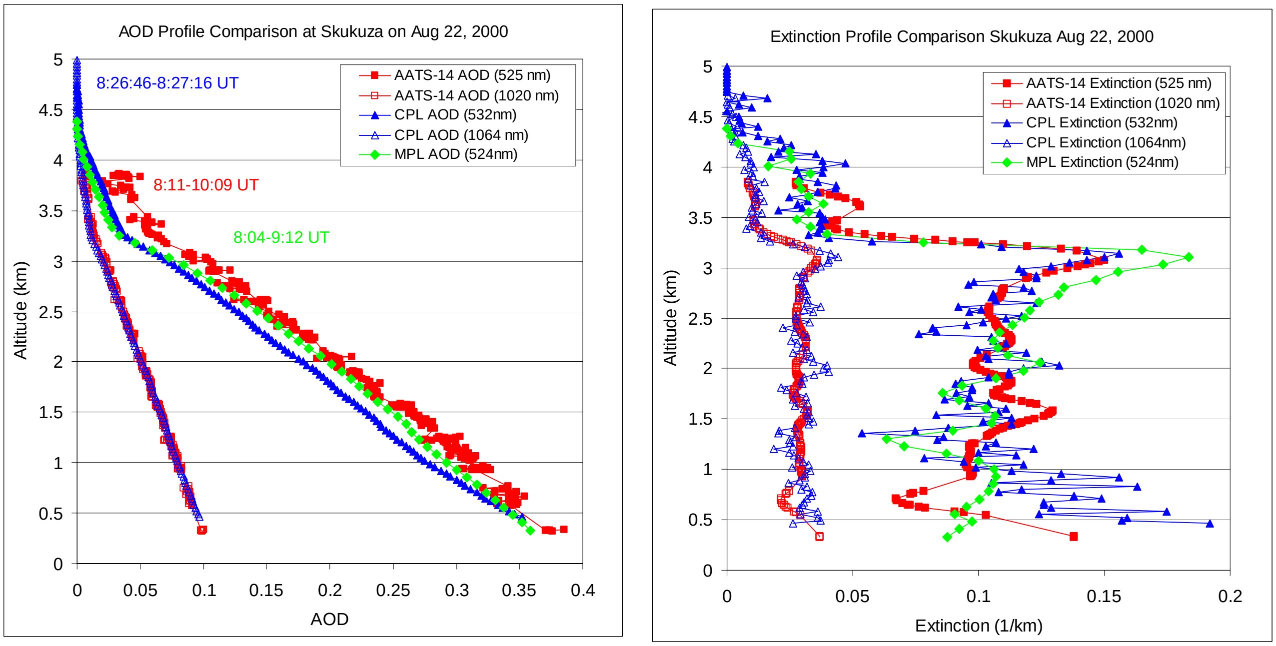

Figure 4: Comparison of aerosol vertical profiles from AATS-14 on the University of Washington Convair-580 aircraft, the Cloud Physics Lidar (CPL) on the ER-2 aircraft, and ground-based Micro Pulse Lidar (MPL) over Skukuza, Kruger National Park, South Africa, August 22, 2000. From *Schmid et al*., 2002.

Closure studies that examine the degree of consistency between sunphotometer measurements, in situ measurements, and the models that link them are an important source of information on the strengths and weaknesses of the examined measurement and modeling techniques. The investigators of this proposal have considerable experience in such closure experiments (TARFOX, ACE-2, PRIDE, SAFARI-2000, ACE-Asia and CLAMS) involving AATS-6 and AATS-14.

A typical result from such a closure study is shown in Figure 5. The data were obtained in ACE 2 when the Pelican aircraft ascended through a marine boundary layer, carrying AATS-14 and a variety of in situ samplers. The optical depth spectrum labeled “Caltech OPC” was obtained by combining in situ size spectra with refractive index models obtained from size-resolved chemical composition measurements at a nearby surface site (which were consistent with size-integrated chemistry measured on the aircraft). The optical depths labeled “Neph+PSAP” were obtained by combining nephelometer measurements of aerosol light scattering at 1 or 3 wavelengths (see e.g. *Anderson et al*., 1996; *Anderson and Ogren*, 1998) with absorption measurements from a Particle Soot Absorption Photometer (PSAP, see section 2b).

Another layer AOD closure result is shown in Figure 6 (from *Magi et al*., 2002). It shows a comparison of an AOD profile derived from AATS-14 and from in situ measurements (again combining nephelometer measurements of aerosol light scattering with absorption measurements from a PSAP) over northeast Mozambique on August 31, 2000 during SAFARI-2000. Figure 7 (from *Magi et al*., 2002) shows a scatter-plot comparison of layer AOD from AATS-14 and in situ measurements obtained from 15 vertical profiles measured during SAFARI-2000. The high correlation (r^2=0.98), the regression line slope near unity and the fact that all error bars overlap with the 1-to-1 line indicate that layer AOD closure has been achieved in that study (primarily of smoke particles with relatively small hygroscopicity).

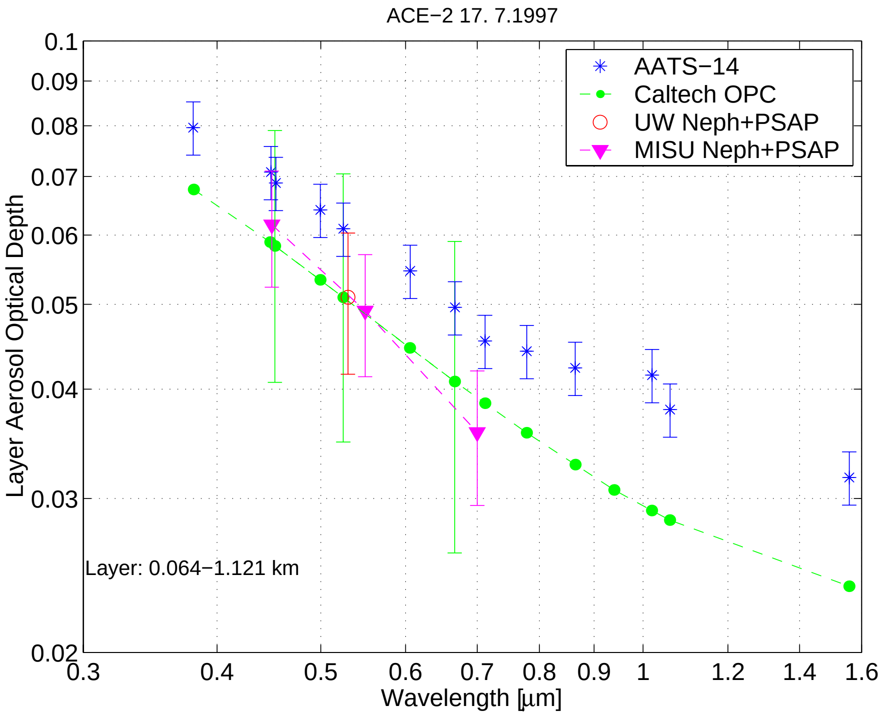

Figure 5: Spectral aerosol optical depth for the marine boundary layer (64-1121m) during Pelican flight tf20 on July 17, 1997 (ACE-2, Canary Islands). From *Schmid et al.*, 2000.

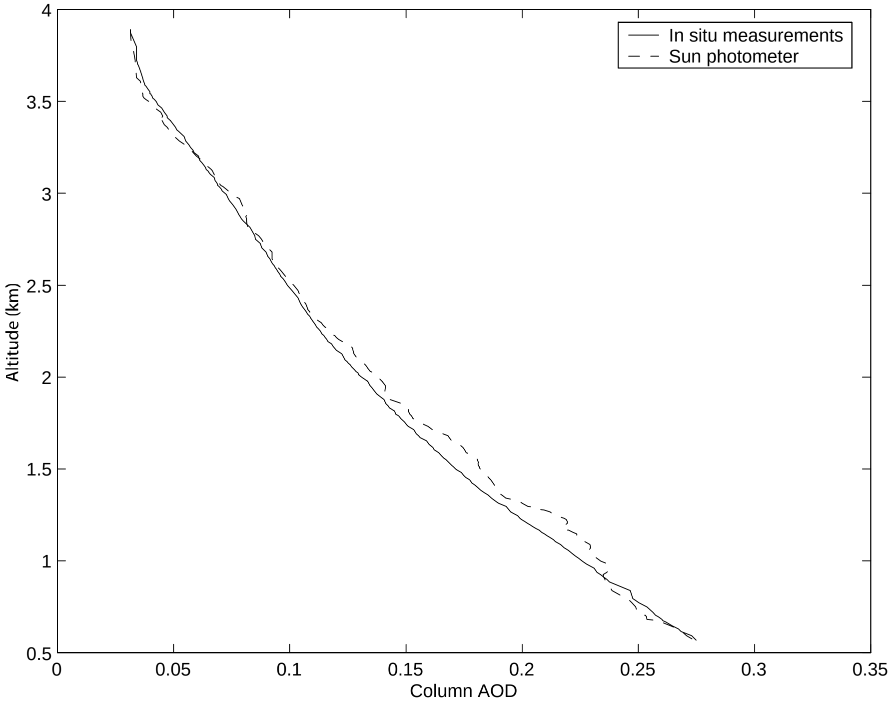

Figure 6: Comparison of column aerosol optical depths (AOD) at 550 nm derived from airborne sunphotometer, AATS-14 (dashed line) and the in situ measurements (solid line) over northeast Mozambique at 1229-1244 UTC on August 31, 2000 during SAFARI-2000. From *Magi et al.*, 2002.

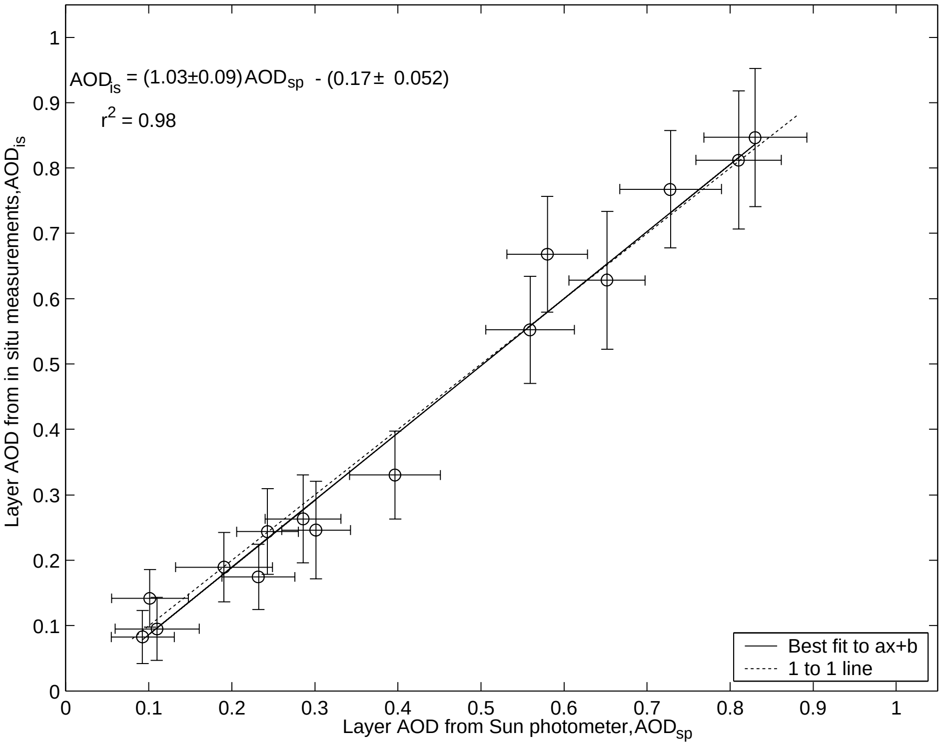

Figure 7: Comparison of layer aerosol optical depths (AOD) at a wavelength of 550 nm derived from airborne Sunphotometer and in situ measurements obtained from 15 vertical profiles. The solid line shows the best-fit straight line to the data points; the 1-to-1 perfect correlation is shown by the dashed line. From *Magi et al.,* 2002.

b) Aerosol absorption closure

Like aerosol extinction, aerosol absorption can be measured using in situ or remote sensing methods. Most of the existing in situ measurements are derived from filter-based techniques, which derive absorption from the change in light transmission through a filter on which particles have been collected (*Bond et al*., 1999). These methods include the Integrating Plate, the Integrating Sandwich, the Aethalometer and the Particle Soot Absorption Photometer (PSAP) (*Horvath,* 1993; *Bond et al.,* 1999). Additional in situ methods include Chemical Speciation, Optical Extinction Cell (OEC), the Photoacoustic method and others (see *Horvath,* 1993; *Reid et al*., 1998; *Arnott et al.*, 1999; *Moosmüller et al.*, 1998).

Especially for airborne measurements, the PSAP, which provides real-time measurements, has been used widely. A relatively new method to measure aerosol absorption is the Continuous Wave Cavity Ring-Down (CW-CRD) technology. As with the OEC, absorption is derived as the difference between extinction and scattering. However, the CW-CRD technique will be able to measure extinction (and absorption) for much lower aerosol mass concentrations than the OEC (*Reid et al.,* 1998, *Strawa et al.,* 2002). Note that the CW-CRD instrument developed by Dr. Strawa will also measure scattering with a light detector built into the instrument.

A mini-IOP focusing on aerosol absorption under controlled conditions is planned at the Desert Reseach Institute in Reno, NV, in Summer 2002. Comparisons between the following methods are planned: PSAP, Aethalometer, Photoacoustic, CW-CRD, and OEC. The first four techniques will then be used on the ground and in the air during the May 2003 IOP at the SGP site (*Schwartz et al.*, 2002).

Extinction closure studies (as described in section 2a) are usually not a good way to test in situ absorption measurements. This is because absorption is usually a small component of extinction (10% for ω_0=0.9). In contrast, getting absorption from radiative flux is better posed experimentally. (Radiative flux is the direct [beam] + diffuse radiant energy crossing 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 provide a direct way of determining the absorption by whatever is in an atmospheric layer, in its ambient state. Subtracting the gas absorption yields the aerosol absorption. Perturbation or loss of aerosol by inlet and filter effects is avoided.

We will use the Solar Spectral Flux Radiometer (SSFR; description see Appendix C) expected to fly aboard the Twin Otter during the May 2003 IOP to measure spectral flux and flux divergence. The model developed by Dr. R. Bergstrom (see *Bergstrom et al.*, 2002b) will then be used to derive spectral $\omega_0(\lambda)$ of aerosol layers using as input the AOD spectrum above and below the layer measured with AATS-14.

An example of such a derivation of $\omega_0(\lambda)$ based on SSFR and AATS-14 data obtained in SAFARI-2000, where both instruments flew on the University of Washington Convair-580, is shown in what follows. Figure 8 shows SSFR and AATS-14 data from two flight legs at 4.8 km and 1.2 km altitude on 6 September 2000 over Mongu, Zambia. Shown are upwelling and downwelling spectra from SSFR, albedo spectra (ratio of up- to downwelling) and aerosol optical depths spectra derived from AATS-14. Figure 9 shows the fractional absorption of the aerosol layer between the flight legs shown in Figure 8. Fractional absorption is defined as flux divergence across a layer divided by the downwelling flux at the top of the layer. Also shown is the fractional absorption predicted with the Bergstrom model (*Bergstrom et al.*, 2002b) assuming two different values of aerosol single scattering albedo ω_0 (constant with wavelength) and using the aerosol optical depth spectra and columnar water vapor measured by AATS-14 as inputs. Finally Figure 10 shows the spectrally varying $\omega_0(\lambda)$ retrieved by minimizing the differences between model and observations.

For the May 2003 IOP we will compare the absorption obtained from this remote sensing method to the airborne in situ measurements from the airborne PSAP, CW-CRD, and Photoacoustic instruments.

It should be noted that the error bars in $\omega_0(\lambda)$ retrieved with the flux divergence method increase with decreasing aerosol loading in the layer considered. However, the flux divergence results presented here and in *Pilewskie et al*. (2002) and *Bergstrom et al*., (2002b) have been carried out with the SSFR mounted in a fixed position with respect to the aircraft. Hence the data needed to be corrected for aircraft attitude (pitch and roll angles). In fact the error bars in the retrieved $\omega_0(\lambda)$ are dominated by uncertainties in the attitude correction. For the May 2003 IOP the situation will be much improved because we plan to mount the uplooking SSFR (and also the broadband radiation instruments, see Table 1) on a newly developed stabilized platform, which will keep the instruments level up to aircraft pitch and roll angles of 5°.

Given sufficient aerosol loading the ground-based Cimel Sun/sky radiometer at SGP will yield an additional remote sensing measurement of $\omega_0(\lambda)$ (see *Dubovik et al*., 2002).

As shown above and further evidenced in peer-reviewed literature (*Bergstrom et al*., 2002a, *Bergstrom et al*., 2002b, *Redemann et al*., 2001, *Russell et al*., 1999, *Russell et al.*, 2002) the investigators of this proposal are uniquely qualified to perform the interpretation of aerosol absorption data from remote sensing and in situ methods as outlined above.

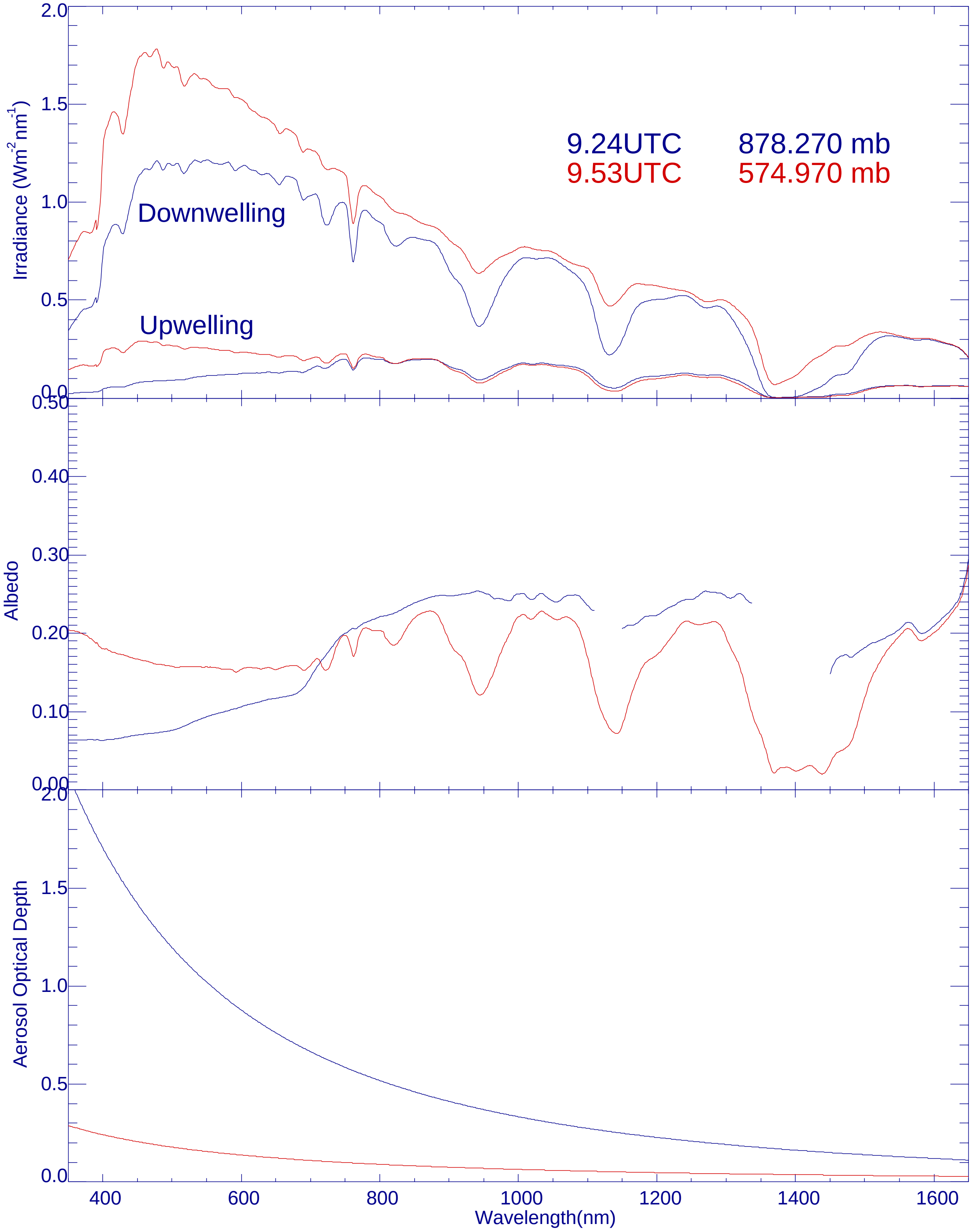

Figure 8: SSFR and AATS-14 data from two flight legs at 4.8 km (red curves) and 1.2 km altitude (blue curves) on 6 September, 2000 over Mongu, Zambia. Top panel: Upwelling and downwelling spectra from SSFR. Middle panel: Albedo spectra (ratio of up- to downwelling). Bottom panel: Aerosol optical depths derived from fit through AATS-14 measurements at 12 discrete wavelengths. From *Pilewskie et al*. (2002).

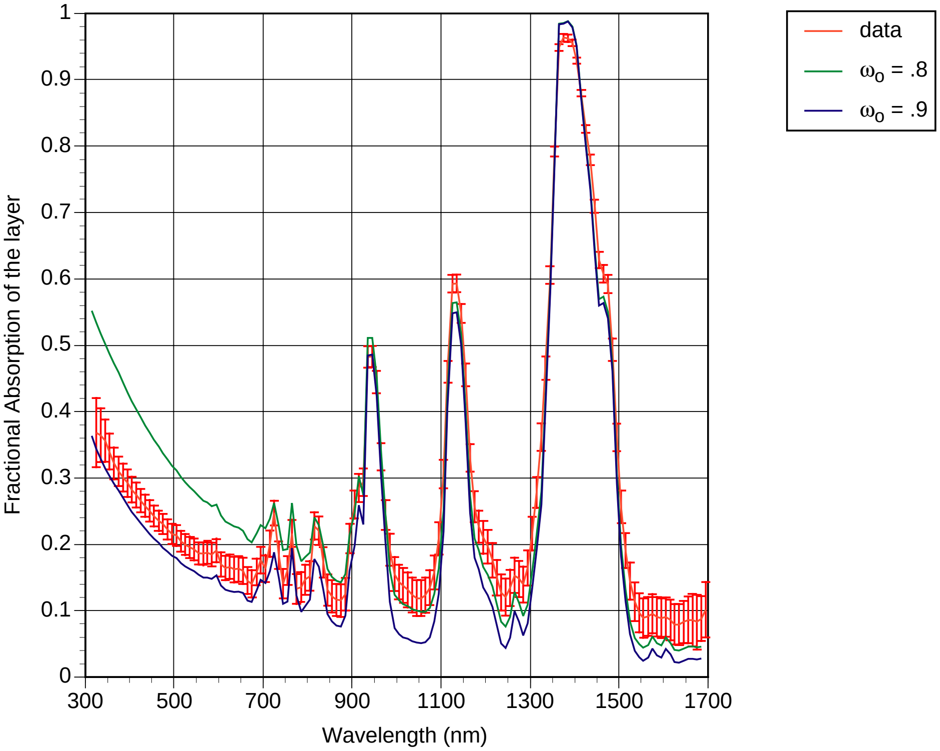

Figure 9: Fractional absorption of the aerosol layer between the flight legs shown in Figure 8. Fractional absorption is defined as flux divergence across a layer divided by the downwelling flux at the top of the layer. The flux divergence across a layer is the net (downwelling minus upwelling) flux at the top of the layer minus the net flux at the bottom (i.e., the energy absorbed by the layer). Also shown the fractional absorption predicted with the Bergstrom model assuming two different values of aerosol single scattering albedo ω_0 (constant with wavelength) and using the aerosol optical depth spectra and columnar water vapor measured by AATS-14 as input. From *Bergstrom et al.* (2002b).

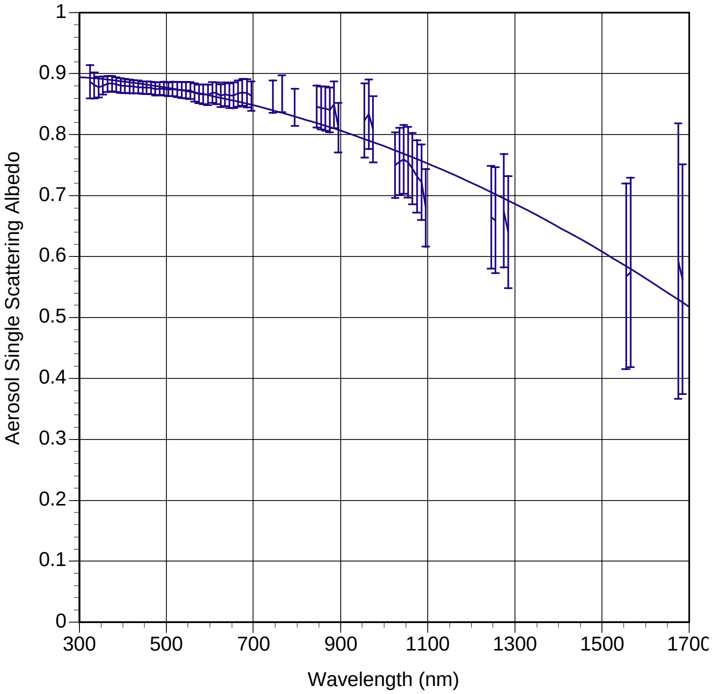

Figure 10: Spectrally varying $\omega_0(\lambda)$ retrieved by minimizing the differences between model and the observations shown in Figure 8. From *Bergstrom et al.* (2002b).

3. Schedule of Work

- According to Notice 02-07 the starting date is on or about November 1, 2002.
- In FY03 we will work on preparation and planning of the May 2003 IOP, carry out the measurements during the IOP, carry out pre- and post mission calibrations and produce preliminary data sets and perform initial comparisons as described in this proposal. Funding to perform the IOP measurements, for pre- and post mission calibrations and to produce preliminary data sets will be sought in a separate IOP proposal.
- In FY04 we will work on the integrated analysis described in this proposal, produce and archive final datasets, and present the results at ARM and international meetings.
- In FY05 we will continue to work on the integrated analysis described in this proposal, present the results at ARM and international meetings and publish the results in peer-reviewed literature.

4. Investigators' Commitment

Dr. Beat Schmid, Principal Investigator, will be responsible for the overall direction of the scientific effort. He will assure completion within time and budget constraints. He will be responsible for the proposed analysis, algorithm development, and validation. Dr. Schmid has been involved with the ARM program since 1997 and has participated in two ARM IOPs at the SGP site in Oklahoma. He is co-leading a subgroup of the ARM Water Vapor group, and he is a member of the ARM Aerosol working group where he has been heavily involved in the planning of the May 2003 IOP and has developed a proposal for a potential airborne payload based on the CIRPAS Twin Otter aircraft. Dr. Schmid will spend 30% of his time on this project.

Dr. Anthony Strawa, Co-Investigator, will be responsible for the analysis of the data from the Cavity Ring-Down instrument. He will also participate in the publication and presentation of the results. Dr. Strawa will spend 20% of his time on this project.

An analyst/programmer (TBD) will work 25%, of her/his time on this project under the guidance of Dr. Strawa and Dr. Schmid.

Dr. Peter Pilewskie, Co-Investigator, will be responsible for the analysis of the data from the SSFR instrument He will also participate in the publication and presentation of the results. Dr. Pilewskie has been a member of the ARM Science team since 1999 and has participated in numerous ARM IOPs. Dr. Pilewskie will spend 20% of his time on this project. However, his costs are not charged to this proposal.

Dr. Philip Russell, Co-Investigator, will be the NASA Technical Monitor of this project. He will also help guide the proposed analysis and will participate in the publication and presentation of the results. Dr. Russell will spend 5% of his time on the project. However, his costs are not charged to this proposal.

Dr. Robert Bergstrom, Co-Investigator, will assist in the proposed absorption study by providing guidance and oversight of the use of his radiative transfer model. He will also participate in the publication and presentation of the results. Dr. Bergstrom will spend 4% of his time in the first year and 7% of his time in the second and third year of this project.

Dr. Jens Redemann, Co-Investigator, will assist in the proposed aerosol extinction and absorption study. He will also participate in the publication and presentation of the results. Dr. Redemann will spend 5% of his time on this project.

5. Facilities and Resources

The facilities and personnel at NASA Ames Research Center will support this project by providing scientific and technical assistance through use of available facilities, hardware, and data. This includes all relevant computational needs, such as workstations and personal computers.

6. References

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7. Budget

a) Budget Summary

	FY03			FY04			FY05			TOTAL	
	Work Yr	$K /WY	Cost, $K	Work Yr	$K /WY	Cost, $K	Work Yr	$K /WY	Cost, $K	Work Yr	Cost, $K
Civil Service+Contractors											
A. Strawa (Co-I)	0.20			0.20			0.20			0.60	
Programmer (Contract TBD)	0.25	79	19.8	0.25	86	21.5	0.25	94	23.5	0.75	64.7
P. Pilewskie (Co-I) not charged to this proposal*	0.20			0.20			0.20			0.60	
P. Russell (Co-I) not charged to this proposal**	0.05			0.05			0.05			0.15	
Total	**0.70**		**19.8**	**0.70**		**21.5**	**0.70**		**23.5**	**2.10**	**64.7**
F&A costs* **	0.45	50.5	22.7	0.45	60.5	27.2	0.45	66.5	29.9	1.35	79.9
Co-op											
B. Schmid, PI (BAERI)	0.30	142	42.6	0.30	155	46.4	0.30	169	50.6	0.90	139.6
R. Bergstrom, Co-I (BAERI)	0.04	159	6.4	0.07	169	11.8	0.07	179	12.5	0.18	30.7
J. Redemann, Co-I (BAERI)	0.05	129	6.5	0.05	141	7.0	0.05	153	7.7	0.15	21.1
Total	**0.39**		**55.4**	**0.42**		**65.3**	**0.42**		**70.8**	**1.23**	**191.5**
F&A costs* **	0.39	14.5	5.7	0.42	16.5	6.9	0.42	18.0	7.6	1.23	20.1
Computation & Lab Support											
Network and computer support			4.0			4.4			4.8		13.2
Computer Hardware			5.0			5.0			3.0		13.0
Travel			6.5			6.5			6.5		19.6
Publications			0.0			4.0			5.0		9.0
Division Reserve (1.5%)			1.8			2.1			2.3		6.2
NASA Reimbursable Taxes (6%)			7.1			8.5			9.1		24.7
Total			**128.0**			**151.4**			**162.5**		**442**

	FY03	FY04	FY05	TOTAL
*F&A cost covered by NASA Radiation Science Program	10.1	12.1	13.3	36
**F&A covered by NASA Programs	2.5	3.0	3.3	9

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

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

Directorate Reserve is $2.0k per workyear

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.

b) Travel Budget

Travel

	Airfare			Per Diem			Car					**Total** incl. co-op agreement travel burden
	Trips	$/trip	Total	Days	$/day	Total	Days	$/day	Total	**Misc**	Total	
FY2003												
ARM Science Team Meeting or Subcommitee Meeting assumed Washington D.C.												
Schmid	1	500	500	5	196	980			0	100	$1,580	$1,857
ARM Science Team Meeting or Subcommitee Meeting, assumed Washington D.C.												
Schmid	1	500	500	5	196	980			0	100	$1,580	$1,857
ARM Science Team Meeting or Subcommitee Meeting, assumed Chigaco, IL												
Strawa	1	450	450	3	201	603	3	50	150	100	$1,303	$1,303
ARM Science Team Meeting or Subcommitee Meeting, assumed Chicago, IL												
Schmid	1	450	450	3	201	603	3	50	150	100	$1,303	$1,531
												$6,547
FY2004												
ARM Science Team Meeting or Subcommitee Meeting assumed Washington D.C.												
Schmid	1	500	500	5	196	980			0	100	$1,580	$1,857
ARM Science Team Meeting or Subcommitee Meeting, assumed Washington D.C.												
Strawa	1	500	500	5	196	980			0	100	$1,580	$1,580
ARM Science Team Meeting or Subcommitee Meeting, assumed Chicago, IL												
Schmid	1	450	450	3	201	603	3	50	150	100	$1,303	$1,531
ARM Science Team Meeting or Subcommitee Meeting, assumed Chicago, IL												
Redemann	1	450	450	3	201	603	3	50	150	100	$1,303	$1,531
												$6,499
FY2005												
ARM Science Team Meeting or Subcommitee Meeting assumed Washington D.C.												
Schmid	1	500	500	5	196	980			0	100	$1,580	$1,857
ARM Science Team Meeting or Subcommitee Meeting, assumed Washington D.C.												
Redemann	1	500	500	5	196	980			0	100	$1,580	$1,857
ARM Science Team Meeting or Subcommitee Meeting, assumed Chigaco, IL												
Schmid	1	450	450	3	201	603	3	50	150	100	$1,303	$1,531
ARM Science Team Meeting or Subcommitee Meeting, assumed Chicago, IL												
Strawa	1	450	450	3	201	603	3	50	150	100	$1,303	$1,303
												$6,547

8. Abbreviated Curricula Vitae

a) Beat Schmid

Education

M.S.	1991	Institute of Applied Physics, University of Bern, Switzerland
Ph.D.	1995	Institute of Applied Physics, University of Bern, Switzerland
Postdoctoral Fellowship	1995-97	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)
Research Assistant (1989-1995)
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, Tenerife). 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. Lead sun photometer intercomparison. Extensive comparison of water vapor results with radiosondes, microwave radiometers, lidar, and Global Positioning System.
- Participated with the NASA Ames Airborne Sun photometers in SAFARI 2000 (Southern African Regional Science Initiative; August/September 2000). Validation of lidar and satellite retrievals.
- Participated with the NASA Ames Airborne Sun photometers in ACE-Asia (Asian Pacific Regional Aerosol Characterization Experiment; April 2001)
- Test of candidate methods for SAGE III satellite ozone/aerosol separation using airborne sunphotometer data.
- Application of NOAA/AVHRR satellite data to monitor vegetation growth in Switzerland

Scientific Societies/Committees

- Associate Editor, Journal Geophysical Research (2002-)
- American Geophysical Union
- American Meterological Society

Publications Summary

19 (7 first-authored and 12 co-authored) publications in various scientific journals (published or in press).
6 (1 first-authored and 5 co-authored) publications submitted recently to various scientific journals
64 (20 first-authored and 44 co-authored) conference publications
13 invited talks at conferences, workshops and seminars

List of publications

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Magi, B. I., P. V. Hobbs, **B. Schmid**, and J. Redemann, Vertical profiles of light scattering, light absorption and single scattering albedo during the dry, biomass burning season in southern Africa and comparisons of in situ and remote sensing measurements of aerosol optical depths, *J. Geophys. Res.*, submitted, 2002.

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Bergstrom, R.W., P. Pilewskie, **B. Schmid**, and P.B. Russell, Comparison of Measured and Predicted Aerosol Radiative Effects during SAFARI 2000, *J. Geophys. Res.*, submitted, 2002.

Pilewskie, P., J. Pommier, R. Bergstrom, W. Gore, M. Rabbette, S. Howard, **B. Schmid**, and P.V. Hobbs, Solar Spectral Radiative Forcing During the South African Regional Science Initiative, *J. Geophys. Res.*, submitted, 2002.

b) Peter Pilewskie

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-present
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 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*. Submitted (2002).

Pilewskie, P., M. Rabbette, R. Bergstrom, J. Pommier, and S. Howard, Cloud solar spectral spectral irradiance during ARESE II. *J. Geophys. Res*. Submitted (2002).

Pilewskie, P., R. Bergstrom, J. Ried, H. Jonson, 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).

Kiedron, P., J. Berndt, J. Michalsky, D. Myers, A. Andreas, P. Pilewskie, A. Bucholtz, Absolute calibration of ARESE II spectrometers and spectral radiometers. *J. Geophys. Res*. Submitted (2002).

Rabbette, M. and P. Pilewskie, Principal component analysis of Arctic solar irradiance spectra. *J. Geophys. Res*. In Press (2002).

Rabbette, M. and P. Pilewskie, Multivariate analysis of solar spectral irradiance measurements. *J. Geophys. Res*., 106, D9, 9685-9696 (2001).

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Marshak, A., Y. Knyazikhin, A.B. Davis, W. Wiscombe, and P. Pilewskie. Cloud - vegetation interaction: Use of Normalized Difference Cloud Index for estimation of cloud optical thickness. *Geophys. Res. Lett.,* **27** , 1695-1698 (2000).

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).

Curry, J.A., P.V. Hobbs, M.D. King, D.A. Randall, P. Minnis, G.A. Isaac, J.O. Pinto, T. Uttal, A. Bucholtz, D.G. Cripe, H. Gerber, C.W. Fairall, T.J. Garrett, J. Hudson, J.M. Intrieri, C. Jakob, T. Jensen, P. Lawson, D. Marcotte, L. Nguyen, P. Pilewskie, A. Rangno, D.C. Rogers, K.B. Strawbridge, F.P.J. Valero, A.G. Williams, and D. Wylie, FIRE Arctic Clouds Experiment, *Bulletin of the American Meteorological Society,* **81**, 1 (2000).

Pilewskie, P., A.F.H. Goetz, D.A. Beal, R.W. Bergstrom, and P. Mariani, Observations of the spectral distribution of solar irradiance at the ground during SUCCESS, *Geophys. Res.* **25**, 1141 (1998).

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Valero, F.P.J. and P. Pilewskie, Latitudinal survey of spectral optical depths of the Pinatubo volcanic cloud derived particle sizes, columnar mass loadings, and effects on planetary albedo, *Geophys. Res. Lett.*, **19,** 163 (1992).

Pilewskie, P., F.P.J. Valero, Radiative effects of the smoke from the Kuwait oil fires. *J. Geophys. Res.*, **97**, 14541 (1992).

Pilewskie, P., and S. Twomey, Optical remote sensing of ice in clouds. *J. of Wea. Modif.*, **24**, 80 (1992).

Pilewskie, P. and S. Twomey, Discrimination of ice from water in clouds by optical remote sensing. *Atmos. Research*, **21**, 113 (1987).

Pilewskie, P., and S. Twomey, Cloud phase discrimination by reflectance measurements near 1.6 and 2.2 μm. *J. Atmos. Sci.*, **44**, 3419 (1987).

c) Anthony Strawa

Education

- Ph. D. in Aeronautical and Astronautical Engineering with a minor in Electrical Engineering, 1986, Stanford University, Stanford, California.
- M.S. in Aeronautical and Astronautical Engineering, 1984, Stanford University, Stanford, California.
- B.S. in Aeronautical Engineering, 1973, United States Air Force Academy, Colorado Springs, Co.

Professional Experience

- 1998-Present, Group Leader, Cloud and Microphysics Group, Atmospheric Physics Branch, NASA-Ames Research Center, Moffett Field, California.
- 1993-Present, Scientist, Atmospheric Physics Branch, NASA-Ames Research Center, Moffett Field, California.
- 1990-1992, Principal Investigator, Radiative Heating Experiment, Aeroassisst Flight Experiment, NASA-Ames Research Center, Moffett Field, California.
- 1986-1993, Scientist, Aerothermodynamics Branch, NASA-Ames Research Center, Moffett Field, California.
- 1979-1986, Research Assistant, Stanford University, Stanford, California.

Scientific Contributions

Dr. Strawa has been involved in experimental measurement, analysis, and instrumentation development for over twenty years. Most recently, he is the group leader for the Cloud and Microphysics Group whose long term goal is the study of the formation, evolution, and effects of aerosols and clouds. The group pursues this goal through a combination of measurements, analysis, and modeling. The group has employed impactors and a variety of optical particle counters for airborne measurement in the troposphere and stratosphere and is developing improved measurement capability. Dr. Strawa is exploiting a technique he developed to discriminate types of polar stratospheric clouds using satellite observation and is involved in the development of an instrument capable of measuring aerosol optical properties in situ. He has participated in the development of a ground-based, hemispheric, infrared radiometer and in the deployment of radiometers on remotely piloted vehicles. Previously, he was principal investigator on a spacecraft designed to measure the total radiometric heating and spectral character of the wake of blunt vehicles entering the earth's atmosphere and use these measurement to verify and improve computer simulations of flow fields. He also led experimental efforts to characterize wind tunnel, shock tunnel, and ballistic range flows using advanced laser-based and spectroscopic techniques. All of these efforts involved implementation of and comparison with computer models.

Honors and Awards

NASA Group Achievement Award, 1992, 1997.

Scientific Societies/Committees

Member, Ames Basic Research Council. Senior member in American Institute for Aeronautics and Astronautics. Member of American Geophysical Union, American Meteorological Society. Served as Secretary and Technical Disciplines Subcommittee Chairman on the AIAA Aerodynamic Measurement Technology Technical Committee. Past member of the NASA Aerosensors Working Group and NASP High-Speed Propulsion Technology Maturation Team.

Selected Publications

"The Measurement of Aerosol Optical Properties Using Continuous Wave Cavity Ring-Down Techniques", Strawa, A.W., R.Castaneda, T. Owano, D. Baer, B.A. Paldus, submitted to J. Atmospheric and Oceanic Technology, 2002.

"Discriminating Type Ia and Ib Polar Stratospheric Clouds in POAM Satellite Data," Strawa, A.W., K. Drdla, M. Fromm, R.F. Pueschel, K.W. Hoppel, E.V. Browell, P. Hamill, and D.P. Dempsey, submitted to J. Geophys. Res., 2001.

"Carbonaceous aerosol (soot) measured in the lower stratosphere during POLARIS and its role in stratospheric photochemistry," Strawa, Drdla, Ferry, Verma, Pueschel, Yasuda, Salawitch, Gao, Howard, Bui, Loewenstein, Elkins, Perkins, Cohen, J. Geophys. Res., 104, D21, pp. 26,753-26766, 1999.

"Microphysics and chemistry of sulfate aerosols at warm temperatures," K. Drdla, R.F. Pueschel, A.W. Strawa, R. C. Cohen, T.F. Hanisco, J. Geophys. Res., 104, D21, pp. 26,737-26751, 1999.

"Effects of aircraft on aerosol abundance in the upper troposphere," G.V. Ferry, R.F. Pueschel, A.W. Strawa, Y. Kondo, S.D. Howard, S. Verma, M.J. Mahoney, T.P. Bui, J.R. Hannon, H.E. Fuelberg, Geophys. Res. Lett., 26, no. 15, pp. 2399-2402, 1999.

"Surface Radiation Measurements During the ARESE Campaign," B.C. Bush, S.K. Pope, A. Bucholtz, F.P.J. Valero, A. W. Strawa, J. Quant. Spec. Rad. Trans., V. 61(2), pp. 237-247, 1998.

"Soot and Sulfuric Acid Aerosol from aircraft: Is there enough to cause detrimental environmental effects?", R.F. Pueschel, A.W. Strawa, G.V. Ferry, S.D. Howard, S.Verma, J. Aerosol Sci. Vol. 29, Suppl. 1, p.S519, 1998.

"Sulfuric acid and soot paritcles formation in aircraft exhaust,", R.F. Pueschel, S. Verma, G.V. Ferry, S.D. Howard, S. Vay, S. Kinne, J. Goodman, A.W. Strawa, Geophysical Research Letters, Vol. 25, No. 10, pp. 1685-1688, May 15, 1998.

"The Baseline Surface Radiation Network Pyrgeometer Round-Robin Calibration Experiment," R. Philipona, C. Frolich, K.Dehne, J. DeLuisi, J. Augustine, E. Dutton, D. Nelson, B. Forgan, P. Novotny, J. Hickey, S. Love, S. Bender, B. McAuthur, A. Ohmura, J. Seymour, J. Foot, M. Shiobara, F. Valero, A.W. Strawa, J. Atmos. Oceanic Tech., Vol. 15. No. 3, June 1998.

"Aerosol and Cloud Particles in Tropical Cirrus Anvil: Importance to Radiation Balance," R.F. Pueschel, J. Hallett, A.W. Strawa, G.V. Ferry, S.D. Howard, T. Foster, W.P. Arnott, J. Aerosol Sci. Vol. 28, No. 7, pp. 1123-1136, 1997.

"Characterization of Arc Jet Flows Using Laser-Induced Fluorescence," D.J. Bamford, A. O'Keefe, D.S. Babikian, D.A. Stewart, and A.W. Strawa, J. Thermophysics and Heat Trans., 9, 1, pp. 26-37, 1995.

"Proposed Radiometric Measurement of the Wake of the Blunt Aerobrake," A.W. Strawa, C. Park, W.C. Davy, D. Babikian, and D.K. Prabhu, Journal of Spacecraft and Rockets, vol. 29 no. 6, Nov.-Dec. 1992, pp 765-772.

"Investigation of an Excited Jet Diffusion Flame at Elevated Pressure," A.W. Strawa and B.J. Cantwell, J. Fluid Mech., (1989), vol. 200, pp. 309-336.

"The Ballistic Range and Aerothermodynamic Testing," A.W. Strawa, G.T. Chapman, T.C. Canning, and J.O. Arnold, Journal of Aircraft, vol. 28, # 7, July 1991, pp. 443-449, invited lecture presented at the AIAA Aerodynamic Testing Conference, San Diego, CA, May 18-20, 1988, AIAA Paper 88-2015.

"A Comparison of Experimental and Computational Results for Slender Cones At High Mach Numbers", A. W. Strawa and D. Prabhu, AIAA Thermophysics, Plasmadynamic and Heat Transfer Conference, San Antonio TX, June 27-29, 1988, AIAA Paper 88-2705.

"Visualization of the Structure of a Pulsed Methane-Air Diffusion Flame.", A. W. Strawa and Brain J. Cantwell. Physics of Fluids, vol. 28, no. 8, Aug. 1985.

d) Philip B. Russell

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).

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

Previously, Co-coordinator for the CLEARCOLUMN component of the Second Aerosol Characterization Experiment (ACE-2) of the International Global Atmospheric Chemistry (IGAC) Project. Coordinator for IGAC's Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX).

Previously, Editor-in-Chief (1994-95) and Editor (1993, 1996), *Geophysical Research Letters*; Chair, American Meteorological Society International Committee on Laser Atmospheric Studies (1979-82, Member, 1978-82). Member, National Research Council Committee on Army Basic Research (1979-81). Member, American Meteorological Society Committee on Radiation Energy (1979-81).

Previously, Project Scientist, Small High-Altitude Science Aircraft (SHASA) Project to develop the Perseus A Remotely Piloted Aircraft (RPA, 1992-94). Member, Science/Aeronautics Seam Team of NASA Ames Reorganization Team (1994). Member, Ad Hoc Committee on the NASA Environmental Research Aircraft and Sensor Technology (ERAST) Program (1993-4). 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). Member, National Aero-Space Plane (NASP) Committee on Natural Environment (1988-94).

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 93 peer-reviewed papers)

Russell, P. B., J. Redemann, B. Schmid, R. W. Bergstrom, J. M. Livingston, 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., et al., Aerosol-induced radiative flux changes off the United States Mid-Atlantic coast: Comparison of values calculated from sunphotometer and in situ data with those measured by airborne pyranometer, *J. Geophys. Res.,* 104, 2289-2307, 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.

e) Jens Redemann

PROFESSIONAL EXPERIENCE

Research Scientist Bay Area Environmental Research Institute, San Francisco.	April 1999 to present
Research Assistant University of California, Los Angeles, Department of Atmospheric Sciences.	May 1995 to March 1999
Lecturer University of California, Los Angeles, Department of Atmospheric Sciences.	Jan. 1999 to March 1999
Research Assistant Free University of Berlin, Germany. Department of Physics.	June 1994 to April 1995

EDUCATION

Ph.D. in Atmospheric Sciences. University of California, Los Angeles. Specialization: atmospheric physics and chemistry.	1999
M.S. in Atmospheric Sciences. University of California, Los Angeles. Specialization: atmospheric physics and chemistry.	1997
M.S. in Physics. Free University of Berlin, Germany. Specialization in experimental physics and mathematics.	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, and CLAMS field experiments aimed at 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 a sunphotometer, a lidar (light detection and ranging) system and a spectral solar flux radiometer to in situ measurements of atmospheric (mineral dust) aerosols and gases and modeled the local radiative transfer in Earth’s atmosphere.
- Developed inversion algorithms (C and IDL) and data analysis tools for aircraft-based lidar and sunphotometer measurements during field experiments (PEM, TARFOX).
- Involved in the development of a multi-wavelength, ground-based lidar system at the Free University of Berlin, Germany.
- Specialized course work in atmospheric sciences, geophysical fluid dynamics, cloud physics, radiative transfer and remote sensing.

HONORS

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

ORGANIZATIONS

American Association for Aerosol Research, American Geophysical Union, Co-president of the UCLA - Atmospheric Sciences Graduate Student Group.

PUBLICATIONS SUMMARY

8 peer-reviewed (6 senior-authored + 2 junior-authored), +2 submitted junior-authored journal articles.
18 senior-authored (21 total) conference presentations (16 oral, 5 poster).

PUBLICATIONS

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Appendix A: Description of the Ames Airborne Tracking Sunphotometers, AATS-6 and AATS-14

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1. Introduction

The NASA Ames Airborne Tracking Sunphotometers (AATS-6 and AATS-14) measure the transmission of the solar beam in six and 14 spectral channels, respectively. Azimuth and elevation motors controlled by differential sun sensors rotate a tracking head so as to lock on to the solar beam and keep detectors normal to it. The tracking head of each instrument mounts external to the aircraft skin, to minimize blockage by aircraft structures and also to avoid data contamination by aircraft-window effects. Each channel consists of a baffled entrance path, interference filter, photodiode detector, and integral preamplifier. The filter/detector/preamp sets are temperature-controlled to avoid thermally-induced calibration changes. Each instrument includes an entrance-window defogging system to prevent condensation (a problem otherwise common in aircraft descents). In general, sun tracking is achieved continuously, independent of aircraft pitch, roll, and yaw, provided rates do not exceed ~8° s^{-1} and the sun is above aircraft horizon and unblocked by clouds or aircraft obstructions (e.g., tail, antennas). Data are digitized and recorded by an onboard data acquisition and control system. Realtime data processing and color display are routinely provided. The science data set includes the detector signals, derived optical depths and water vapor column content, detector temperature, sun tracker azimuth and elevation angles, tracking errors, and time. Radiometric calibration is determined via Langley plots, either at high-mountain observatories or on specially designed flights. Repeated calibrations show that the instruments maintain their calibration (including window and filter transmittance, detector responsivity and electronic gain) to within 1% in most spectral channels for periods of several months to a year.

2. Six-Channel Tracking Sunphotometer (AATS-6)

The six-channel instrument [Fig. 1, *Matsumoto et al.*, 1987] uses a differential-shadowing sun sensor to drive the azimuth and elevation tracking motors. The window-defogging system uses bottled dry nitrogen, which also aids in overall instrument thermal control. The six filter/detector/preamp sets are mounted in a common heat sink maintained at 45 ±1 °C. Filter wavelengths are shown in Fig. 2. Filter full widths at half-maximum (FWHM) are 5 nm. Data are digitized and recorded by a laptop computer-based data acquisition and control system, with realtime, onboard processing and color display.

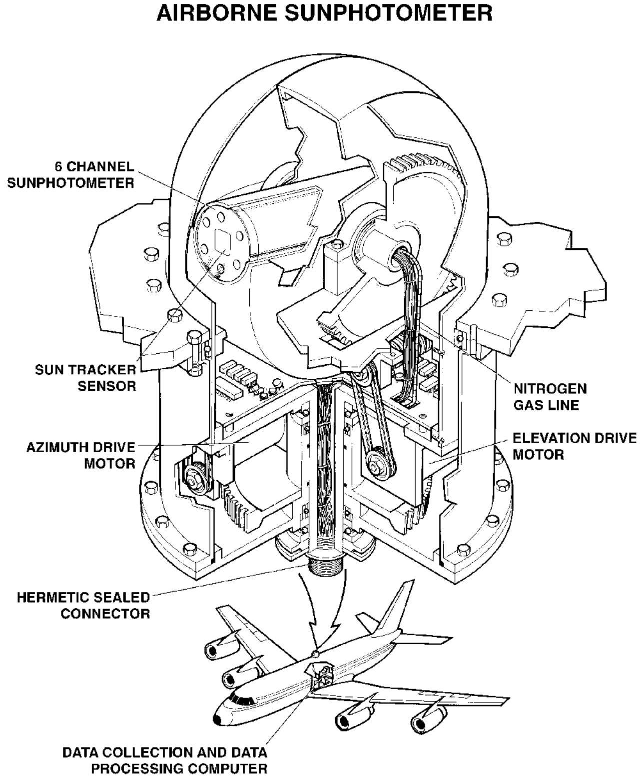

Figure 1. Six-channel Ames Airborne Tracking Sunphotometer (AATS-6).

AATS-6 has flown on a variety of aircraft, including the NASA CV-990, C-130, and DC-8, the Sandia National Laboratories Twin Otter, and the University of Washington C-131A. These measurements have been compared with SAGE II measurements of free-tropospheric and stratospheric aerosols [*Russell et al.*, 1986; *Livingston and Russell*, 1989] and used to characterize the spectral optical depth of oil- and forest-fire smokes and thin clouds [*Pueschel et al.*, 1988; *Pueschel and Livingston*, 1990], to measure tropospheric haze aerosols and their impact on atmospheric radiation and on remote measurements of the Earth's surface [*Spanner et al.*, 1990; *Wrigley et al.*, 1992; *Russell et al.*, 1999], and to document the effect of the 1991 Pinatubo volcanic eruption on global-scale stratospheric aerosol optical depth spectra [*Russell et al.*, 1993a,b; 1996; *Toon et al.*, 1993]. In addition, AATS-6 operated successfully on the ship R/V Vodyanitsky in the second Aerosol Characterization Experiment (ACE-2), making measurements of marine, European, and African aerosol optical depth spectra, as well as water vapor columns [*Livingston et al.*, 1997].

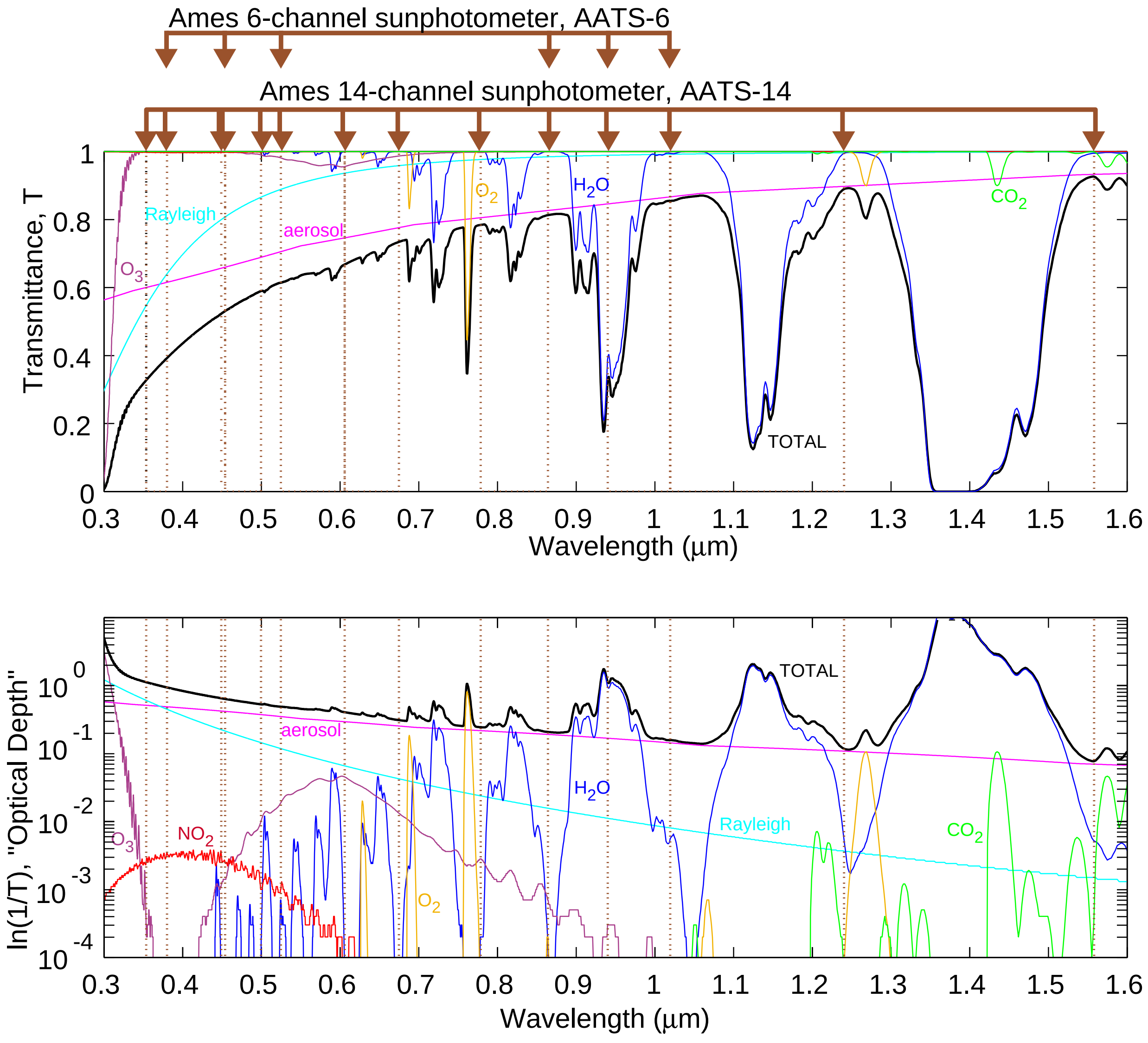

Figure 2. Sunphotometer channel wavelengths (vertical lines with arrows) in relation to atmospheric spectra. The spectra of transmittance T of the direct solar beam at sea level were calculated using MODTRAN-3.7/Version 1.0 with a Midlatitude Summer atmosphere, a rural spring-summer tropospheric aerosol model (Vis = 23 km), and the sun at the zenith. Current center wavelengths of channel filters are 354, 380, 449, 454, 500, 525, 606, 675, 779, 864, 940,1019, 1240, 1558 nm for AATS-14 and 380, 451, 525, 864, 941, 1021 nm for AATS-6. Filter full widths at half-maximum (FWHM) are 5 nm, except for the 449 and 454 nm channels, which have FWHM 0.94 and 2.17 nm, respectively.

3. Fourteen-Channel Tracking Sunphotometer (AATS-14)

AATS-14 (Fig. 3) was developed under the NASA Environmental Research Aircraft and Sensor Technology (ERAST) Program. It provides 14 spectral channels in the same tracking-head size as the six-channel instrument, with a more compact and automated data/control system. AATS-14 is designed to operate on a variety of aircraft, some of which may be remotely piloted or autonomous. Hence it can locate and track the sun without input from an operator and record data in a self contained data system. In addition, it must interface to an aircraft-provided telemetry system, so as to receive and execute commands from a remote operator station, and transmit science and instrument-status data to that station.

AATS-14 uses a quad-cell photodiode to derive azimuth and elevation tracking-error signals. Window defogging is achieved by a foil heater. Channel filters are at wavelengths from 354 to 1558 nm (Fig. 2), chosen to allow separation of aerosol, water vapor, ozone, and nitrogen dioxide transmission. Detectors in the two longest-wavelength channels incorporate thermoelectric coolers. The other 12 channels are maintained at an elevated temperature by a foil heater or a liquid-loop/thermoelectric heater/cooler system.

AATS-14 made its first science flights on the Pelican (modified Cessna) aircraft of the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) in July 1996 [*Russell et al.*, 1999]. More extensive flights on Pelican were made in the second Aerosol Characterization Experiment (ACE-2), providing many measurements of marine, European, and African aerosol optical depth spectra, as well as water vapor columns [*Schmid et al.*, 2000].

AATS-14 completed its first operations on a pressurized aircraft in June 1999, when it made five test flights on the NASA DC-8. Operations included autonomous sun finding, tracking and data acquisition with external temperatures as low as –62 C and sun angles from ~10° off aircraft zenith to local horizontal.

Figure 3. Fourteen-channel Ames Airborne Tracking Sunphotometer (AATS-14). Dimensions are in inches.

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Weight, Power, Size, and Related Information

1. Six-Channel Ames Airborne Tracking Sunphotometer (AATS-6):

Part	Weight	Size (19" panel or other)	Power Required (watts, amps)	Type of Power (V, Hz)	External Sensor Location
a. Sunphotometer telescope	62 lb. (Includes 27-lb head, 1-lb bearing, 5-lb isolator, 1-lb reinforc. ring, 1 lb mounting bolts, 27-lb cable)	Telescope dome 8" OD, Cylinder flange 10" OD Overall telescope height ~15" w/o. bottom cable connector. Extends ~6" above A/C skin, 9" below. Mounted in Zenith port.	See (b.)	See (b.)	Zenith or near-zenith port (See note.)
b. Data/control system	39 lb. (Includes 27-lb control box; 5-lb laptop w/ 2-lb charger and 5-lb rack tray)	13" total rack height in 19" rack mount panel. (Includes 9" high control box and 4" high laptop tray)	3.1 A control box plus 0.8 A laptop	120VAC, 60Hz	N/A
c.	30 lb	7.5" Dia x 21" H	N/A	N/A	N/A
d. *Optional	45-lb 13" diagonal color monitor (needs rack tray). 4-lb printer w/ charger	15" rack height in 19" panel	1.3A	120VAC, 60Hz	N/A

2. Fourteen-Channel Ames Airborne Tracking Sunphotometer (AATS-14):

Part	Weight	Size (19" panel or other)	Power Required (watts, amps)	Type of Power (V, Hz)	External Sensor Location
a. Telescope head w electronics/data system cylinder	131.6 lb. (Includes 121-lb head w/elec., 3.5-lb isolator, 1-lb reinforc. ring, 0.4-lb torque link, 0.7-lb mount bolts, 5-lb cable bundle.	Outside A/C: 8" OD dome (hemisphere) atop 5" H pedestal. (Total H: 9" above A/C skin) Inside A/C: 12" D x 18" H cylinder. (+ laptop computer for checkout and test flights)	5.5A 154 W peak or 4.2 A @ 500 W peak	28 VDC or 120VAC, 50-400 Hz with additional 55-lb power supply.	Top of cabin, nose, wing, or pod. 9" D port (See note.)
b. Operator station (laptop computer)	6-lb laptop & cable, 15-lb tray w/slides.	Laptop computer. Optional tray mounts in 19" rack.	~0.8 A 92 Watts	120 V, 60 Hz	N/A
c. N_2 gas bottle	30 lb	7.5" Dia x 21" H	N/A	N/A	N/A

Note: Telescope dome needs to be mounted as far as possible from viewing obstructions such as A/C tail and antennas.

Appendix B: Description of Cavity Ring-Down Instrument to Measure Aerosol Extinction

INTRODUCTION

Large uncertainties in the effects that aerosols have on climate require improved in situ measurements of extinction coefficient. This section describes a new instrument that uses continuous wave cavity ring-down (CW-CRD) technology to address this problem. The innovations in this instrument are the use of CW-CRD to measure aerosol extinction coefficient, the simultaneous measurement of scattering coefficient, and small size suitable for a wide range of aircraft applications. Our prototype instrument measures extinction and scattering coefficient at 690 nm and extinction coefficient at 1550 nm. The instrument itself is small (61 x 46 x 15 cm) and relatively insensitive to vibrations. The prototype instrument has been tested in our lab and used in the field. Combining extinction and scattering coefficients, one can obtain the single-scattering albedo and absorption coefficient, both important aerosol properties. The use of two wavelengths also allows to obtain a quantitative idea of the size of the aerosol through the Ångstrom exponent. Minimum sensitivity of the prototype instrument is $1.5\text{x}10^{-6}$ m^{-1} (1.5 Mm^{-1}).

INSTRUMENT DESCRIPTION

An excellent review of the CRD techniques and applications can be found in the collection of papers edited by Busch and Busch [1999]. It can be shown that the exponential decay of light exiting the ring-down cell, or ring-down time, is related to the mirror reflectivity and the absorption of the material inside the cavity by the relationship

$$\tau = \frac{L}{c}\left((1-R) + \sigma_{ext}L + \sigma_{Ray}L + \sigma_{gas}L\right)^{-1} \tag{1}$$

where L is the cell length, c is the speed of light, R is the mirror reflectivity, σ_{ext} is the coefficient of extinction due to aerosol, σ_{Ray} coefficient of Rayleigh scattering, and σ_{gas} coefficient of absorption due to gaseous species in the cell. (Note that extinction is the sum of scattering plus absorption.) In the present approach, extinction coefficient is given by the difference between measurements made when the cell contains filtered air and when the cell contains a particulate-laden flow:

$$\sigma_{ext} = \frac{1}{c}\left(\frac{1}{\tau_{aer}} - \frac{1}{\tau_0}\right) \tag{2}$$

where τ_{aer} is the ring-down time of the aerosol laden flow and τ_0 is for the filtered air. The minimum detectable absorption of CW-CRD systems is on the order of 10^{-4} to 10^{-6} km^{-1}. [Paldus and Zare, 1999] Thus a measurement accuracy in extinction coefficient of 1% to 0.01% is achievable at extinction levels of 10^{-2} km^{-1}.

CW-CRD results in several advantages over the pulsed laser technique. [Romanini et al., 1997] CW lasers diodes can be obtained with very narrow line widths that can be more effectively coupled into the cavity so that the sensitivity of the system is not limited by the laser linewidth. The resulting overlap between the laser and cell linewidth results in actual energy build up in the cell. This benefits both the extinction and the scattering measurements. CW laser diodes also have a higher duty cycle than pulsed lasers, which results in faster sampling. Finally, the use of CW laser diodes results in a more compact and rugged instrument suitable for aircraft operations. Pulsed laser systems are bulky and their sample rate is limited by the repetition rate of the laser, typically about 10 Hz.

The prototype system, depicted in Figure 1, uses two CW laser diodes at wavelengths of 690 nm and 1550 nm, located at the bottom. The laser beams are conditioned with spatial filters, combined with a dichroic beamsplitter, and coupled into a single cavity/flow cell. This cell configuration consists of three mirrors that form a narrow isosceles triangle. Input and output mirrors are set at 45 deg at one end of the cell and the third mirror is set at the other end of the cell 20 cm away. Light from the output mirror is focused onto the ring-down detectors that are located on the right of the diagram. One wall of the flow cell is made of BK-7 glass. In this configuration, the scattering detectors are located next to the glass wall. Aerosol-laden or filtered air enters the cell through 0.64 cm diameter tubing with a flow rate of 1.5 L/min. The optical path of the instrument, the path of the laser light through the aerosol-laden flow, was 36 cm. In this CW-CRD application, the back mirror is moved rapidly with a piezo-electric while monitoring the light output of the cell. When a resonance occurs, the light energy builds up in the cell and after it reaches a threshold, the laser is switched off rapidly, on the order of 50 ns. Ring-down times for this system are on the order of micro seconds. The ring down signal is then recorded as in pulsed-CRD. Ring-down occurs at a frequency of 50 to 100 Hz in this prototype system and 500 to 1000 shots were averaged over about 10 sec. to achieve one sample.

LABORATORY AND FIELD RESULTS

The performance of the prototype instrument was tested by generating various types of aerosols in our laboratory and measuring their optical properties. Figure 2 shows a plot of measured extinction coefficient versus particle number density for various particle compositions: ammonium sulfate, and polystyrene spheres (PSS) of 0.72 and 1.05 μm in diameter. Particle number density was measured with a TSI Model 3025 Condensation Particle Counter (CPC). Both laser wavelengths, 690 and 1550 nm, measured a minimum extinction coefficient of about 1.5×10^{-6} m^{-1} (1.5 Mm^{-1}) for ammonium sulfate aerosol. Our goal is to improve upon this performance in an instrument that is small enough to fly on any aircraft. The proposed improvements are outlined below. The sensitivity of the flight instrument is expected to be at least an order of magnitude better than the performance of the prototype. The dynamic range of the prototype instrument is seen to be about 3.5 orders of magnitude.

After the initial laboratory tests were completed, the instrument was involved in some limited field work at NASA-ARC. Air was drawn through a common stack approximately 3 meters from the instruments, with an inlet 20 meters above the ground, and sampled by the prototype instrument, a Radiance Research nephelometer, CPC, and PCASP. Figure 3 shows results from a portion of this test. Extinction coefficients at 690 and 1550 nm measured with the prototype are plotted in Figure 3a; scattering coefficient from the prototype instrument and the nephelometer are plotted in Figure 3b. Scattering at 1550 nm was not obtained in this instrument configuration. At approximately 35 min into the test, flow to the prototype instrument and nephelometer was switched to filtered air for 5 min to obtain a zero for the extinction measurement. The aerosol-laden flow to the PCASP was not interrupted. During this sampling period the airfield fire department conducted a practice exercise, lighting a small petroleum fire and extinguishing it with water. This generated a white plume that dissipated and passed over our location at approximately 50 min. The signature of the plume can be seen in all of the instruments.

The next generation instrument should have several improvements. Instrument sensitivity and particle loss inside the instrument need to be better characterized. Most importantly, the mirrors need to be kept as clean as possible. Decreases in mirror reflectivity contributed greatly to uncertainties in initial measurements with the prototype system. All of these factors are being currently addressed. The sensitivity of the measurement of extinction and scattering coefficient can be improved by the use of more highly reflective mirrors. This helps by increasing the ring-down time which allows for a more precise and sensitive extinction measurement. The resulting build up of radiant energy in the cell also improves the scattering measurement. An improved flow design will be employed to help keep the mirror surfaces clean and to avoid putting the particle-laden flow through small tubes and tight turns. A better optical scheme for the scattering measurement will be used. It is expected that this instrument will be capable of making particulate extinction and scattering measurements from the surface to the upper-troposphere to an accuracy of 1% for extinction coefficients of 10^{-3} km^{-1} (0.1 Mm^{-1}). Improved electronics will result in increased repetition rates on the order of 500 to 2000 Hz. This improvement can decrease the acquisition time or allow averaging over more samples for greater sensitivity. An instrument with this capability will reduce uncertainty currently associated with aerosol optical properties and their spatial and temporal variation. It could contribute to visibility studies, aid in our understanding of climate forcing by aerosol, and assist in satellite validation and the validation of aerosol retrieval schemes from satellite data.

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Romanini, D., Kachanov AA, Sadeghi N, and Stoeckel F. (1997). "CW cavity ring down spectroscopy ," Chem. Phys. Lett., 264 , 3-4, 316-322.

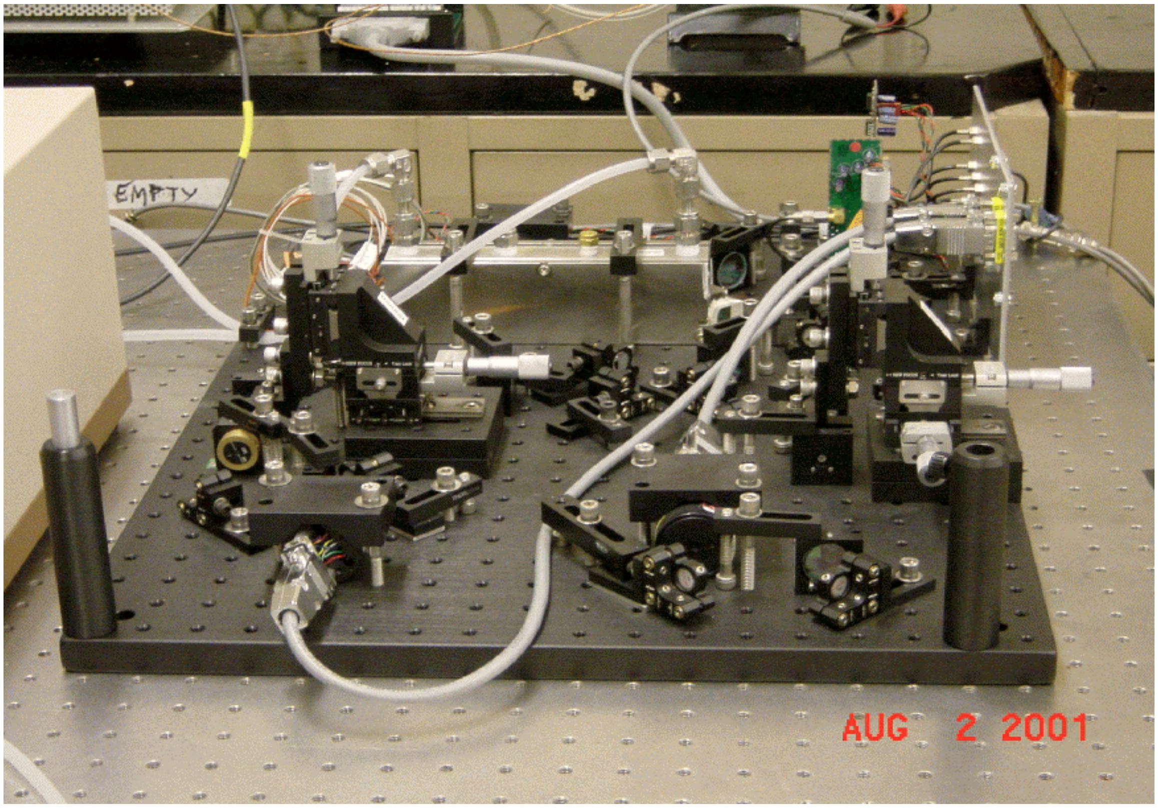

Figure 1. Photo of prototype instrument in Lab at NASA-ARC.

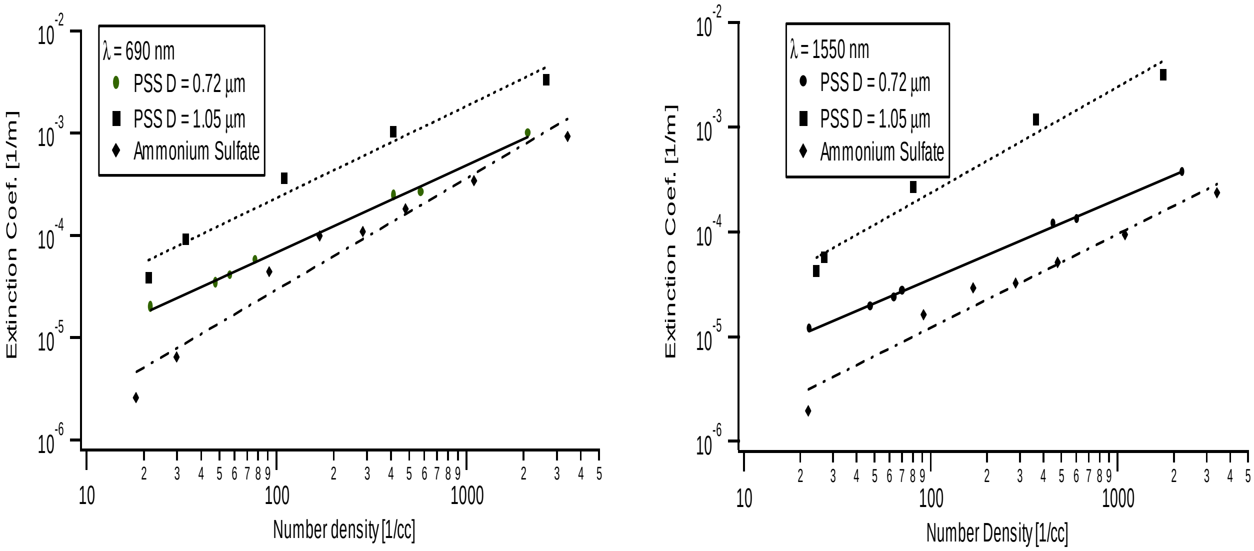

Figure 2. Measurements of extinction coefficient versus number density for various aerosol composition and size. left) wavelength = 690 nm, right) wavelength = 1550 nm.

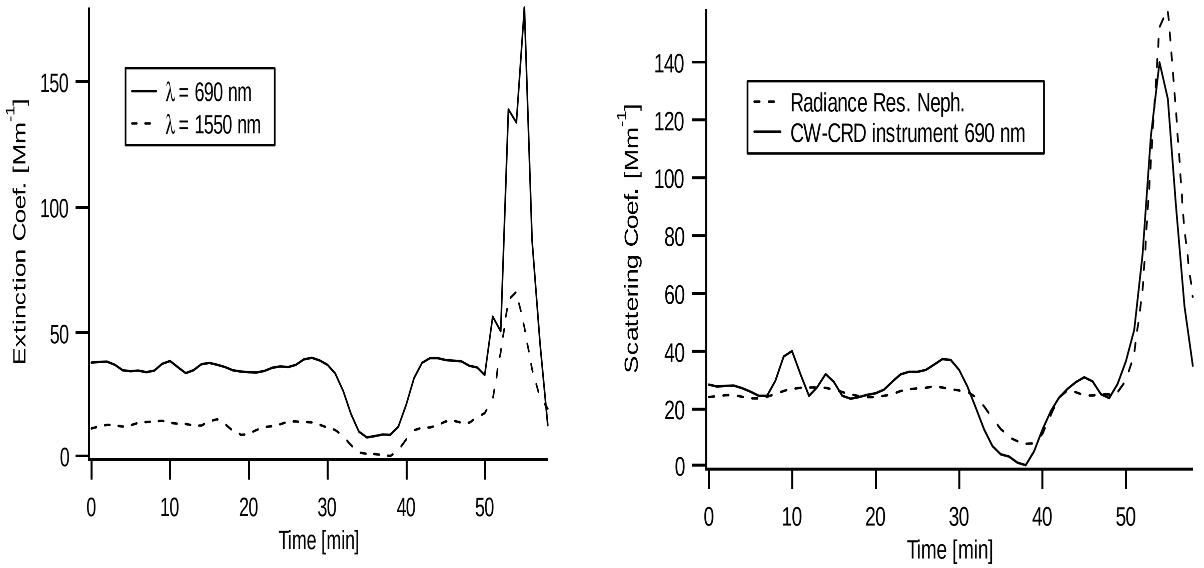

Figure 3. Field measurement. left) Extinction coefficient at both wavelengths; right) Prototype scattering measurement compared with Radiance Research nephelometer. The dip in signal at 35 minutes results from zero air. The peak at 50 minutes results from a plume encounter.

Appendix C: Description of the Solar Spectral Flux Radiometer (SSFR)

The Solar Spectral Flux Radiometer (SSFR) is a moderate resolution flux (irradiance) spectrometer covering the wavelength range from 300 nm to 1700 nm. The SSFR is comprised of an identical pair of Zeiss Monolithic Miniature Spectrometer Modules (MMS 1 and MMS NIR) for simultaneous zenith and nadir viewing. The MMS-1 is equipped with a flat-field, 366 1/mm grating and a Hamamatsu Si linear diode array detector. We apply thermal control to the MMS-1 module, holding temperature at 27º C ± 0.3º C. The MMS-NIR has a 179 1/mm 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 used for the spectral diffuse/global irradiance meter designed by Crowther (1998). It is a spectralon integrating sphere with a conical baffle, also made of spectralon, and a barium sulfate coated knife edge. The design for this sphere has been tested for angular response by computer simulation and in the laboratory. It shows a high degree of linearity with cosine of incidence angle to values as low as 0.1. The light collector is protected in flight by a water-free quartz hyperdome. At the base of the spectralon sphere is a high-grade custom-made fiber optic bundle (Ceram Optec) which is bifurcated to transmit the incident light to the two spectrometer input slits for visible and near-infrared detection. The data acquisition and control system is driven by a 100 MHz 486 PC in a PC104 format. The dynamic resolution is 15 bits full range. Sampling resolution is approximately 3.25 nm. Integration time for the each of the spectrometers is nominally 100 ms. Spectral sampling rate is approximately 1 Hz. Data is recorded on a compact 225 Mbyte PCMCIA flash memory card.

Figure 1: The Solar Spectral Flux Radiometer with detector heads for up – und downwelling radiation

The SSFR is calibrated for wavelength, angular response, and absolute spectral power. Spectral calibration is achieved by referencing to the HeNe laser line at 632.8 nm, a temperature stabilized laser diode line at 1298 nm, and several line sources from Hg, Xe, and Ar lamps. The spectral power calibration was conducted prior to the SAFARI campaign using a NIST secondary standard lamp at the NASA Ames Airborne Sensor Facility Laboratory and in our Atmospheric Physics Radiation Laboratory using a LI-COR Field Calibrator. They are NIST standards is operated at 1000 W and viewed at 50 cm. The Licor units are fully enclosed devices (200 W lamps with exit aperture at 20 cm), which are more suitable for field use. In the field we calibrate the SSFR before and after flights using the same portable LI-COR devices to monitor the stability of the SSFR over the duration of the experiment.

Measures of instrument stability can be seen in the spectral distribution of standard deviation in a collection of 100 calibration spectra (Figure 2, left frame) and a comparison of pre- and post-deployment instrument response spectra (Figure 2, right frame). Over most of the active spectral range the short-term stability, or precision, depicted in Figure 2 (right frame), is better than 0.1% for the Silicon detector array and less than 0.2% for the InGaAs detector array. At the short and long wavelength detection limit for each array precision is less because of reduced detector quantum efficiency and stray light effects. The longer term stability shown by the comparison of pre- and post-deployment response function comparisons is around 0.5% for the Si array and 0.75% for InGaAs, with similar falloff at the detection limits.

Absolute accuracy of SSFR irradiance spectral depends mostly of the accuracy of the transfer standard. The error over our spectral range for the NIST standard used to calibrate the SSFR was between 1-3%. The LI-COR calibrator lists a 3% uncertainty across the spectrum. Additional error occurs during aircraft operations because of aircraft pitch and roll. Corrections are applied to the downwelling flux to correct for these offsets.

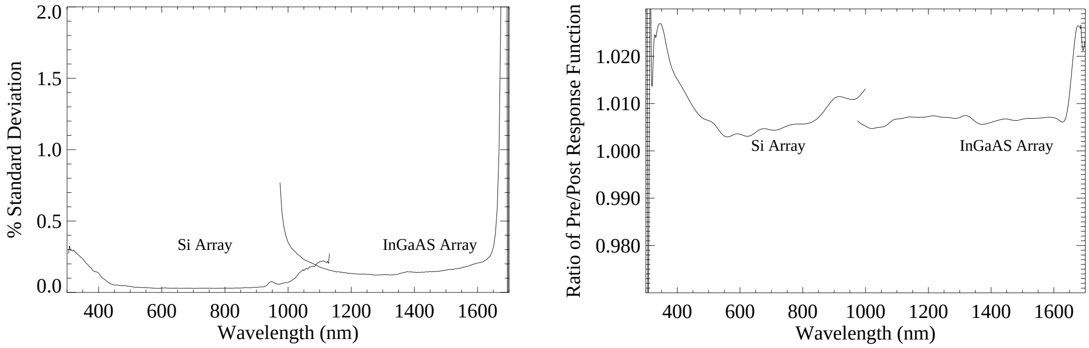

Figure 2 left): Spectral distribution of relative standard deviation in a collection of 100 calibration spectra. right): Comparison of pre- and post-deployment instrument response spectra (from Pilewskie et al, 2002).

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