ARM Aerosol IOP

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Principal Investigators (ARM Aerosol Working Group).

Richard Ferrare[1], John Ogren[2], Steve Schwartz[3], Pete Daum[4], Beat Schmid[5], Steve Ghan[6]

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 parameterizations to accurately predict the atmospheric radiative properties. Consequently, ARM has pursued measurement and modeling activities that attempt to determine how aerosols impact atmospheric radiative transfer, both directly and indirectly. These efforts have primarily focussed on measurements of aerosol optical thickness, retrievals of vertical profiles of aerosol scattering and extinction, and surface measurements of aerosol optical (i.e. scattering, absorption, extinction) and physical (i.e. size, composition) characteristics. However, although these efforts have provided valuable insight regarding aerosol properties and the impact of aerosols on radiation, ARM must pursue additional measurement and modeling studies to accurately address how aerosols directly and indirectly impact radiative fluxes and radiances throughout the entire column. This IOP is proposed to acquire measurements required for addressing both direct and indirect effects of aerosols on radiation.

Direct

Aerosol influences on shortwave radiation are substantial locally and globally. An aerosol optical thickness (AOT; acronyms are presented in Appendix) of 0.1 results in an instantaneous decrease in direct normal surface irradiance (DNSI) of ca 100 W m^{-2}, and (depending on particle size and single scattering albedo) a top of atmosphere forcing of ca 30 W m^{-2}. Such optical depths are not uncommon at SGP (Michalsky et al., 2001). Aerosols also substantially influence the diffuse downwelling surface irradiance; the magnitude of this influence, and also of the vertical distribution of atmospheric heating, depends sensitively on the aerosol single scattering albedo.

[1] NASA Langley Research Center, MS 401A, Hampton, VA 23681, (757) 864-9443, (757) 864-7790 (fax), r.ferrare@larc.nasa.gov
[2] NOAA Climate Monitoring and Diagnostics Laboratory, 325 Broadway R/CMDL1, Boulder, CO 80303, USA, (303) 497-6210, (303) 497-5590 (fax), John.A.Ogren@noaa.gov
[3] Brookhaven National Laboratory, Bldg. 815E (75 Rutherford Dr.) PO Box 5000, Upton NY 11973-5000, (631) 344-3100, (631) 344-2887 (fax), ses@bnl.gov
[4] Brookhaven National Laboratory, Bldg. 815E (75 Rutherford Dr.) PO Box 5000, Upton NY 11973-5000, (631) 344-7283, (631) 344-2887 (fax), phdaum@bnl.gov
[5] Bay Area Environmental Research Institute, NASA Ames Research Center, MS 245-5, Moffett Field, CA 94035-1000, (650) 604-5933, (650) 604-3625 (fax), bschmid@mail.arc.nasa.gov
[6] Pacific Northwest National Lab, MS K9-30, PO Box 999, Richland, WA 99352, (509) 372-6169, (509) 372-6247 (fax), steve.ghan@pnl.gov

Accurate knowledge of pertinent aerosol properties is required to accurately represent aerosol forcing in models. A key ARM objective is to demonstrate the ability to match measured and modeled radiation components. In view of the magnitude of aerosol influences, it is necessary, therefore, that the relevant aerosol properties be known. ARM CART has been systematically measuring aerosol properties at the surface. However it is shown by lidar and in-situ measurements that much of the aerosol at SGP is aloft, often in layers that are decoupled from the surface, raising question of the representativeness of surface aerosol properties for these calculations. ARM CART has taken beginning steps in characterization of aerosol vertical properties by regular sampling by small aircraft. These measurements provide a substantial advance in the ability to represent aerosol properties in models. However, the light aircraft sampling is limited in the kinds of measurements that can be made, therefore limiting the testing of aerosol models and the evaluation of the performance of remote sensing to supplant in-situ measurements. For these reasons an IOP dedicated to characterization of aerosols aloft and their radiative influence is required.

Specifically, vertical profiles of aerosol properties are key parameters required for the computation of radiative flux profiles. ARM has supported the development of systematic and routine measurements of aerosols at the ARM SGP site, including measurements by surface in situ instruments as well as by lidars and periodic aircraft-borne in situ sensors in the vertical column above the site, to try to obtain the relevant aerosol profile measurements required for these flux computations. However, initial comparisons of aerosol optical thickness and aerosol extinction, two of these key aerosol properties, have revealed discrepancies among the routine lidar, Sun photometer, and routine small aircraft in situ measurements. More detailed measurements of aerosol optical properties are required to resolve these discrepancies, as well as to more completely characterize the aerosol optical, microphysical, and chemical properties at the surface and above the SGP site for accurately computing radiative fluxes. Such well-characterized data would permit a more detailed evaluation of the performance of radiative transfer models to compute flux profiles and heating rates.

Indirect

In addition to the direct effects of scattering and absorption, aerosols also impact atmospheric radiation indirectly by affecting cloud properties. Aerosols may increase cloud reflectivity due to more and smaller cloud droplets forming on the aerosol, and by increasing the lifetime of clouds due to reduced precipitation in clouds with more and smaller droplets. From in situ measurements in Florida (small cumulus clouds) and the eastern Atlantic (stratus clouds), a strong effect of higher pre-cloud particle concentrations (cloud condensation nuclei CCN) on precipitation initiation (an order of magnitude fewer drizzle drops) has been found. However, there is a lack of CCN measurements at cloud base. Since most of the presently available data have been obtained in cleaner (maritime) areas, the addition of data from more polluted areas (i.e. Oklahoma) would be a large step forward for the indirect aerosol effect. ARM funded CCN spectrum measurements from aircraft during the 1997 Fall IOP, but unfortunately during that IOP there were few clouds that satisfied the requirements for remote sensing of the cloud microphysical properties, and aircraft measurements of CCN spectra were not available for any one them. Without coincident measurements of CCN spectrum and cloud microphysics it is impossible to evaluate models of the influence of aerosols on cloud microphysics. This IOP will measure CCN at cloud base and will also attempt to determine if surface measurements of CCN can be used to infer CCN at cloud base.

ARM/TAP Coordination

It is intended that this IOP will be coordinated with a DOE Tropospheric Aerosol Program (TAP) aerosol characterization study that has been proposed to be held at the DOE SGP site. TAP interest in this IOP is directed primarily to relating aerosol chemical and microphysical properties to the optical properties, relating surface aerosol properties to the properties aloft, and characterizing the humidity dependence of the aerosol properties. ARM is also interested in obtaining a well-characterized set of aerosol optical properties for assessing the impact of aerosols on radiative transfer and radiative fluxes. Therefore, a joint experiment to acquire data for studying the relationships among the physical, chemical, and optical properties of aerosols will help both ARM and TAP meet their objectives.

Scientific Hypotheses

Several of the scientific hypotheses that will be examined in this IOP are conveniently expressed as "closure experiments" -- that is that an observable quantity may be observed in two different ways, or may be observed as well as calculated (modeled) using other observable quantities. The comparison of these two (or multiple) measures of the same quantity is often called a "closure experiment"; that is, closure is achieved if the measures agree within the propagated uncertainties. The hypothesis under examination is that the understanding embodied in the measurements or the models is sufficient to represent the observable. Examples would be comparison of remote sensing measurements with *in-situ* measurements, justifying the further use and application of the remote sensing data; or comparison of measured aerosol property (say, extinction coefficient) with that calculated from knowledge of size distribution and index of refraction, justifying the use of the latter to calculate the former, say in chemical transport models. Examples of closure experiments are described here, with specific comparisons and measurement requirements presented below.

1. Closure of irradiances and fluxes

Can closure between measurements and models of diffuse radiation be achieved under low AOT conditions with accurate measurements of the aerosol single scattering albedo?

ARM’s interest in aerosols deals primarily with the impacts of aerosols on direct and diffuse irradiances and radiative fluxes. The primary aerosol parameters required to assess these effects are the aerosol optical thickness, single scattering albedo, and backscatter fraction. The assessments of aerosol optical thickness discussed above should be carried out in conjunction with measurements of downwelling irradiance (both direct and diffuse) as a function of wavelength and altitude. These measurements would be used to help evaluate the performance of radiative transfer models using well-characterized aerosol measurements. Because there has been considerable uncertainty in the values of aerosol absorption and single scattering albedo ω_o that have been derived from various methods, additional measurements of ω_o should be acquired. These should include measurements by the photoacoustic method, which measures the sound pressure produced in an acoustic resonator caused by light absorption. Measurements of diffuse radiation (under cloud-free conditions) would be acquired on days with simultaneous measurements of ω_o acquired by both (i.e. PSAP filter and photoacoustic) types of surface measurements discussed above as well as airborne profiles of aerosol absorption. Measurements of aerosol single scattering albedo are crucial to constraining models of diffuse irradiance for comparison with measurements. For these measurements, the photoacoustic absorption measurements could be used to "calibrate" the surface PSAP measurements as well as a PSAP on an aircraft. Measurements of aerosol absorption should be acquired at several wavelengths to determine the validity of the common assumption that aerosol absorption is constant in the visible part of the spectrum. The goal of these measurements would be to accurately constrain the lower limit on ω_o throughout the atmospheric profile during periods of low AOT and to then compare the measured absorption with that derived from the comparisons of modeled and measured diffuse radiation.

Specific closure experiments (See Table 1 for measurements/instruments; required measurements/instruments are underlined)

1. Aerosol absorption (surface, dry)
   a. PSAP (AOS) vs. aethalometer
   b. PSAP (AOS) vs. photoacoustic
   c. Aethalometer vs. photoacoustic
   d. Measurements/instruments (1, 2)

2. Aerosol Absorption Profiles derived from SGP Routine Measurements
   a. IAP (dry) vs. PSAP (airborne) (Calibrated using photoacoustic)
   b. Photoacoustic (airborne) vs. IAP (dry) vs. PSAP (airborne)
   c. Comparison of in situ profiles (IAP, PSAP, photoacoustic) vs. derived from Cimel and/or MFRSR and/or polarization
   d. Measurements/Instruments (1, 16, 23, 2, 11, 25)

3. Diffuse Downwelling (broadband)
   a. Measured (shaded pyranometer) vs. Model (aerosol+gas) input
   b. Measurements/Instruments (16, 17, 18, 10, 6, 14, 15, 16, 27)

4. Diffuse Downwelling (spectral)
   a. Measured (RSS, SSFR) vs. Model (aerosol+gas) input
   b. Measurements/Instruments (16, 17, 9, 10, 7, 14, 15, 16, 27)

5. Diffuse/Direct Ratio (spectral)
   a. Measured (RSS,SSFR) vs. Modeled (aerosol+gas) input
   b. Measurements/Instruments (16, 17, 9, 10, 7, 14, 15, 16, 27)

2. AOT closure

How well do the routine CART Raman lidar and In Situ Aerosol Profiling measure of aerosol scattering and extinction profiles and AOT? How well can the surface measurements of aerosol scattering humidification factor be used for aerosols aloft?

Aerosol optical thickness is derived from routine measurements by the Cimel Sun photometer, Multifilter Rotating Shadowband Radiometer (MFRSR), Rotating Shadowband Radiometer (RSS), and CART Raman lidar (CARL). (We also anticipate aerosol extinction profiles will be routinely computed from Micropulse Lidar (MPL) measurements beginning in the summer, 2001.) The in situ aerosol profiling (IAP) measurements acquired during the periodic small aircraft flights have been also been integrated with altitude derive AOT. While comparisons of aerosol optical thickness between the Raman lidar and Sun photometer have shown small (<5%) systematic biases, these same comparisons have shown rms differences of 20-30% (Turner et al., 2001). The reasons for the 30% rms differences between the instruments is not clear, but may be caused by variations in aerosol extinction/backscatter ratio used for lidar retrievals below 800 meters, uncertainty in the lidar overlap function correction, differences in the pointing directions between the instruments, and calibration errors in the Sun photometer. Initial comparisons have shown that AOT derived from IAP sensors is approximately 30% less than the corresponding values derived from the ground-based Cimel Sun photometer and MFRSR (Andrews et al., 2001). These differences may be due to uncertainties in the humidification factor, correction factor for supermicron scattering, and the aerosol Angstrom exponent used to scale the lidar measurements to 550 nm.

Additional airborne measurements acquired during an aerosol IOP would be used to better quantify the errors associated with these measurements and identify potential reasons for these differences. The NASA Ames airborne Sun photometer has been used to measure profiles of aerosol optical thickness and aerosol extinction as a function of wavelength at ambient conditions. These profiles could be used to evaluate the CARL, IAP, and MPL aerosol extinction profiles as well as to evaluate the aerosol Angstrom exponent used to scale the CARL measurements. Airborne measurements of the hygroscopic growth factor for scattering would also be required to convert the measurements of dry aerosol scattering to ambient conditions and to test closure for retrieving aerosol scattering and extinction from in situ aerosol measurements. These measurements would also be used to determine how well the surface measurements of the aerosol hygroscopic factor could be used to estimate this factor for the vertical profile and to assess the IAP measurements of aerosol scattering at an elevated relative humidity.

These aerosol measurements will be valuable for evaluation and validation of current (e.g. Terra MODIS and MISR) and future (e.g. Aqua MODIS and GLAS) satellite measurements, and so we expect that there will be considerable interest in this IOP from the satellite aerosol community. Coordinating the analyses of these aerosol IOP measurements along with these satellite data could potentially provide a mechanism to extend the results to other locations besides the ARM SGP site. In addition, these measurements would be valuable for assessing and potentially improving the ability of aerosol assimilation models to accurately portray the vertical distribution of aerosol properties. These global aerosol models have become critical in integrating satellite and in-situ measurements for use in assessing the effects of atmospheric aerosols.

Specific closure experiments (See Table 1 for measurements/instruments; <u>required measurements/instruments are underlined</u>)

1. Aerosol Extinction (surface, dry)
    a. PSAP (AOS) +nephelometer (AOS) vs. CRD
    b. photoacoustic+nephelometer (AOS) vs. CRD
    c. aethalometer+nephelometer (AOS) vs. CRD
    d. Measurements/instruments (<u>1, 2, 3</u>)

2. Aerosol Extinction (surface, wet)
    a. nephelometer (AOS) + absorption(s) + humification factor (AOS) vs. Sun photometers (surface + airborne)
    b. CRD(s) + humification factor (AOS) vs. Sun photometers (surface + airborne)
    c. Measurements/instruments (<u>1</u>, 2, <u>3</u>, 4, <u>6, 14</u>)

3. Aerosol Humification Factor (profile)
    a. AOS (surface) + IAP (single elevated RH) vs. Aircraft humidigraph
    b. Measurements/Instruments (<u>15</u>, 13, <u>23</u>)

4. Aerosol Scattering Profiles derived from SGP Routine Measurements
    a. IAP (dry) vs. nephelometer (airborne)
    b. Measurements/Instruments (<u>15</u>, 11, <u>23</u>, 25)

6. Aerosol Absorption Profiles derived from SGP Routine Measurements
    a. IAP (dry) vs. PSAP (airborne) (Calibrated using photoacoustic)
    b. Photoacoustic (airborne) vs. IAP (dry) vs. PSAP (airborne)
    c. Comparison of in situ profiles (IAP, PSAP, photoacoustic) vs. derived from Cimel and/or MFRSR and/or polarization
    d. Measurements/Instruments (<u>1</u>, <u>16</u>, <u>23</u>, 2, 11, 25)

7. Aerosol Extinction Profiles derived from SGP Routine Measurements
    a. Raman/MPL lidars vs. Sun photometer (airborne)
    b. Raman/MPL lidars vs. nephelometer + PSAP + humification factor (airborne)
    c. IAP (dry) vs. neph + PSAP (airborne) vs. CRD
    c. IAP (dry) vs. nephelometer + PSAP (airborne)
    d. IAP (dry) vs. nephelometer + photoacoustic (airborne)
    e. IAP (dry) + humification vs. Sun photometer (airborne)
    f. Measurements/Instruments (<u>14, 15, 16, 23</u>, 1, 4, 11, 12, 25)

3. CCN/Cloud

What is the relationship between CCN number concentration (at several supersaturations in the range ~0.1 - 1%) and aerosol size distribution, at the surface and at cloud base?

How well can the cloud nucleating properties of particles just below cloud base be represented using surface measurements of cloud nucleating properties of particles along with profiles of relative humidity and aerosol extinction?

What is the relationship between the cloud base CCN number concentrations and size distributions, cloud base turbulence, and cloud droplet number concentrations and size distributions?

The effects of aerosols on cloud properties need to be quantified in order to meet the ARM objectives of relating observed atmospheric radiative fluxes and radiances to clouds. These effects include both the increase in cloud reflectivity due to more and smaller cloud droplets forming on the aerosol, as well as the increase in the lifetime of clouds due to reduced precipitation in clouds with more and smaller droplets. While ARM has pursued cloud IOPs that have acquired airborne measurements of cloud droplet size distribution (FSSP, PMS, CPI) and cloud liquid water content (CVI, Rosemount Icing Meter), ARM lacks measurements of the CCN spectrum at cloud base. Since most of the presently available data have been obtained in cleaner (maritime) areas the addition of data from continental areas (i.e. Oklahoma) would be a large step forward for the indirect aerosol effect.

One CCN experiment would test a surface-based CCN vertical profile retrieval method that uses surface measurements of the relative humidity dependence of extinction to convert Raman lidar estimates of aerosol extinction coefficient to dryextinction, given the Raman relative humidity retrieval. The vertical profile of dry extinction is used to scale surface measurements of CCN to produce a vertical profile of CCN. This retrieval method assumes the composition and size distribution of the aerosol at the surface is the same as that aloft. In addition to comparing in situ measurements of vertical profile of CCN with the retrieved CCN(z), in situ measurements of extinction can be compared with the Raman lidar retrieval, and the vertical profile of the humidification factor can be compared with the surface measurements. If it can be shown that the retrieval works under most conditions then ARM can provide a long time series of CCN profile retrievals from surface-based measurements.

If possible, these CCN studies should include direct measurements of CCN using thermal diffusion chamber(s) as well as measurements of the aerosol nucleation mode size distribution and aerosol compositions. The direct CCN measurements are important for determining the feasibility and uncertainty in estimating CCN using aerosol size distributions (for radius range 0.01 to 0.1 µm) and particle composition. The addition of airborne CCN measurements, at least during a Cloud/Aerosol IOP, would permit the evaluation of the vertical variability of CCN and would provide data to assess the utility of continuous surface CCN measurements.

Specific closure experiments (See Table 1 for measurements/instruments; required measurements/instruments are underlined)

1. CCN (surface)
   a. CCN (spectrometers)
   b. Measurements/Instruments (7, 8, 26)

2. CCN (cloud base)
   a. CCN (spectrometer) vs. Aerosol size distribution
   b. Measurements/Instruments (7, 8, 19, 20, 21, 23)

3. CCN (profile)
   a. CCN (surface) + lidar aerosol extinction + humidification+RH vs. CCN aircraft
   b. Measurements/Instruments (7, 8, 15, 23)

4. Cloud liquid water path
   a. in situ (vertical integral of LWC from Johnson probe, Gerber probe) vs. remote (MWR, radar)
   b. in situ (vertical integral of cloud drop conc.) vs. in situ (vertical integral of LWC from Johnson probe, Gerber probe)
   c. Measurements/Instruments (21, 22, 23)

5. Cloud transmittance
   a. surface measurements of optical depth (RSS) vs. Model+LWP+drop concentration
   b. Measurements/Instruments (20, 21, 22, 23)

6. Cloud drop concentration
   a. Model from radar vs. aircraft in situ
   b. Model from radar vs. Model+CCN spectrum+vertical velocity
   c. Measurements/Instruments (7, 8, 20, 21, 23, 24)

Instrument and platform requirements

This section presents a tabulation of instrument and measurement requirements to meet the measurement needs outlined above. These requirements are distinguished into measurements that are a part of the standard SGP suite and supplemental measurements specifically for this IOP.

Routine (i.e. standard) SGP measurements

1. AOS measurements
    a. aerosol light scattering at 3 wavelengths (RH≤40%), (0.1, 10 μm size cuts)
    b. aerosol absorption coefficient (PSAP methods) (RH≤40%), (0.1, 10 μm size cuts)
    c. single scattering albedo
    d. Angstrom exponents
    e. total condensation particle concentration
    g. ozone
    h. aerosol number distribution (0.1 to 10 μm)
    i. light scattering (green) as a function of relative humidity (f(RH))
    Derived parameters include
    1.Extinction coefficient
    2.Single scattering albedo
    3.Ångström coefficient, Å
    4.Hemispheric backscatter fraction, b, no units or in %
2. CSPHOT Cimel Sun and sky photometer
    a. AOT 5 wavelengths
    b. Angstrom exponents
    c. Sky radiance in principal plane and almucantar.
        1. aerosol size distribution
        2. refractive index and single scattering albedo if possible
        Derived parameters include
        1. aerosol size distribution
        2. refractive index (under certain conditions)
        3. single scattering albedo (under certain conditions)
3. MFRSR
    a. AOT 5 wavelengths
    b. Angstrom exponent
4. RSS
    a. direct spectral irradiance
    b. diffuse spectral irradiance
5. CART Raman lidar
    a. water vapor mixing ratio profiles
    b. aerosol backscattering and extinction profiles
    c. aerosol optical thickness
    Derived parameters include:
    1. RH
6. MPL
    a. aerosol backscattering and extinction profiles
7. In Situ Aerosol Profiling (IAP) flights

   a. aerosol scattering at three wavelengths (dry)
   b. aerosol scattering at one wavelength (high RH)
   c. aerosol absorption at one wavelength (dry)
   d. hemispheric backscatter fraction
   e. AOT (derived from scattering and absorption)
   f. Angstrom exponents (derived from AOT)
8. Aerosol mass concentration and ionic composition (surface) PMEL
9. Broadband fluxes (Eppley 8-48 diffuse pyranometers, Eppley AHF cavity radiometers, and Eppley PIR infrared radiometers)

Proposed IOP Measurements/Instruments

An estimate has been obtained for the use of the CIRPAS Twin Otter (CTO). This includes 60 flights hours for science missions, 18 flight hours for ferry flights, and 8 hours for test flights. Aircraft altitudes are less than 18 kft. Aircraft operations assumes no range or landing fees, access to hangar space, no facility use fees, and flight activity does not require FAA CoA. In the table that follows, the CIRPAS facility instruments/measurements are indicated.

A separate aircraft is desired to deploy the DRI CCN instruments. Potential aircraft are Cessna 210 or 206, Piper Aztec or Navajo.

The proposed aircraft measurements are listed separately in Table 2. The proposed additional surface measurements are listed in Table 3.

Table 1. Potential Aerosol IOP Measurements (Airborne and Surface)

	Measurement	Instrument	PI/team	Surface and/or Aircraft
1	Aerosol absorption (532 nm)	Photoacoustic	Arnott/Moosmueller/DRI	S, A (CTO)
2	Aerosol absorption (450, 550, 700 nm)	Modified aethalometer	Ogren/CMDL	S
3	Aerosol extinction (532 nm)	Cavity Ringdown (CRD)	Arnott/Moosmueller/DRI	S
4	Aerosol extinction (700 nm)	Cavity Ringdown (CRD)	Strawa/NASA/Ames	A (CTO)
5	Broadband irradiance	Broadband cavity radiometer	PNNL (Michalsky)	S
6	Aerosol optical thickness (0.3-2.5 mm), sky radiance, polarization, BRDF	Sun-sky-surface sensor	Tsay/NASA/GSFC	S
7	CCN	CCN spectrometer	Hudson/DRI	A (TBD), S
8	CCN	CCN spectrometer	Seinfeld/Cal Tech	A (CTO)
9	Diffuse/direct radiance (300-380 nm)	UVRSS	Michalsky (SUNY Albany)	S
10	Column ozone	UVRSS or CSU-MFRSR	Michalsky/SUNY Albany	S
11	Aerosol extinction profiles, aerosol mean radius, refractive index, single scatter albedo (nighttime)	Multiwavelength Raman/Rayleigh-Mie lidar	Ansmann/Wandinger/IfT	S
12	Aerosol extinction (horizontal profile) (355 nm)	Scanning Raman Lidar	NASA/GSFC	S
13	Aerosol size distribution 10 nm- 1 mm at 2 RH	TDMA	Cal Tech	A (CTO)

	Measurement	Instrument	PI/team	Surface and/or Aircraft
14	Aerosol optical thickness, extinction profiles	Airborne AATS-14 Sun photometer	Russell/Schmid NASA Ames	A (CTO)
15	Aerosol hygroscopic scattering	Humidified Nephelometer, humidigraph	Covert (U. Wash)	A (CTO)
16	Aerosol absorption	PSAP	Covert (U. Wash)	A (CTO)
17	Upwelling and downwell SW spectral irradiance/radiance, surface albedo 300-2500 nm	Solar Spectral Flux Radiometers (SSFR)	Pilewskie/NASA Ames	A (CTO)
18	Total upward and downward fluxes	Kipp and Zonen CM-22 pyranometers, CG-4 pyrgeometers	A. Bucholtz/NRL and/or McCoy Sandia	A (CTO)
19	Aerosol Size Distribution 0.3-2.5 mm	PCASP (0.1-2.5 mm) >0.3 mm (CAPS)	CIRPAS	A (CTO)
20	Aerosol Size Distribution >0.5 mm	TSI aerodynamic particle sizer	CIRPAS	A (CTO)
21	Aerosol/Cloud Drop Size Distribution 0.5-50 mm	CAPS, FSSP	CIRPAS	A (CTO)
22	Cloud liquid water	Johnson probe in CAPS, Gerber PVM probe if borrowed	CIRPAS	A (CTO)
23	Meteorological state	Standard instruments	CIRPAS	A (CTO)
24	Turbulence, updraft velocity	Analysis	CIRPAS	A (CTO)
25	Polarization measurements of radiance (aerosol refractive index), BRDF	Research Scanning Polarimeter (RSP) (http://www.giss.nasa.gov./data/rsp_air/) or Cimel	Cairns/NASA/ GISS	S
26	Aerosol Size Distribution (20 - 500 nm)	SMPS	Hudson/DRI	S
27	reflectance, radiance or irradiance spectra (350-2500 nm)	ASD spectroradiometer	??	S

Table 2. Potential Aerosol IOP Measurements (Airborne only)

Available Measurement	Instrument	PI/Organization
Aerosol size distribution 10 nm-1μm at 2 RH (one can be ambient)	TDMA System (cabin)	Caltech/CIRPAS 1 student
Aerosol/cloud size distribution 0.1-2.5 μm (PCASP) >0.3 μm (CAPS)	PCASP CAPS Probe	CIRPAS
Aerosol/cloud size distribution >0.5 μm (FSSP)	FSSP probe	CIRPAS
Aerosol size distribution >0.5 μm	TSI Aerodynamic Particle Sizer (wing)	CIRPAS
Total aerosol number concentration	Condensation Nucleus Counters (CNCs)	CIRPAS
Cloud liquid water content	Gerber PVM (CIRPAS would need to borrow) 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/CIRPAS 1 student
Turbulence Updraft velocity	Analysis	1 Researcher from Irivine or NPS

Table 2. Potential Aerosol IOP Measurements (Airborne only)

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
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) (cabin)	B. Schmid /NASA Ames
Aerosol light extinction coefficient (700 nm)	Cavity ring-down extinction cell	A. Strawa /NASA Ames
Downwelling and upwelling solar and IR broadband irradiance	CM-22 pyranometers CG-4 pyrgeometers (Kipp and Zonen, Sandia modified)	A. Buchholz/NRL (McCoy/SANDIA)
Downwelling and Upwelling Solar Spectral Irradiance, 1320 channels	NASA Ames Solar Spectral Flux Radiometer (cabin)	P. Pilewskie /NASA Ames
Aerosol absorption	Photo-acoustic Instrument	P. Arnott/DRI

Table 3. Potential Aerosol IOP Measurements (Surface only)

Measurement	Instrument	PI/team	Surface
Aerosol absorption (532 nm)	Photoacoustic	Arnott/Moosmueller/DRI	S
Aerosol absorption (450, 550, 700 nm)	Modified aethalometer	Ogren/CMDL	S
Aerosol extinction (532 nm)	Cavity Ringdown (CRD)	Arnott/Moosmueller/DRI	S
Broadband irradiance	Broadband cavity radiometer	PNNL (Michalsky)	S
Aerosol optical thickness (0.3-2.5 mm), sky radiance, polarization, BRDF	Sun-sky-surface sensor	Tsay/NASA/GSFC	S
CCN	CCN spectrometer	Hudson/DRI	S
Diffuse/direct radiance (300-380 nm)	UVRSS	Michalsky (SUNY Albany)	S
Column ozone	UVRSS or CSU-MFRSR	Michalsky/SUNY Albany	S
Polarization measurements of radiance (aerosol refractive index), BRDF	Research Scanning Polarimeter (RSP) (http://www.giss.nasa.gov./data/rsp_air/) or Cimel	Cairns/NASA/GISS	S
Aerosol Size Distribution (20 - 500 nm)	SMPS	Hudson/DRI	S
Aerosol extinction profiles, aerosol mean radius, refractive index, single scatter albedo (nighttime)	Multiwavelength Raman/Rayleigh-Mie lidar	Ansmann/Wandinger/IfT	S
Aerosol extinction (horizontal profile) (355 nm)	Scanning Raman Lidar	NASA/GSFC	S
reflectance, radiance or irradiance spectra (350-2500 nm)	ASD spectroradiometer	??	S

References

Andrews, E., P.J. Sheridan, and J.A. Ogren, In-situ Aerosol Profiles over the Southern Great Plains CART Site, Eleventh ARM Science Team Meeting Proceedings, Atlanta, Georgia, March 19-23, 2001.

Turner, D.D., R.A. Ferrare, L.A. Heilman, W.F. Feltz, and T. Tooman, Automated Retrievals of Water Vapor and Aerosol Profiles over Oklahoma from an Operational Raman Lidar, submitted to *J. Atmos. Oceanic Tech.*, 2001.

APPENDIX
Acronym List

AATS	Ames Airborne Tracking Sunphotometer
AOS	Aerosol Observing System [ground based instrument suite at SGP]
AOT	Aerosol Optical Thickness
ARM	Atmospheric Radiation Measurement [Program]
AWG	Aerosol Working Group
BSRN	Baseline Surface Radiation Network (suite of photometers and radiometers)
CARL	CART Raman Lidar
CART	Cloud And Radiation Testbed [operating entity of ARM]
CCN	Cloud Condensation Nucleus
CN	Condensation Nucleus (total aerosol number)
CSPHOT	Cimel Sun and Sky Photometer
DOE	Department of Energy
FSSP	Forward Scattering Spectrometer
GLAS	Geoscience Laser Altimeter System
GSFC	Goddard Space Flight Center
IAP	In-situ Aerosol Profiling [light aircraft in-situ measurement activity]
IOP	Intensive Observational Period
LW	Longwave (thermal infrared radiation)
LWC	Liquid Water Content
LWP	Liquid Water Path
MFRSR	MultiFilter Rotating Shadowband Radiometer
MISR	Multi-angle Imaging Spectroradiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MPL	MicroPulse Lidar
OBER	Office of Biological and Environmental Research
PCASP	Passive Cavity Aerosol Spectrometer Probe
PMEL	Pacific Marine Environmental Laboratory (NOAA)
PSAP	Particle Soot Absorption Photometer
RH	Relative Humidity
RSS	Rotating Shadowband Spectrometer
SGP	Southern Great Plains [ARM site]
SW	Shortwave (Solar radiation)
TAP	Tropospheric Aerosol Program [DOE OBER]