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Department of Energy Atmospheric Radiation Measurement Southern Great Plains Cloud and Radiation Testbed Site, Lamont, Oklahoma Science Plan for the Aerosol IOP

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Executive Summary

To gain improved understanding and model-based representation of aerosol radiative influences an Intensive Observational Period will be conducted at the Department of Energy's Atmospheric Radiation Measurement Southern Great Plains Site in north central Oklahoma, in May 2003. This experiment will use ground and airborne measurements of aerosol absorption, scattering, and extinction over the Atmospheric Radiation Measurement Southern Great Plains site to characterize the routine Atmospheric Radiation Measurement aerosol measurements, and help resolve differences between measurements and models of diffuse irradiance at the surface. The assessments of aerosol optical thickness and aerosol absorption will be carried out in conjunction with measurements of downwelling direct and diffuse irradiance as a function of wavelength and altitude. The Intensive Observational Period will carry out a variety of closure experiments on aerosol optical properties and their radiative influence. Measurements of the aerosol chemical composition and size distribution will allow testing of the ability to reconstruct optical properties from these measurements. Additional effort will be directed toward measurement of cloud condensation nucleus concentration as a function of supersaturation and relating cloud condensation nuclei concentration to aerosol composition and size distribution. This relation is central to description of the aerosol indirect effect. Additional measurements will also be carried out to assess the extent that remotely sensed parameters are adequate for detecting the indirect effect.

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Department of Energy Atmospheric Radiation Measurement Southern Great Plains Cloud and Radiation Testbed Site, Lamont, Oklahoma

Science Plan

1. Introduction

This document describes an Intensive Operating Period (IOP) dedicated to the measurement of atmospheric aerosols over at the Southern Great Plains (SGP) Cloud and Radiation Testbed site during May 2003. This IOP is a collaborative effort between the Department of Energy's Atmospheric Radiation Measurement and Atmospheric Chemistry Programs (ACPs). Contained here is a statement of goals for these efforts, background on the previous and ongoing aerosol measurements, and plans for the May 2003 Aerosol IOP. This document also describes the instrumentation, an outline of operational issues, and implementation details important for the execution of the IOP.

2. Background

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 activities are briefly discussed below.

2.1 Direct

Aerosol direct influences on shortwave radiation are substantial locally and globally. An aerosol optical thickness (AOT; acronyms are presented in Appendix A) 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.

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 Cloud and Radiation Testbed 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 questions about the representativeness of surface aerosol properties for these calculations. ARM Cloud and Radiation Testbed 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. Therefore, this IOP will be dedicated to charactering aerosols aloft and their radiative influence.

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.

2.2 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.

ARM is also currently supporting research investigating whether the indirect effect can be detected at SGP using ground-based remote sensors (Feingold et al. 2003). The working premise is that cloud response to changes in aerosol can be quantified using existing data sets. This IOP will help evaluate this premise and will provide additional data to determine whether models adequately predict probability density functions of cloud droplets and updraft velocities.

3. Scientific Requirements

This experiment will use ground and airborne measurements of aerosol absorption, scattering, and extinction over the ARM SGP site to characterize the routine ARM aerosol measurements and help resolve differences between measurements and models of diffuse irradiance at the surface. The planned IOP will carry out a variety of closure experiments on aerosol optical properties and their radiative influence. Additionally, planned measurements of the aerosol chemical composition size distribution, to be conducted by investigators in the DOE Atmospheric Chemistry Program and Tropospheric Aerosol Program, will allow testing of the ability to reconstruct optical properties from these measurements. Additional efforts will be directed toward measuring cloud condensation nucleus concentration as a function of supersaturation and relating to aerosol composition and size distribution. This relationship is central to describing the aerosol indirect effect.

3.1 Science 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.

3.1.1 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?

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 aerosol optical thickness (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-yr 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 relative humidity [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).

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 aerosol absorption will be acquired using both in situ and 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.

In order to assess and better characterize these measurements of aerosol absorption, a "mini-IOP" was conducted during 3-28 June 2002 at the Desert Research Institute in Reno, Nevada (Sheridan et al. 2002). The Reno Aerosol Optics Study was conducted to characterize, under controlled conditions, both existing and new in situ instruments designed to measure aerosol light extinction, absorption, and scattering. Participating in this experiment were three cavity ringdown extinction instruments, one classic extinction cell, three integrating nephelometers, two photoacoustic absorption instruments, and five filter-based absorption instruments. Good coverage of the visible spectrum was achieved from the operating wavelengths of the various instruments, with limited measurements being made in the near ultraviolet (UV) and near infrared (IR). A new mixing chamber (~76 L volume) was used to deliver varying amounts of white, black, and ambient aerosols and filtered air to all instruments. The white aerosols were submicrometer ammonium sulfate, while several submicrometer black aerosols including kerosene soot and diesel emission particles were studied. Individual tests were run with aerosol extinction varying between low (~50 Mm^{-1}) and high (~500 Mm^{-1}) values and aerosol single-scattering albedos ranging from ~0.3 (pure black aerosol) to ~1.0 (pure ammonium sulfate). Two independent standards for aerosol absorption were found to agree within about 4-8% at a wavelength of 532 nm: photoacoustic absorption vs. the difference of extinction and scattering. The commonly used PSAP filter based method agreed with these measurements with about +/-3% for typical atmospheric absorption levels. This study also found that the filter based methods (e.g. PSAP, aethalometer) require improved corrections for multiple scattering effects and filter loading. Also, the cavity ring down extinction cells measured lower extinction (~10%) relative to the long path extinction cell and the sum of the scattering and absorption measurements.

The Aerosol IOP will make use of several of these instruments that were characterized during the Reno experiment to measure aerosol absorption in a series of closure experiments listed below. In addition, aerosol absorption will also be derived using flux divergence measurements. (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. The Solar Spectral Flux Radiometer (SSFR) will fly aboard the Twin Otter during the IOP to measure spectral flux and flux divergence. A model 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 (Bergstrom et al. 2002). The absorption obtained from this remote sensing method will be compared to the airborne in situ measurements from the airborne PSAP, CW-CRD, and photoacoustic instruments.

Note 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 the uplooking SSFR (and also the broadband radiation instruments) will be mounted 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).

Broadband and spectrally resolved measurements of the surface albedo would also be required for resolving the differences between measured and modeled diffuse irradiance. Recent modeling has shown that better estimates of the surface albedo significantly reduce the differences between measured and modeled diffuse irradiance. Therefore, measurements of the surface reflectance acquired by the SSFR during low altitude aircraft flights would be used to derive the surface albedo. Surface albedo will also be derived using point measurements acquired at the site as well as satellite using methods similar to those employed during August 2002 (Trishchenko et al. 2003; Li et al. 2003). Surface spectral albedo/reflectance for several representative surface types will be measured using a GER-3700 spectroradiometer with a spectral coverage between 300 and 2500 nm, while satellite data (geostationary operational environmental satellite [GOES], Clouds and Earth's Radiant Energy System [CERES]) will be used to extend such point-specific observations to much larger areas. The goal of these measurements would be to accurately constrain the surface albedo and 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/intercomparison experiments

1. Aerosol absorption intercomparison (surface, dry)
    a. PSAP (AOS) vs. aethalometer
    b. PSAP (AOS) vs. photoacoustic
    c. Aethalometer vs. photoacoustic

2. Aerosol Absorption Profile Intercomparison 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

3. Diffuse Downwelling Closure (broadband)
   a. Measured (shaded pyranometer) vs. Model (aerosol+gas) input

4. Diffuse Downwelling Closure (spectral)
   a. Measured (RSS, SSFR) vs. Model (aerosol+gas) input

5. Diffuse/Direct Ratio Closure (spectral)
   a. Measured (RSS,SSFR) vs. Modeled (aerosol+gas) input

3.1.2 Aerosol Optical Thickness Closure

How well do the routine Cloud and Radiation Testbed 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?

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. Aerosol optical thickness is derived from routine measurements by the Cimel Sun photometer, Multifilter Rotating Shadowband Radiometer (MFRSR), RSS, and Cloud and Radiation Testbed Raman lidar. 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.

Since March 2000, ARM has been measuring 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 <1 μm. 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 <u>all</u> 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. Schmid et al. (1999; 2001) assessed the accuracy of ground-based AOD measurements made by ARM sunphotometers (cimel photometer [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, the AODs agreed within 0.02 (root mean square [rms], absolute AOD value) 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, 2003). I 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. 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).

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 Tracking 14-channel Sunphotometer, AATS-14 (Schmid et al. 2000) has been used to measure profiles of aerosol optical thickness and aerosol extinction as a function of wavelength at ambient conditions. 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. These profiles could be used to evaluate the Cloud and Radiation Radiation Testbed Raman lidar, IAP, and MPL aerosol extinction profiles as well as to evaluate the aerosol Angstrom exponent used to scale the CARL measurements. In addition, the relatively new CW-CRD technology will be used to measure the aerosol extinction coefficient. A CW-CRD instrument recently developed by Dr. Strawa at NASA Ames will 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. 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. The AATS-14 measurements will be compared with the CW-CRD results and also with the airborne in situ measurements of scattering from humidified nephelometry and absorption. Aerosol extinction will also be calculated 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.

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 be used to help assess methods to provide aerosol parameters (aerosol optical thickness, single scatter albedo, asymmetry parameter) for the BBHRP.

Specific closure/intercomparison experiments

1. Aerosol Extinction (surface, dry)
    a. PSAP (AOS) +nephelometer (AOS) vs. CRD
    b. photoacoustic+nephelometer (AOS) vs. CRD
    c. aethalometer+nephelometer (AOS) vs. CRD

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)

3. Aerosol Humidification Factor (profile)
    a. AOS (surface) + IAP (single elevated RH) vs. Aircraft humidigraph

4. Aerosol Scattering Profiles Intercomparisons derived from SGP Routine Measurements
    a. IAP (dry) vs. nephelometer (airborne)

5. 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

6. 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
    d. IAP (dry) vs. nephelometer + PSAP (airborne)
    e. IAP (dry) vs. nephelometer + photoacoustic (airborne)
    f. IAP (dry) + humification vs. Sun photometer (airborne)

3.1.3 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 (forward scattering spectrometer probe [FSSP], particle measuring system [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 dry extinction, given the Raman relative humidity retrieval (Ghan 2003). 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.

The CCN profile will be retrieved according to the following algorithm:

$$CCN(z) = CCN(z_0)E_d(z)/E_d(z_0)$$

where $E_d(z)$ is the dry extinction profile determined by scaling the extinction at ambient relative humidity by the extinction humidification factor f at relative humidity $RH(z)$:

$$E_d(z) = E(z)/f(RH(z))$$

The extinction at ambient humidity and the relative humidity are measured by Raman lidar. The humidification factor *f(RH)*, which is the ratio of extinction at relative humidity *RH* to the extinction under dry conditions, will be measured at the surface by humidified nephelometer as function of relative humidity. The scaling of the extinction profile by the humidification factor measured at the surface $f(RH,z_0)$ relies on the assumption that the humidification function measured at the surface is applicable to all altitudes. Such an assumption will be valid if the particle size distribution and composition are independent of altitude. Measurements of the vertical profile of $f(RH,z)$ will be used to determine how departures of $f(RH,z)$ from $f(RH(z),z_0)$ depend on other factors that be used to characterize the uncertainty in the humidification factor.

The scaling of the surface measurement of the CCN concentration by the dry extinction normalized by the surface (as close as possible) extinction relies on the assumption that vertical variations in CCN concentration are associated with variations in the same particles that control variations in extinction. If the particle composition and size distribution are uniform in height then such an assumption is valid. But if the composition or size distribution shifts with altitude then the association between CCN concentration and dry extinction breaks down. For example, extinction is most sensitive to particles with diameters close to the wavelength of the lidar, which is several tenths of a micron for most lidar (0.355 micron for the ARM Raman lidar). For the Raman lidar wavelength the aerosol extinction is most sensitive to particles with diameters between 0.2 and 0.6 micron. The CCN concentration for supersaturations typical of the maximum supersaturation in cloud updrafts (0.1-1%) is most sensitive to particles with diameter smaller than 0.1 micron. If vertical variations in particles with diameters between 0.2 and 0.6 are unrelated to variations in particles with diameters less than 0.1 micron then the vertical structure of extinction will be uncorrelated with the vertical structure of CCN concentration, and the retrieval will be no better than the surface measurement. CCN concentrations at lower supersaturations are sensitive to the same particle sizes that control aerosol extinction (for ammonium sulfate only particles with diameters larger than 0.2 micron are activated at 0.06% supersaturation), but their variations will only scale with extinction if the composition is uniform.

Dry extinction is only one remotely sensed measure of aerosol that can be used to scale the CCN concentration. Raman lidar also measures aerosol backscatter and hence could also be used to scale the CCN concentration. Aerosol backscatter would be more effective if it was more sensitive to the smaller particles that control CCN concentration at the supersaturations of interest.

The validation of the CCN retrieval scheme can be broken down into several tests:

1. Retrieval of aerosol extinction. The aerosol extinction retrieved from remote sensing is compared with in situ measurements. This is already being done as part of the ARM in situ aerosol profiling program (Ferrare et al. 2002, 2003; Clayton et al. 2002).

2. Retrieval of relative humidity. The relative humidity retrieved from remote sensing is compared with in situ measurements. This is also being done as part of the ARM Raman lidar effort (Ferrare et al. 2002, 2003; Clayton et al. 2002).

3. Uniformity of *f(RH)*. Surface measurements of *f(RH)* are compared with vertical profiles of *f(RH)* measured as part of an aerosol IOP.

4. Uniformity of aerosol size distribution. The CCN profile is estimated from the vertical profile of the dry aerosol size distribution, using Kohler theory. It is also estimated by scaling the CCN concentration at some reference level (estimated from the size distribution there, again using Kohler theory) by the dry extinction profile normalized by the dry extinction at the reference level, where the dry extinction is calculated from the measured size distribution using Mie theory. The vertical profiles of CCN are compared. Only vertical profiles of size distribution are required.

5. Covariance of CCN concentration and dry extinction. Vertical profiles of CCN concentration and dry extinction are determined from in situ measurements. The linearity of the relationship is tested.

6. CCN retrieval. The vertical profile of CCN concentration retrieved using the full retrieval scheme is compared with in situ measurements.

To test the scaling of the CCN concentration by the dry extinction (or backscatter), measurements of the following quantities are needed.

1. Surface CCN spectrum. A spectrum is needed to determine which supersaturations the CCN can be retrieved. Supersaturations should span the range 0.05-1%, with vertical profiles of concentrations at the lowest value expected to be retrieved more accurately than at the highest supersaturation.

2. Surface extinction humidification function. The wavelength should be roughly consistent with that of the Raman lidar. Humidified nephelometer.

3. Vertical profile of CCN spectrum. The instrument must measure the CCN at the same supersaturations as the instrument at the surface, and be able to provide CCN concentrations that agree with the surface instrument.

4. Vertical profile of aerosol extinction from remote sensing. Raman lidar.

5. Vertical profile of relative humidity from remote sensing. Raman lidar.

6. Vertical profile of relative humidity from in situ measurements.

7. Vertical profile of dry aerosol size distribution. DMA.

8. Vertical profile of extinction humidification function from in situ measurements. The instrument must be able to provide measurements that agree with the surface instrument. Humidified nephelometer.

Specific closure/intercomparison experiments

1. CCN (surface)
   a. CCN (spectrometers)

2. CCN (cloud base)
   a. CCN (spectrometer) vs. Aerosol size distribution

3. CCN (profile)
   a. CCN (surface) + lidar aerosol extinction + humidification+RH vs. CCN aircraft

4. Cloud liquid water path
   a. in situ (vertical integral of liquid water content [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)

5. Cloud transmittance
   a. surface measurements of optical depth (RSS) vs. Model+LWP+drop concentration

6. Cloud drop concentration
   a. Model from radar vs. aircraft in situ

3.1.4 Aerosol Indirect Effect

To what extent are remotely sensed parameters adequate for detecting indirect effect – (i.e. what is the response of cloud drop effective radius r_e to changes in aerosol extinction *for clouds of similar liquid water path (LWP)* in a statistical manner?)

The extent to which one can detect the indirect effect at SGP using ground-based remote sensors will be examined. The working premise is that cloud response to changes in aerosol can be quantified using existing data sets (see Feingold et al. 2003). Cloud response is measured in terms of the drop effective radius r_e. Changes in aerosol are represented by aerosol extinction at a prescribed level beneath cloud base. This approach avoids the assumptions that (a) surface measured aerosol is representative of aerosol affecting the cloud, or that (b) column integrated extinction (i.e., optical depth) in cloud free areas is representative of the aerosol affecting the cloud.

The primary measurements are therefore:

1. Effective radius r_e derived from a variety of techniques, including radar/microwave radiometer, radar, microwave radiometer and surface aerosol concentration, MFRSR (Min and Harrison 1996), and moderate-resolution imaging spectroradiometer (MODIS) (satellite).

2. Liquid water Path LWP derived from the microwave radiometer.

3. Aerosol extinction from the Raman lidar.

Goals for Airborne experiments during Spring IOP:

1. To determine the extent to which these remotely sensed parameters are adequate for detecting the indirect effect. Using remote sensors, the indirect effect should be addressed as the response of r_e to changes in aerosol extinction *for clouds of similar LWP* in a statistical manner. In situ measurements will provide a sense of the adequacy of these basic measurements.

   a. LWP – In spite of problems with measurement of LWP at values < ~ 30 g/m^2 microwave radiometers can provide a strong constraint on LWP.

   b. r_e – the question of the adequacy of remote r_e measurements is an open question. In situ measurements, if they can be collocated with radar/lidar/radiometer measurements at the Central facility (CF), will be used to assess changes in r_e.

   c. Aerosol extinction – the primary question is whether sub-cloud base extinction can provide a statistically meaningful proxy for the aerosol affecting cloud. Clearly size distribution and composition are important factors and the IOP will enable us to address this issue by measuring size distributions of aerosol. We plan to infer some information on composition from the CCN measurements. In addition, in well-mixed boundary layers some rough information on composition will be inferred from surface nephelometer-derived *f*(RH), or enhancements in lidar extinction as a function of RH from the surface RH to cloud base.

2. To obtain in situ data pertaining to the indirect effect at a well-instrumented site where the infrastructure will enable us to constrain ourselves to comparing the effect of aerosols on clouds at the same LWP. Many field experiments have not been able to avail themselves of this LWP constraint, or utilize the plethora of surface-based in situ and remote sensing observations. Without the LWP constraint, quantification of the indirect effect is ambiguous.

3. To test models. Specifically, to determine how well models adequately predict the probability density function pdf of the number of cloud droplets, given a measured pdf of updraft velocities. In the absence of particle composition measurements, to determine how well models can explain the observations given reasonable assumptions of particle composition. Additionally, observations will provide valuable tests for large-eddy simulation (LES) that resolve aerosol-cloud interactions. Since LES predict pdfs of vertical velocity, as well as drop size distributions, further model evaluations could be made in more realistic dynamical environments than the parcel model. A third option exists. This would use LES of given case studies to derive ensembles of parcel trajectories. Once it has been established that the LES provides adequate pdfs of updraft velocities, parcel models can be run along these trajectories to compare pdfs of drop number concentration.

4. Experiment Approach

The Aerosol IOP will be conducted from May 5 –30, 2003 over the ARM SGP facility. This period was chosen in order to obtain a wide range of aerosol optical thickness conditions to address hypotheses 1 and 2. This period also has a good probability of encountering warm liquid phase clouds desirable for addressing hypotheses 3 and 4.

In addition to the normal compliment of instrumentation at the ARM SGP site, the IOP will use a number of additional ground based and airborne instruments. Tables 1 through 5 list the instruments and measurements to be performed during this IOP, and whether they will be operated on the ground or on an aircraft. The location of those instruments to be operated at the ARM SGP site is also indicated. Note that these tables include measurements acquired by both the routine ARM SGP instruments (denoted by * in columns 4 or 5) as well as additional instruments deployed for the IOP.

4.1 Aircraft

The IOP will use two aircraft during this IOP. The first is the Cessna 172N aircraft operated by Greenwood Aviation as part of the DOE ARM IAP Program. A detailed description of this program, included instruments, measurements, and recent data plots, can be found at http://www.cmdl.noaa.gov/aero/net/iap/index.html. The second aircraft is the Naval Postgraduate School (NPS) Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) Twin Otter research aircraft. This aircraft will be equipped with a suite of in situ aerosol instruments for measuring aerosol scattering, absorption, and extinction, the National Aeronautics and Space Administration (NASA) Ames Sun photometer, CCN spectrometer (Cal Tech), NASA Ames Solar Spectral Flux Radiometers, and a newly developed stabilized platform for mounting the upward looking radiometric instruments. Appendix B gives a description of this aircraft and instruments for this mission. During April 2003, many of these same in situ and remote instruments will also be deployed on the Twin Otter for the Asian Dust Above Monterey (ADAM) experiment. The Ponca City airport will be the base of operations for both aircraft during the aerosol IOP. Daily status/flight planning meetings will be held at the Greenwood Aviation facilities at the Ponca City airport during the mission.

4.2 Surface Measurements

A number of additional instruments will be deployed at the SGP CF during the Aerosol IOP. These additional sensors, which are also listed in Tables 1 through 5, include sensors for in situ and remote sensing measurements of aerosols, aerosol radiative influences, and aerosol and gas composition. These sensors will be located in either the aerosol trailer (AT) (http://www.arm.gov/docs/sites/sgp/guest/sgp_guest_facility.html) or the guest instrument facility (GIF) (http://www.arm.gov/docs/sites/sgp/guest/sgp_guest_facility.html) at the SGP site. These instruments include the Surface-sensing Measurements for Atmospheric Radiative Transfer (SMART) instrument suite (http://smart-commit.gsfc.nasa.gov/index.html) operated by NASA Goddard Space Flight Center. A more complete listing of the Aerosol IOP surface instruments to be deployed at the SGP site is given in Appendix C. A schematic showing the layout of the GIF is also given in Appendix C.

Table 1. Aerosol Optical Properties.				
Measurement	**Instrument**	**PI/team**	**Surface**	**Air**
Aerosol absorption (532 nm)	Photoacoustic	Arnott (DRI)	GIF	TO
Aerosol absorption (450, 550, 700 nm)	Modified Aethalometer	Ogren (CMDL)	AT	
Aerosol absorption (7 wavelengths)	Modified Aethalometer	Arnott	GIF	
Aerosol absorption (565 nm)	PSAP	Ogren (CMDL) (ARM AOS)	AT *	
Aerosol absorption (565 nm)	PSAP	Ogren (CMDL) (ARM IAP)		IAP
Aerosol absorption (466, 530, 660 nm)	Modified PSAP	Covert/Alquist (UW)	AT *	TO
Aerosol scattering and hemispheric back scattering (450, 550, 700 nm, Dp < 1 µm and Dp < 10 µm, all at both low and varying RH)	TSI 3563 integrating nephelometers, scanning humidograph system	Ogren (CMDL) (ARM AOS)	AT *	
Aerosol scattering and hemispheric back scattering (450, 550, 700 nm, Dp < 1 µm and Dp < 10 µm), all at low RH)	TSI 3563 integrating nephelometers, scanning humidograph system	Ogren (CMDL)	GIF	
Aerosol scattering and hemispheric bac scattering (450, 550, 700 nm, Dp < 1 µm) low RH and aerosol scattering (550 nm) at RH=85%)	TSI 3563 integrating nephelometers, scanning humidograph system	Ogren (CMDL) (ARM IAP)		IAP *
Aerosol scattering and hemispheric back scattering (450, 550, 700 nm)	TSI 3563 integrating nephelometers	Covert/Elleman (UW)		TO
Aerosol hygroscopic scattering (RH=30, 60, 85%) (550 nm)	Humidified Nephelometer, humidigraph	Covert/Elleman (UW)		TO
Aerosol scattering (532 nm)	Nephelometer (DRI integrating sphere)	Arnott/DRI	GIF	
Aerosol scattering (530 nm)	Nephelometer (Radiance Research)	Arnott/DRI	GIF	
Aerosol extinction (532 nm)	Cavity Ringdown (CRD)	Arnott/DRI	GIF	
Aerosol extinction (700 nm)	Cavity Ringdown (CRD)	Strawa (NASA/Ames)		TO

Table 2. Aerosol & Cloud Microphysical Properties.

Measurement	**Instrument**	**PI/team**	**Surface**	**Air**
Aerosol Size Distribution 0.3-2.5 μm	PCASP (0.1-2.5 μm) >0.3 μm (CAPS)	CIRPAS		TO
Aerosol Size Distribution >0.5 μm	TSI aerodynamic particle sizer	CIRPAS		TO
Aerosol Size Distribution (20 - 500 nm)	SMPS	Hudson (DRI)	GIF	
Aerosol size distribution (0.1–10 μm)	PCASP	Ogren (CMDL) (ARM AOS)	AT *	
Aerosol size distribution 10 nm- 1 μm at 2 RH	TDMA	Rissman/Seinfeld (Cal Tech)		TO
Aerosol/cloud drop size distributions (0.5-50 μm)	CAPS, FSSP	CIRPAS		TO
Total particle number (>0.01 μm)	TSI 3010 CPC	Ogren (CMDL) (ARM AOS)	AT *	
CCN (several supersaturations)	CCN spectrometer	Hudson (DRI)	GIF	
CCN 0.2%, 0.4%, and 0.7% (TO); 0.3% (GIF)	CCN spectrometer	Rissman/Seinfeld (Cal Tech)	GIF	TO
Cloud liquid water	Johnson probe in CAPS	CIRPAS		TO
Cloud liquid water	Gerber PVM probe	CIRPAS		TO
Meteorological: Pressure, Temp, RH, Winds		CIRPAS		TO, IAP *

Table 3. Aerosol Radiative Influences.				
Measurement	**Instrument**	**PI/team**	**Surface**	**Air**
Broadband irradiance	Broadband cavity radiometer	ARM SGP	X*	
Broadband irradiance	PSP/CM21, NIP/CH1, PIR/CG4, NILU-UV	Tsay/Ji (NASA GSFC)	S	
UV Diffuse/direct radiance (300-360 nm)	UVRSS	Slusser (CSU)	X*	
Direct/diffuse irradiance (360-1060 nm)	RSS	Michalsky (SUNY-Albany)		
Upwelling and downwell SW spectral irradiance/radiance, surface albedo 300-2500 nm	Solar Spectral Flux Radiometers (SSFR)	Pilewskie (NASA Ames)		TO
reflectance, radiance or irradiance spectra (350-2500 nm)	SWS (Shortwave Spectroradiometer), ASD Solar spectrometer	Pilewskie (NASA Ames) Tsay/Ji (NASA GFSC)	X	
Downwelling spectral irradiance (3-20 µm)	AERI	ARM SGP, Tsay/Ji (NASA/GSFC)	S	
Total upward and downward fluxes	Kipp and Zonen CM-22 pyranometers, CG-4 pyrgeometers	A. Bucholtz (NRL)		TO
Surface Albedo	ASD Fieldspec, APAR radiometer	A. Trishchenko	X	
Sky radiance	Whole Sky Imager (WSI)	ARM SGP	X*	
Sky images	Total Sky Imager (TSI)	ARM SGP, Tsay/Ji NASA/GSFC	X*, S	

Table 4. Aerosol Optical Thickness and Profile.				
Measurement	**Instrument**	**PI/team**	**Surface**	**Air**
Aerosol optical thickness, extinction profiles	Airborne AATS-14 Sun photometer	Schmid (NASA Ames)		TO
Aerosol optical thickness (6 wavelengths, sky radiance) derive Angstrom exponent, SSA, aerosol size distribution, refractive index	Cimel Sun and sky photometer	ARM SGP and AERONET	X*	
Aerosol optical thickness (5 wavelengths), direct/diffuse ratio, Angstrom exponent	MFRSR	ARM SGP	X*	
Direct, diffuse spectral irradiance, AOT	RSS	ARM SGP	X*	
Aerosol optical thickness (0.3-2.5 µm), sky radiance, polarization (870 nm), BRDF	Sun-sky-surface sensor	Tsay/Ji (NASA/GSFC)	S	
Aerosol optical thickness (355 nm), aerosol extinction, backscatter, water vapor mixing ratio, relative humidity profiles	Raman lidar	ARM SGP	X*	
Aerosol backscatter profiles (523 nm)	MPL	ARM SGP and Tsay/Ji (NASA/GFSC)	X*, S	

Table 5. Aerosol & Gas Compositions				
Measurement	**Instrument**	PI/team	Surface	Air
Aerosol major ion concentration	Aerosol filters, IC	Quinn (PMEL)	AT	
Aerosol major ion concentration	PILS sampler-Ion Chromatog.	Lee (BNL)	GIF	
Aerosol major ion concentration	Quartz filter	Lee (BNL)	GIF	
Aerosol mass concentration	TEOM	Lee (BNL)	GIF	
Aerosol mass concentration	TEOM	Arnott (DRI)	GIF	
Aerosol mass	Dusttrack	Arnott (DRI)	GIF	
Size-segregated aerosol composition	Drum sampler, PIXE	Cahill (UCD)	GIF	
Refractive index, hygroscopicity	DMA, OPC	Wang (BNL)	GIF	
Refrative index, hygroscopicity	TDMA	Collins (Texas AM)	GIF	
Total/organic/elemental carbon (TC/OC/EC)	Aerosol filters	Kirchstetter (LBL)	AT	
Total organic carbon	PILS sampler-UV oxidation	Lee (BNL)	GIF	
Ozone concentration (surface)	Dasibi ozone monitor	Ogren (CMDL) (ARM AOS)	AT	
Ozone column	UV-MFRSR and UV-RSS	Slusser (CSU)	X	

4.3 Satellite Measurements

Data from various satellite instruments will be used to:

- Monitor aerosol amounts and transport,
- Aid in flight planning for the Twin Otter aircraft, (e.g. determining when to fly),
- Extend localized surface and airborne observations to regional scales,
- Evaluate spatial variability of aerosol optical thickness

In addition, standard meteorological satellites will be used for weather prediction and flight planning. A brief description of relevant satellite data for aerosol/radiation studies is given below.

4.3.1 TOMS Aerosol Index

The Total Ozone Mapping Spectrometer (TOMS) on the NASA Earth Probe satellite (http://toms.gsfc.nasa.gov/index.html) is a 6-channel backscatter ultraviolet sounder launched in 1996. Earth Probe TOMS is in a circular, sun-synchronous, polar orbit at a height of 740 km. Overpasses occur near local noon. The NASA Goddard Space Flight Center (GSFC) has developed a technique that retrieves the global distribution of UV-absorbing aerosols from the spectral contrast of the backscattered ultraviolet radiance from two of the UV channels of the TOMS instrument (Torres et al. 1998, 2002). An aerosol index (AI) is derived that gives an indication of the concentration of UV-absorbing aerosols.

4.3.2 Multi-Angle Imaging SpectroRadiometer

The Multi-angle Imaging SpectroRadiometer (MISR) (http://www-misr.jpl.nasa.gov/) onboard the NASA Terra satellite has nine cameras pointed toward Earth at nine look angles ranging from +70° through nadir to –70° in the forward and aft directions along the spacecraft's ground track. Each camera contains four line arrays with blue, green, red, and near-IR filters. MISR produces 36 simultaneous images (9 angles x 4 wavelengths) at up to 275-meter resolution. MISR on Terra was launched in 1999 and is in a sun-synchronous polar orbit. The MISR swath is approximately 360 to 400 km wide. For a given mid-latitude location an image is obtained every 3-5 days with an overpass time around 10:30 local time. MISR can obtain estimates of the aerosol amount, particle size, and composition. During the Aerosol IOP, if the opportunity exists, comparisons will be carried out between surface, airborne, and MISR satellite measurements of aerosols. Airborne measurements from the Aerosol IOP may also aid in MISR calibration efforts, MISR/MODIS intercomparisons, and validation of MISR aerosol retrievals. In standard "Global" mode, which is obtained whenever MISR is on the day side of Earth, 12 channels of data are taken data at full 275 meter resolution and the remaining 24 channels are reported at 1.1 km. For Local mode, all 36 channels are acquired at full resolution, for the full 360 to 400 km swath, and for 300 km along-track. Local mode coverage has been requested for each of the MISR overpasses during the campaign, plus two weeks before and after. Predicted MISR coverage for the SGP site is given in Appendix D.

4.3.3 Moderate Resolution Imaging Spectroradiometer

The Moderate Resolution Imaging Spectroradiometer (http://modis.gsfc.nasa.gov/) is a 36-channel (0.4 µm to 14.4 µm), cross track scanning spectroradiometer onboard both the NASA Terra (EOS AM) and Aqua (EOS PM) satellites. Terra, launched in December 1999, and Aqua, launched in May 2002, are in circular, near-polar, sun-synchronous orbits at an altitude of 705 km. Terra crosses the equator from north to south in the morning (10:30 a.m.) while Aqua crosses the equator from south to north in the afternoon (1:30 p.m.). MODIS is designed to retrieve information on aerosols, clouds, ocean color, land use, water vapor, ozone, etc. For the Aerosol IOP, specific MODIS products of interest are the retrieved aerosol optical depth and precipitable water vapor. Terra and Aqua overpass times can be computed at http://earthobservatory.nasa.gov/MissionControl/overpass.html. A preliminary list of these times are given in Appendix D. MODIS direct broadcast images can be found at http://eosdb.ssec.wisc.edu/modisdirect/.

4.3.4 Clouds and the Earth's Radiant Energy System

The CERES experiments on the Terra and Aqua satellite are used to produce both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. CERES has four main objectives:

1. For climate change analysis, provide a continuation of the Earth Radiation Budget Experiment (ERBE) record of radiative fluxes at the top of the atmosphere (TOA), analyzed using the same algorithms that produced the ERBE data.

2. Double the accuracy of estimates of radiative fluxes at TOA and the Earth's surface.

3. Provide the first long-term global estimates of the radiative fluxes within the Earth's atmosphere.

4. Provide cloud property estimates that are consistent with the radiative fluxes from surface to TOA.

The CERES instrument has three channels—a shortwave channel to measure reflected sunlight, a long-wave channel to measure Earth-emitted thermal radiation in the 8-12 µm "window" region, and a total channel to measure all wavelengths of radiation. Onboard calibration sources include a solar diffuser, a tungsten lamp system with a stability monitor, and a pair of blackbodies that can be controlled at different temperatures. Cold space looks and internal calibration are performed during normal Earth scans. The CERES measurements made on Terra have continued to demonstrate the remarkable stability and calibration knowledge/traceability first demonstrated on Tropical Rainfall Measuring Mission (TRMM), where there has been no discernable change in instrument gain for any channel at the 0.2% level with 95% confidence. Ground and in-space calibrations agree to within 0.25%. CERES Top-of-Atmosphere (TOA) and Surface Products use cloud imager data for scene classification and CERES measurements to provide radiative fluxes for both cloudy and clear sky conditions. Surface radiation budget estimates are based on direct observational relationships between top-of-atmosphere and surface fluxes. TOA and surface products are used for studies of land and ocean surface energy budget, as well as climate studies that require high accuracy fluxes. CERES TOA radiative fluxes are the "truth" reference used to constrain the theoretical calculations. Atmosphere products are designed for studies of energy balance within the atmosphere, as well as climate studies that require consistent cloud, top-of-atmosphere, and surface radiation data sets. Additional information can be found at http://asd-www.larc.nasa.gov/ceres/ASDceres.html.

The CERES instrument is a narrow field-of-view scanning radiometer; its scan plane can be rotated in azimuth from -90° to +90° with respect to the satellite orbit plane. Cross-track scanning, perpendicular to the orbit plane, provides the largest possible spatial coverage; but each target is viewed once, at a single angle, per overpass. Along-track scanning, in the orbit plane, allows a target to be observed several times per orbit under a range of viewing angles; but the spatial coverage is limited to a narrow swath around the sub-satellite track. The rotating azimuth capability of the CERES instrument has been used primarily to sample the anisotropic radiance field from all directions. This capability can be used to enhance our ability to intercalibrate instruments on different spacecraft and to augment the spatial and angular coverage of targeted areas during intensive observation field campaigns.

Programmable azimuth plane scanning (PAPS) is a scanning mode in which the instrument head is rotated so that its scanning plane contains a prescribed target. This capability can be used to enhance the ability to intercalibrate instruments on different spacecraft and to augment the spatial and angular coverage of targeted areas during intensive observation field campaigns. PAPS mode has been setup for the Terra CERES instrument during the Aerosol IOP. Additional information about this mode can be found at http://asd-www.larc.nasa.gov/PAPS/documents/background.html.

5. Analysis and Calibration

Prior to the May 2003 Aerosol IOP, two "calibration" exercises will be conducted to ensure that major inlet losses are not occurring and that instruments measuring aerosol optical properties are getting roughly the same answers for identical aerosols. The exercises are described in Sections 5.1 and 5.2 below. Pat Sheridan and John Ogren (National Oceanic and Atmospheric Administration [NOAA]/Climate Monitoring and Diagnostics Laboratory [CMDL]) will be leading these exercises.

5.1 Inlet Loss/Distribution Study

During the week prior to the start of the IOP, a limited inlet loss and distribution study will be conducted. (A more detailed complete study is beyond the scope of the available IOP resources.) The inlet comparison with submicron aerosols is a necessary, but not sufficient, condition for a successful closure experiment. This study will set the stage for the optical comparisons.

For the GIF and Aerosol Trailers, test aerosols will be sampled both at the front of the inlet and at a sampling port inside each trailer. Submicrometer ammonium sulfate aerosols will be generated (number peak at ~ 0.3 µm diameter) for this exercise. We have had reasonable success at this in the past. Logistical constraints mean that this will not be at stack top, but rather at the sub-sampling point inside the stack. We shall assume that there are not significant particle losses in the 8-inch diameter stack before the sub-sampling point. Each stack can be modified so that sampling can be conducted at the front of the 2-inch stainless tube. A condensation particle counter (CPC) and an integrating nephelometer will be used to simultaneously measure aerosols at the inlet (outside of the trailer) and at a distribution port on the sampling plenum inside the trailer. This will allow comparisons of not only the number of particles passing the inlet tube, but also give some information on whether the aerosol sizes (by looking at total scattering and Angstrom coefficients) are similar at the two locations.

For the two aircraft, the same aerosols will be generated; a large hose will be used to move the aerosols up to and past the aircraft inlets. Aerosol sampling will be performed using CPCs and nephelometers both outside and inside the aircraft.

These exercises should be able to identify if there are major submicron aerosol passing efficiency problems in any of the inlets. The trailer inlets have all been designed with flow rates, conductive tubing, and tubing diameters appropriate to pass sub-10 µm particles so no major problems are expected. If there are problems, there will not be time to redesign and fabricate new inlets, so we shall attempt to develop an appropriate correction factor if major discrepancies exist.

The distribution of aerosols from the various inlet manifolds will be checked in a similar manner. The CPC and nephelometer that were positioned at the front of each inlet will be brought inside the platform and moved to the various sampling ports. In this way a relative assessment can be made as to whether some ports receive more aerosols than others.

These tests will all be performed at the sampling ports, not at the individual instruments. It is the responsibility of each investigator to get the aerosols from the sampling port into his or her instrument with minimal losses. In order to do this, several things should be considered. These include:

- The use of conductive tubing,
- The choice of appropriate flow rates, tubing bends, and tubing sizes so as to minimize particle losses due to gravitational settling, turbulent deposition, inertial impaction, etc.,
- The use of reducing fittings and connectors that vary smoothly in internal diameter rather than have step changes, and
- The use of isokinetic pickoffs rather than tees to split flows to several instruments

5.2 Instrument Intercomparison

After the inlet loss tests, the various instruments making aerosol optical property measurements will be checked to determine if they get similar answers on identical aerosols. A mixed test aerosol of ammonium sulfate and kerosene soot will be generated using a target extinction and single-scattering albedo to be in an intermediate range (e.g., 50 Mm^{-1} and 0.90 might be appropriate for the SGP site). Instruments in the Aerosol Trailer will be compared first. After this comparison, a PSAP light absorption photometer and a nephelometer used in the AOS (along with the aerosol generation system) will be taken to the GIF Trailer as moveable reference instruments. The exercise will be repeated at the GIF trailer and the agreement between different instruments documented. This exercise is most important for the instruments measuring aerosol optical properties. It would be desirable, however, to have instruments measuring size distributions involved. It would be useful, for example, to try to calculate aerosol scattering from a size distribution measurement and compare that with a nephelometer scattering measurement. If we can't do a good job of this with a known test aerosol (either ammonium sulfate or mixed ammonium sulfate and kerosene soot), then it will be difficult to do this on ambient aerosols of unknown and varying size, shape, and composition. It is not as important to try to compare the chemical measurements, because each of the techniques measures different components of the aerosol chemistry. Also, we do not have mobile reference standards for chemistry measurements to move from place to place.

When a time is chosen for the aircraft instrument calibration exercise, the mobile aerosol generation system (along with an AOS nephelometer and PSAP which will be used as transfer reference instruments) will be transported to the Ponca City airport. This will require a few hours to get set up and to let the aerosol generation system stabilize. Aerosols will be generated outside of the aircraft (and probably outside of the hangar if a flame source for soot is available). Aerosols under a slight positive pressure will be pushed through the mixing chamber and out through a large diameter hose. The generated aerosols will be sampled first using the AOS nephelometer and PSAP to ensure proper measurement levels. When the generated aerosols have a reasonable extinction level and single scattering albedo (~50 Mm^{-1} and 0.90 m, respectively), the hose will be located near the CIRPAS aircraft inlet. A hose diameter larger than the aircraft inlet will be chosen so the excess aerosol flow is exhausted (outside the cabin) after it passes the inlet tip. The AOS nephelometer and PSAP will then be moved inside the aircraft cabin to sample from the aerosol inlet line. During the tests, both the AOS instruments and the aircraft optical property instruments will sample the same test aerosols through the aircraft inlet using their normal pumps. Again, the measurements will be compared and any differences between measurements from aircraft instruments or between measurements from the

AOS instruments and the aircraft instruments will be noted. Investigators need to be able to measure temperature RH at or very near the measurement volume of their instruments during these tests.

5.3 Radiometer Calibration

All radiometers used in the ARM Program for measuring broadband shortwave (solar) irradiance are calibrated with absolute cavity radiometers having traceability to the World Radiometric Reference (WRR) established in 1977 by the World Meteorological Organization as an internationally recognized measurement reference. Two calibration events performed at the SGP Radiometer Calibration Facility (RCF) each year maintain radiometer calibration traceability to the World Radiometric Reference and assure reliable and uniform measurements at each Cloud and Radiation Testbed site. Calibrations are performed using the Radiometer Calibration and Characterization (RCC) software developed by the National Renewable Energy Laboratory. These calibrations use the cavity radiometer during the Broadband Outdoor Radiometer Calibration (BORCAL) periods. The cavity radiometer provides the best measure of direct irradiance. SGP BORCAL 2003-01 will most likely still be occurring during the AOS IOP. On those occasions when cavity radiometer are required and a BORCAL is not underway, we shall request the SGP site personnel include a cavity run.

6. Flight Plans

The CIRPAS Twin Otter is the primary airborne in situ platform for the IOP. The Cessna 172N operated by Greenwood Aviation will also collected aerosol data as part of the ongoing IAP program. A series of experiments designed to address the scientific hypotheses described in Section 3.1 is discussed in Section 6.1 below. Note that the aircraft flights above the SGP site will be located in Vance Air Force Base memorandum of agreement (MOA) subsector 8 as shown in Figure 1. Therefore, Vance officials were briefed on the proposed flight plans at a meeting on March 18, 2003 and have agreed to Twin Otter and Cessna 172N operations with the following provisions.

- Flights to occur primarily in subsector 8
- Flights to occur primarily below 12000 ft. Potential to go above 12000 ft in exceptional cases
- No flights within cloud above 7000 ft
- Notify Vance of potential next day flight plans by 4 pm local (21 UT)
- Notify Vance of flight plans at least 1 hr prior to takeoff
- Pete Daum (or designate) will be sole person communicating to pilots
- There will be meeting of pilots, Daum, etc. at Vance at before flights begin. Meeting to discuss flight areas, communications, etc.

- May 9-11 air show at Vance may impact flights

During the Aerosol IOP, we anticipate that there will be 14 IAP (Cessna 172N) flights; three of these will be coordinated flights with Twin Otter. Note that in the flight descriptions that follow, the level legs of 15-30 km, oriented at an angle in relation to the mean wind. This means that some legs will be flown to the east of the Vance MOA, and that these legs will not be centered directly over the SGP site.**Experiment 1 – Evaluation of Raman lidar, MPL lidar aerosol backscatter, extinction profiles**

Objective(s):

a. evaluate aerosol extinction profiles retrieved by Raman and MPL lidars, airborne Sun photometer, and derived from in situ aerosol scattering, absorption, extinction sensors on aircraft

b. evaluate near field overlap correction on both Raman lidar and MPL systems

c. evaluate assumption of constant aerosol extinction/backscatter ratio in lowest kilometer used in Raman lidar aerosol extinction profile retrievals

d. evaluation of vertical variability of aerosol humidification factor

e. closure study *f*(RH) from lidar vs. *f*(RH) from surface passive cavity aerosol spectrometer probe (PCASP), composition, and calculated enhancement of extinction or backscatter

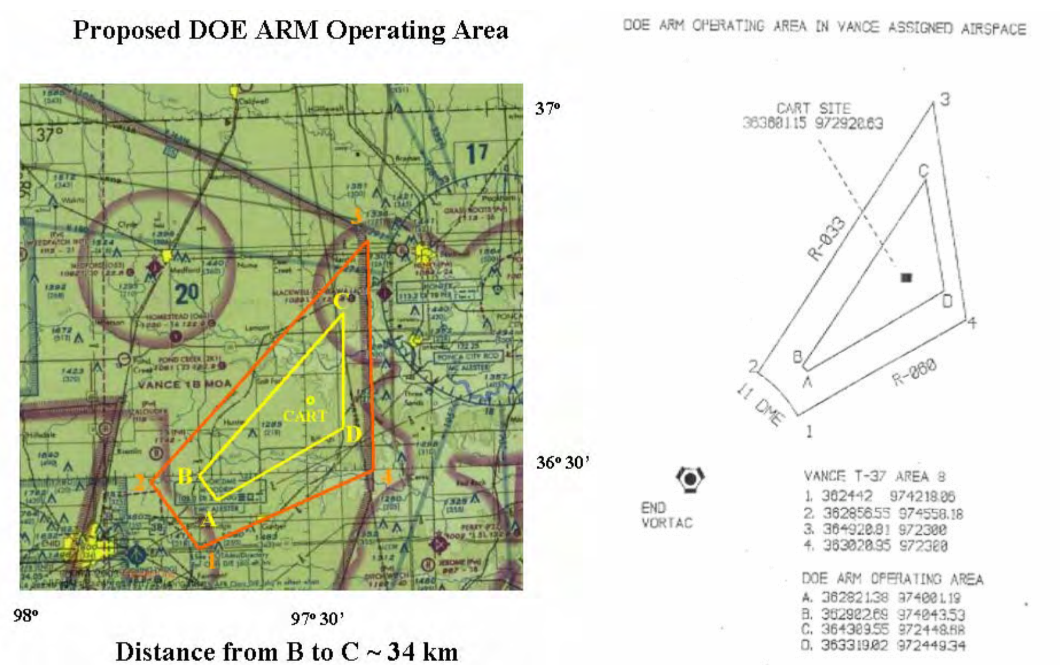

Figure 1. Maps showing Vance MOA with location of DOE ARM operations area for Aerosol IOP.

Advocate(s): Ferrare, Schmid, Redemann, Feingold

Measurement strategy: Use Twin Otter flights at various altitudes over the SGP facility so that in situ and remote (Sun photometer) instruments on Twin Otter can measure aerosol extinction, scattering, absorption simultaneously with ground-based lidar and surface AOS measurements. Skies should be cloud free or with scattered small Cumulus clouds so that the Sun photometer instruments can measure aerosol optical thickness. Small patchy cirrus clouds are acceptable as long as these clouds do not adversely affect Sun photometer measurements of aerosol optical thickness. Since the Raman lidar profiles are most sensitive to high aerosol optical thickness conditions, these flights should occur during the daytime when aerosol optical thickness (355 nm) is above 0.15-0.20. The Raman lidar directly measures aerosol extinction for altitudes above about 800 meters; therefore, in order to directly evaluate Raman lidar boundary layer aerosol extinction profiles, flights are preferred when the boundary layer thickness, z_i, is above 1.0 to 1.2 km. Estimated takeoff time would be around 11 a.m. CDT (16 UT). A radiosonde is normally launched from the SGP site at 1730 UT (12:30 CDT). It would be desirable to launch a sonde at the beginning of the flight (~16 UT) and at the end also (~19-20 UT).

Critical Instruments: Raman lidar, MPL, AOS scattering/absorption, Cimel Sun photometer, MFRSR, Twin Otter scattering/absorption/extinction measurements

Flight Strategy 1a (fast extinction closure): This flight pattern would be used when there would be little or no cloud interference with the Sun photometer measurements. The flight would utilize two spirals to get aerosol extinction and optical thickness profiles from the Sun photometer. The Twin Otter (TO) will takeoff from Ponca City and transit to the SGP vicinity. (~30 min) TO would then perform a fast (clockwise or counterclockwise) spiral (~ at about 500 ft/min) over the SGP site, starting at 300 ft and ending at 10000 ft to facilitate Sun photometer measurements of aerosol optical thickness. Spiral diameter would be about 1 km in diameter. After this spiral, the TO will then perform a series of level leg flights at several altitudes oriented generally 10° – 20° from the mean wind direction in order to avoid aircraft exhaust. These level legs are centered at the SGP site. These flight legs will start at 10000 ft (above ground level [AGL]), with legs at 7000 ft (10 min), 5000 ft (10 min), 4000 ft (5 min), 3500 ft (5 min), 3000 ft (5 min), 2000 ft (5 min), 1000 ft (5 min), and 300 ft (5 min). Estimated time for descending turns between legs is 2-3 min. The aircraft will then repeat this fast spiral ascent followed by level leg descent pattern. During the leg level descent pattern, the leg at 7000 ft could be replaced by other altitude(s) if the TO scientist notes significant aerosol loading associated with elevated aerosol layers at other altitudes. The leg at 3500 ft or 4000 ft could be replaced by a leg at/near the top of the boundary layer where the TO scientist noted high aerosol scattering associated with high relative humidity. After completing this portion, the aircraft will return to base on Ponca City. Total flight time is estimated to be 04:20. If the Vance MOA prevents the flight leg orientation described above, then the orientations of the legs, and the position at which the aircraft passes over the SGP could be adjusted. Twin Otter flight speed is about 100 knots (~ 3 km/min) so that the 5 (10) minute legs would be about 15 km (30 km) long.
Flight Strategy 1b (slow extinction closure):

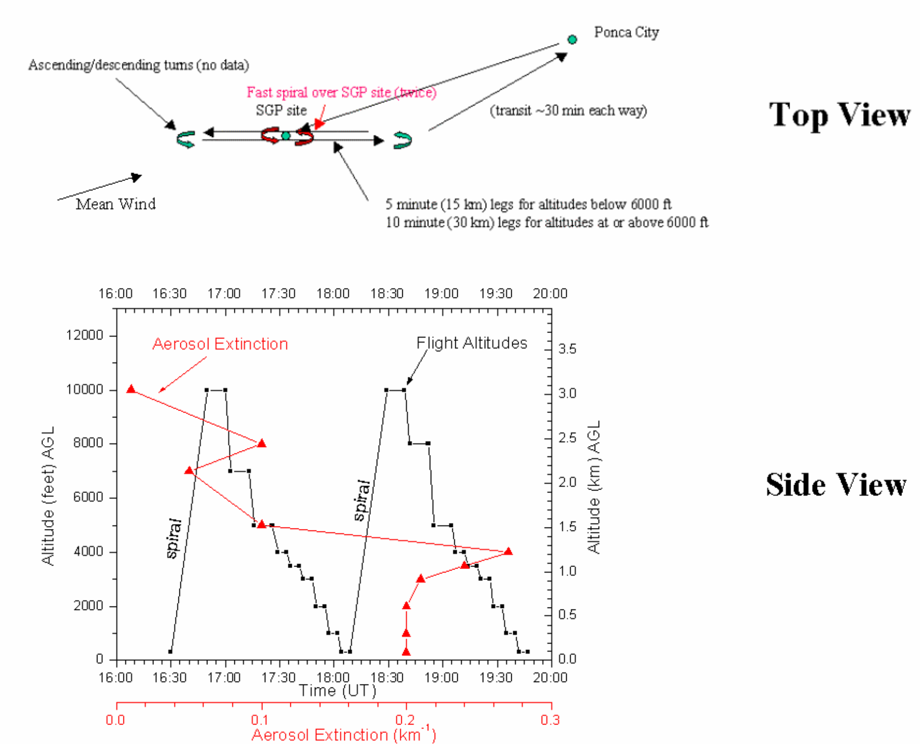

Figure 2a. Top and side views of flight plan 1a.

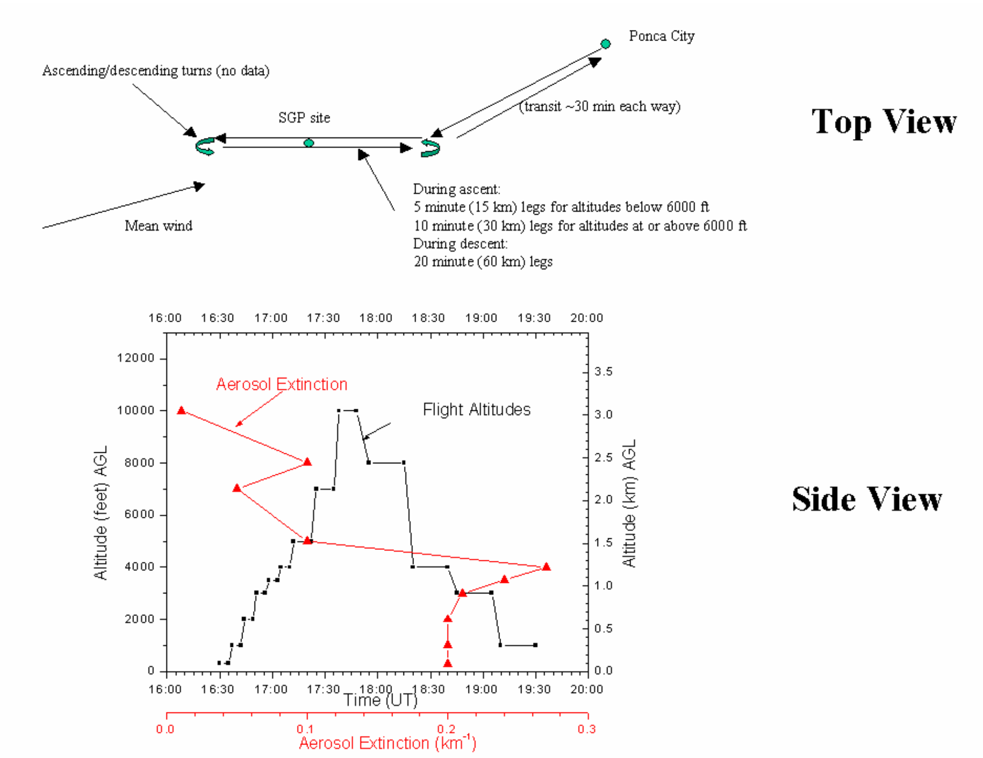

Figure 2b. Top and side views of flight plan 1b.

This flight pattern would be used when clouds would be expected to interfere with the Sun photometer measurements. The Twin Otter will takeoff from Ponca City and transit to the SGP vicinity. (~30 min) TO will then perform a series of level leg flights at several altitudes oriented 10° – 20° from the mean wind direction to avoid aircraft exhaust. These level legs are centered at the SGP site. These flight legs will start at 300 ft (AGL), and proceed to 1000 ft (5 min), 2000 ft (5 min), 3000 ft (5 min), 3500 ft (5 min), 4000 ft (5 min), 5000 ft (10 min), 7000 ft (10 min), 100000 ft (10 min). Estimated time for climbing turns between legs is 2-3 min. The aircraft will then perform a series of level legs during a descent. These level legs would be performed at altitudes with significant aerosol loading as noted by the TO scientist/operator. For example, the leg at 7000 ft would be replaced by a (longer) leg at 8000 ft if the TO scientist/operator noted significant aerosol loading associated with an elevated aerosol layer at this altitude. Likewise, the leg at 3500 ft or 4000 ft could be replaced by a leg at/near the top of the boundary layer where the TO scientist noted high aerosol scattering associated with high relative humidity. After completing this portion, the aircraft will return to base on Ponca City. Total flight time is estimated to be 04:00. If the Vance MOA prevents flights along the orientation described above, then the orientations of the legs, and the position at which the aircraft passes over the SGP could be adjusted. Twin Otter flight speed is about 100 knots (~ 3 km/min) so that the 5 (10) min legs would be about 15 km (30 km) long.

Experiment 2 – Evaluation of IAP aerosol measurements

Objective(s):

a. evaluate aerosol scattering, absorption, extinction measurements retrieved by instruments on IAP Aircraft

b. evaluate aerosol extinction and optical thickness measurements acquired simultaneously by Raman and MPL lidars, Cimel Sun photometer, MFRSR, airborne Sun photometer, and derived from in situ aerosol scattering, absorption, extinction sensors on aircraft

c. evaluation of vertical variability of aerosol humidification factor

Advocate(s): Ferrare, Ogren, Andrews, Schmid, Redemann

Measurement strategy: This would involve a coordinated flight pattern with the IAP Cessna C-172N aircraft. The IAP aircraft would be the lead aircraft and perform its normal measurement sequence. The Twin Otter would fly in formation and would be the trailing aircraft in this formation. Both aircraft would fly at various altitudes over the SGP facility so that in situ and remote (Sun photometer) instruments on Twin Otter can measure aerosol extinction, scattering, absorption simultaneously with the IAP instruments and with ground-based lidar and surface AOS measurements. Skies should be cloud free or with scattered small Cumulus clouds so that the Sun photometer instruments can measure aerosol optical thickness. Small patchy cirrus clouds are acceptable as long as these clouds do not adversely affect Sun photometer measurements of aerosol optical thickness. These flights should cover both low (AOT<0.1, medium (0.1<AOT<0.3), and high (AOT>0.3) aerosol loading conditions if possible. Flights could occur anytime during daylight hours although preferred times would be during late morning and/early afternoon to coincident with earth observing plan (EOS) Terra or Aqua overpasses. It would be desirable to launch a sonde at the beginning of the flight (~16 UT) and at the end also (~19-20 UT).

Critical Instruments: IAP, Raman lidar, MPL, AOS scattering/absorption, Cimel Sun photometer, MFRSR, Twin Otter scattering/absorption/extinction measurements

Flight Strategy 2: The Cessna will takeoff first and transit to the SGP vicinity. (~30 min) During this transit the Cessna will climb to 12000 ft. The TO will also takeoff from Ponca City and transit to the SGP vicinity and climb to 12000 ft en route. Both aircraft will perform a series of level leg flights at several altitudes over the SGP site. The Cessna will be the lead aircraft and initiate maneuvers; the TO will trail and will keep a minimum horizontal separation distance of 1000 ft. Both aircraft will maintain an approximate speed of 100 knots. The series of level legs will proceed from 12000 ft (10 min), 10000 ft (10 min), 8000 ft (10 min), 6000 ft (10 min), 5000 ft (5 min), 4000 ft (5 min), 3000 ft (5 min), 2000 ft (5 min), 1500 ft (5 min), 1000 ft (5 min). Both aircraft will then fly another level leg at the altitude of high aerosol scattering/extinction near the top of the boundary layer. The TO scientist will determine this altitude during the flight and communicate this altitude to the Cessna pilot via radio. Upon completion, both aircraft will return to Ponca City airport. With a nominal flight speed of about 100 knots (~ 3 km/min), the 5 (10) min legs would be about 15 km (30 km) long. Total flight time would be about 03:30.

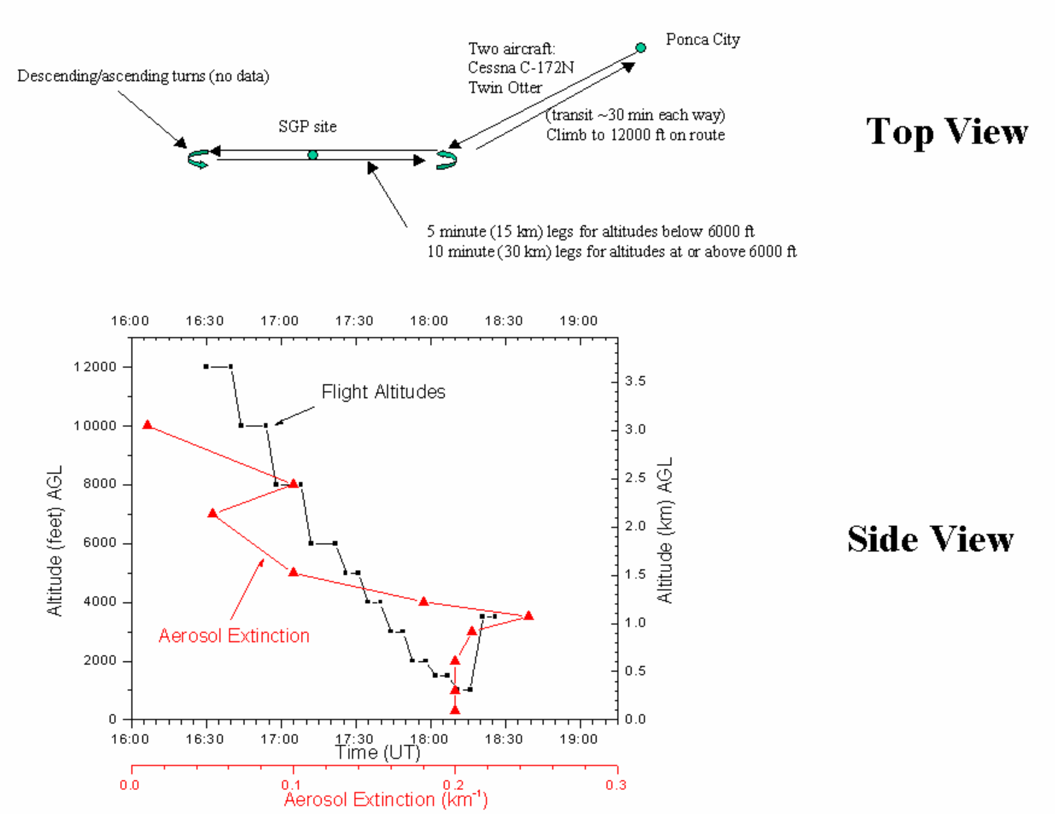

Figure 3. Top and side views of flight plan 2.

Experiment 3 – (a) Layer Absorption Closure - Irradiance closure, (b) In situ absorption closure

Objective(s):

a. Assess the mutual consistency between aerosol-induced flux divergence measurements (derived using airborne flux radiometers) to in situ measurements of aerosol absorption.

b. By combining the airborne flux divergence and AOD measurements, derive a "remotely sensed" aerosol single scattering albedo for comparison with in situ derived single scattering albedo.

c. Evaluate the comparability between the various in situ aerosol absorption sensors.

d. Compare the airborne results of aerosol single scattering albedo to the ground-based retrievals of aerosol properties derived using the SGP AERONET instrument.

Advocates: Schmid, Redemann, Pilewskie, Arnott, Strawa

Fly Twin Otter horizontal legs; one each at the top and at the bottom of the main aerosol layer for flux divergence observations and a subsequent leg near the altitude of maximum aerosol scattering/extinction for in situ observations of aerosol absorption. The goal is to compare measurements and models of diffuse irradiance and flux during low aerosol optical thickness conditions while accurately constraining the aerosol single scattering albedo. First preference is for these flights to occur under low aerosol optical thickness conditions (AOT<0.1) with additional flights under higher aerosol optical thickness conditions. Estimated takeoff time would be around 11 a.m. CDT (16 UT). A radiosonde is normally launched from the SGP site at 1730 UT (12:30 CDT). It would be desirable to launch a sonde at the beginning of the flight (~16 UT) and at the end also (~19-20 UT).

Critical Instruments: Twin Otter radiative flux sensors (SSFR, total flux radiometers), Twin Otter in situ absorption measurements, Twin Otter airborne sunphotometer, ground-based flux radiometers, SGP AERONET instrument

Flight Strategy 3a (layer absorption closure): Skies should be cloud free or with relatively constant small cirrus clouds. The Twin Otter will take off from Ponca City and transit to the SGP vicinity (~30 min). TO will then descend to the minimum allowable altitude (~300 ft) and fly a quick ascent profile (or spiral) (~500 ft/min) to assess the vertical structure of the aerosol field. Maximum altitude of the initial survey ascent should be a location where midvisible AOD from sunphotometer has dropped below 0.05 or the TO ceiling, if former criterion cannot be attained. Assuming a transit altitude of 3,000 ft and a top of the aerosol layer at ~10,000 ft, the initial descent/ascent maneuver would take about (26 min). Alternatively vertical structure information could be relayed to the TO from the ground-based lidar systems. At the top of the main aerosol layer (as determined by the fast-response in situ aerosol measurements during the initial ascent; here assumed to be about 8000 ft) the TO will fly a horizontal leg for solar spectral flux radiometer (SSFR) and integrating flux radiometer measurements centered at SGP for a duration of about (8-10 min). Twin Otter flight speed is about 100 knots (~ 3 km/min) so that a 10 minute legs would be about 30 km long. After a descent to the maximum of the aerosol layer (assumed here at 5,000 ft), the TO should go back at this altitude (5000 ft) along the same flight track in the heart of the aerosol layer to facilitate in situ observations of aerosol absorption. This would consist of a 10 min leg, with a 180° turn, followed by another 10 min leg reversing the course. After another descent to an altitude below the aerosol layer or alternatively to the lowest permissible TO altitude (assumed 300 or 500 ft), a final horizontal run for the flux radiometers along the same orientation as the initial flux radiometer run should be performed, again centered at SGP for a duration of 8-10 min. Ascent to cruise altitude (4 min) and transit back to Ponca City (30 min.) would make this flight plan a short flight (~02:30). In the case of a distinct two-layered aerosol vertical structure, one additional flux radiometer run (two 10-min legs with a 180° turn in between) between the layers (6000 ft) and one more in situ observation run (two 10-min legs with a 180° turn in between) in the heart of the second layer (7000 ft) could be performed. In this case, total flight time would be about 03:30. In reality, trying to find areas with minimal (or very constant) cloud coverage as required by the flux radiometer method may require significant flight time.

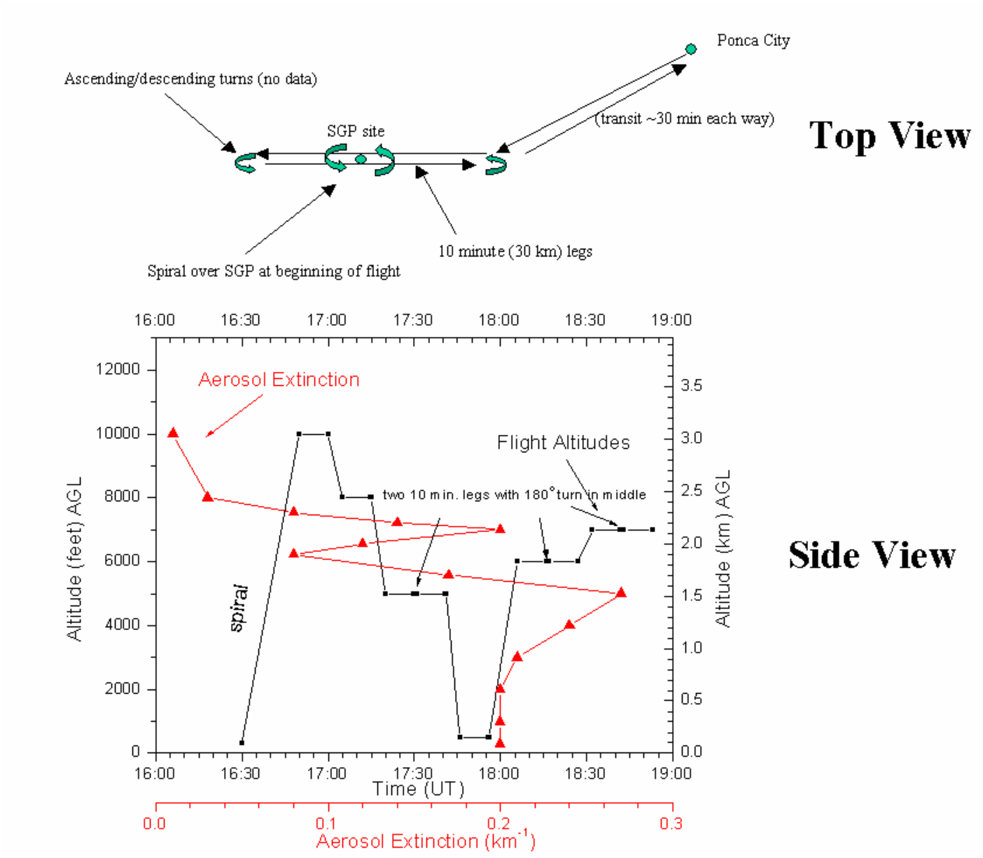

Figure 4a. Top and side views of flight plan 3a.

Flight Strategy 3b (in situ absorption closure): This experiment does not require cloud free conditions and so can occur when scattered or broken low or high clouds are present. Flights should occur under low, medium, and high aerosol optical thickness conditions. The Twin Otter will take off from Ponca City and transit to the SGP vicinity (~30 min). TO will then descend to the minimum allowable altitude (~300 ft) and fly a quick ascent profile to assess the vertical structure of the aerosol field. Maximum altitude of the initial survey ascent should be a location where midvisible AOD from Sun photometer has fallen off below 0.05 or the TO ceiling, if former criterion cannot be attained. Assuming a transit altitude of 3,000 ft and a top of the aerosol layer at ~10,000 ft, the initial descent/ascent maneuver would take about (26 min). Alternatively vertical structure information could be relayed to the TO from the ground-based lidar systems, although information on the altitude of maximum aerosol absorption needs to come from the aircraft observations. The TO will then fly horizontal L shape patterns. The SGP site should be located under one of these legs. The duration of these patterns should be such that the slowest in situ absorption measurement is still accommodated. Depending on aerosol loading, this should take about 30-40 min per L-shape pattern, resulting in two 15-20 min L-shape legs, which cover about 45-60 km each. If aerosol loadings are small, the length/duration of the L-shape legs may have to be increased. The orientation of L-shape legs relative to the prevailing wind should be such that the in situ measurements are minimally contaminated, i.e., the L-shape legs should both be at a 45° angle to the prevailing wind direction. This flight pattern should be repeated at three altitudes at least with sufficient aerosol loading. If an elevated aerosol layer is present, and if time permits, an additional L shaped pattern should be flown at the altitude of this elevated aerosol layer (~7000 ft). Total flight time for a flight including L-shape flight patterns at four altitudes is estimated at ~04:40.

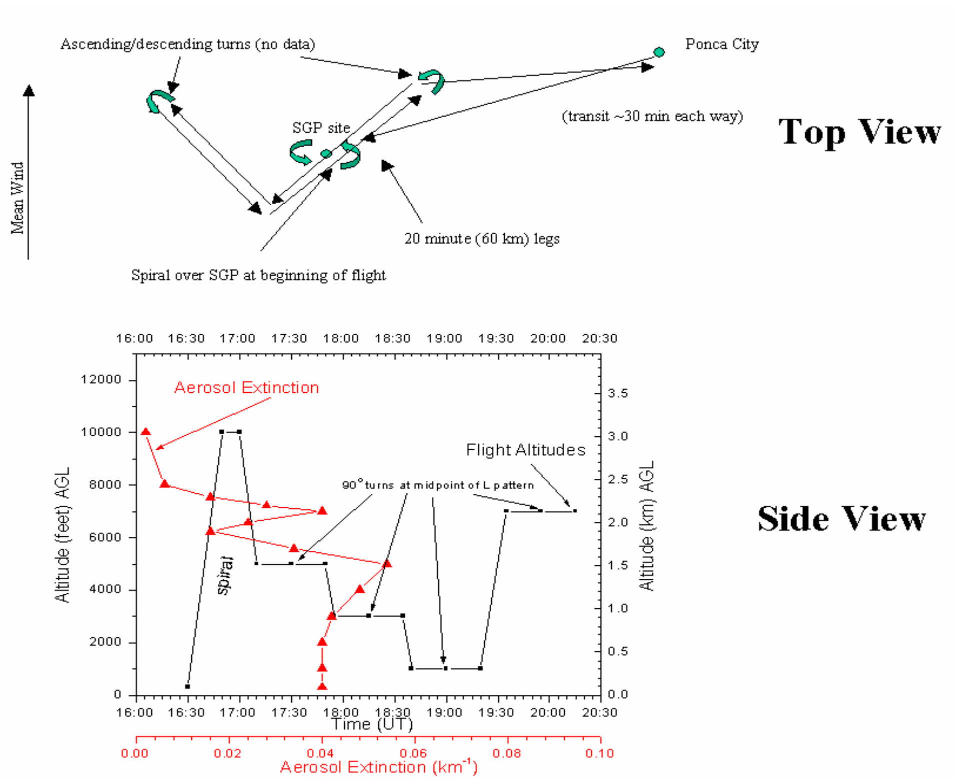

Figure 4b. Top and side views of flight plan 3b.

Experiment 4 – CCN experiment

Objective(s):

a. Investigate 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.

b. Determine whether 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.

c. Determine relationship between the cloud base CCN number concentrations and size distributions, cloud base turbulence, and cloud droplet number concentrations and size distributions.

Advocate(s): Ghan, Rissman

Measurement Strategy: Use Twin Otter flights at various altitudes within and just above boundary layer to measure vertical variability of CCN concentration, aerosol size distribution, aerosol humidification factor, and aerosol extinction. The measurements will be performed with simultaneous measurements of aerosol extinction and relative humidity by the ground based Raman and MPL lidars. Since the Raman lidar profiles of aerosol extinction, which will be used in the CCN retrieval algorithms, are most sensitive to high aerosol optical thickness conditions, the first preference for these flights is during the daytime when aerosol optical thickness (355 nm) is above 0.15-0.20. There is a desire that these flights occur at various times of the day, in order to contrast well-mixed and stable conditions. It would be desirable to launch a sonde at the beginning of the flight and at the end also. Skies can be clear or cloudy; however, cloud base should be above 2000 ft. The Twin Otter flights will consist of a series of level legs, perpendicular to the mean wind, performed at various altitudes over the SGP site. The majority of these level legs will be performed within the boundary layer. There is a desire to tie the Twin Otter measurements of CCN with the surface measurements of CCN so the minimum flight altitude should be about 300 ft AGL. During clear skies, the maximum altitude will be about 2000 ft above the boundary layer height. During cloudy skies with cloud bases above 1000 ft, then the minimum altitude should also be about 300 ft AGL. Cloud base should be at or above 2000 ft, and below 4000 ft, in order to have sufficient aircraft and lidar sampling below cloud base. During cloudy skies, there should be flight legs just below (~100-200 ft) cloud base, and just above cloud base (~100-200 ft) in order to measure cloud droplet number.

Critical Instruments: Raman lidar, MPL, AOS scattering/absorption, AOS aerosol size distribution, surface CCN measurements, Twin Otter scattering, absorption, extinction, humidification, CCN, aerosol/cloud drop size, liquid water measurements

Flight Strategy 4a (clear skies): This flight pattern would be used when there are no clouds below about 10000 ft. The TO would takeoff from Ponca City and transit to the SGP vicinity (~30 min). TO will then perform a series of level leg flights at several altitudes oriented perpendicular to the wind direction. These level legs are centered at the SGP site. These flight legs will start at 300 ft (AGL), and proceed to 1000 ft (5 min), 1500 ft (5 min), 2000 ft (5 min), 2500 ft (5 min), 3000 ft (5 min), 3500 ft (5 min), 4000 ft (5 min), 4500 ft (5 min), 5000 ft (5 min), 6000 ft (10 min). Estimated time for climbing turns between legs is 2-3 min. Turns are to be made upwind after each leg. The aircraft will then perform a series of level legs during a descent. These legs would be at the same altitudes as during the ascent and would also be 5 min each leg. After completing this portion, the aircraft will return to base on Ponca City. Total flight time is estimated to be 04:00. If the Vance MOA prevents flights perpendicular to the wind direction, then the orientations of the legs, and the position at which the aircraft passes over the SGP could be adjusted. Twin Otter flight speed is about 100 knots (~ 3 km/min) so that the 5 min legs would be about 15 km long.

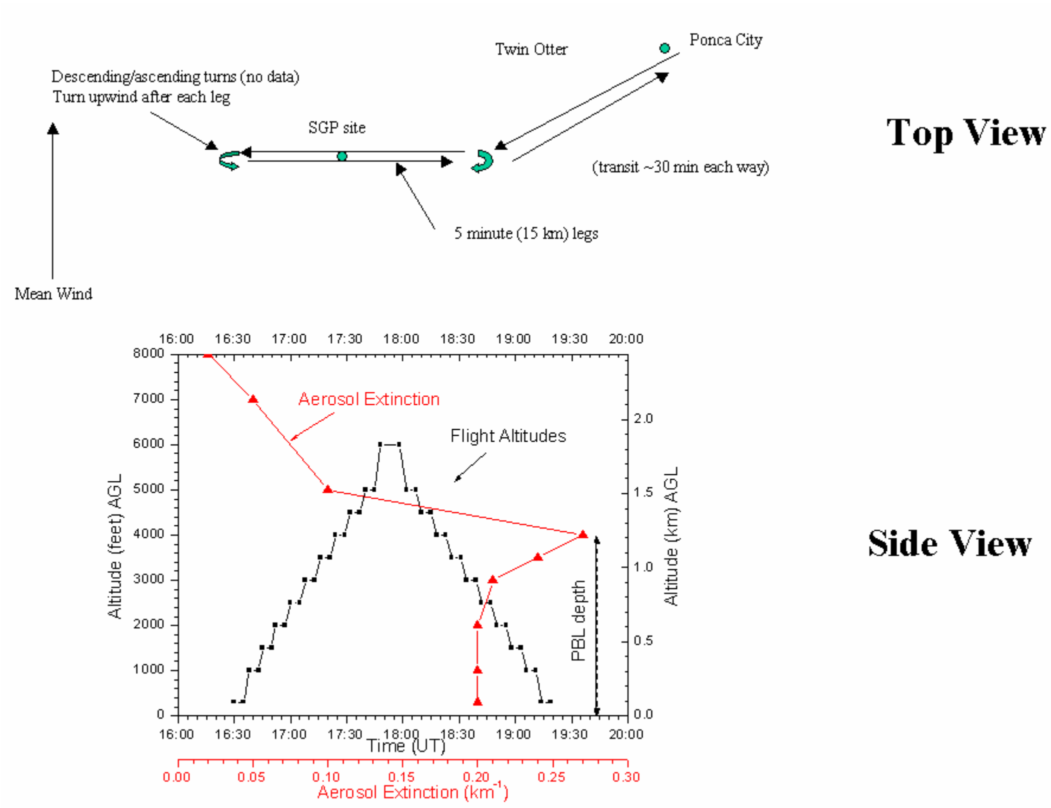

Figure 5a. Top and side views of flight plan 4a.

Flight Strategy 4b (cloudy skies): This flight pattern would be used when there are low clouds (cloud base between 2000-4000 ft). This pattern is similar to pattern 4a above except that flight legs would be performed at about 200 ft below cloud base, at cloud base, and within the cloud (at 500 and 1000 ft above cloud base.) The TO would takeoff from Ponca City and transit to the SGP vicinity (~30 min). TO will then perform a series of level leg flights at several altitudes oriented perpendicular to the wind direction. These level legs are centered at the SGP site. Assuming the cloud base is at 3500 ft AGL, these flight legs will start at 300 ft (AGL), and proceed to 1500 ft (5 min), 2500 ft (5 min), 3300 ft (5 min), 3500 ft (10 min), 4000 ft (20 min), and 4500 ft (20 min). Estimated time for climbing turns between legs is 2-3 min. Turns are to be made upwind after each leg. Within the cloud (at 4000 and 4500 ft), two 10-min (30 km) legs, separated by a 180° turn, would be flown at each altitude. The aircraft will then perform a similar series of level legs during a descent. These legs would be at the same altitudes as during the ascent and would also be 5 min each leg. After completing this portion, the aircraft will return to base on Ponca City. Total flight time is estimated to be 04:00. If the Vance MOA prevents flights perpendicular to the wind direction, then the orientations of the legs, and the position at which the aircraft passes over the SGP could be adjusted. Twin Otter flight speed is about 100 knots (~ 3 km/min) so that the 5 min legs would be about 15 km long.

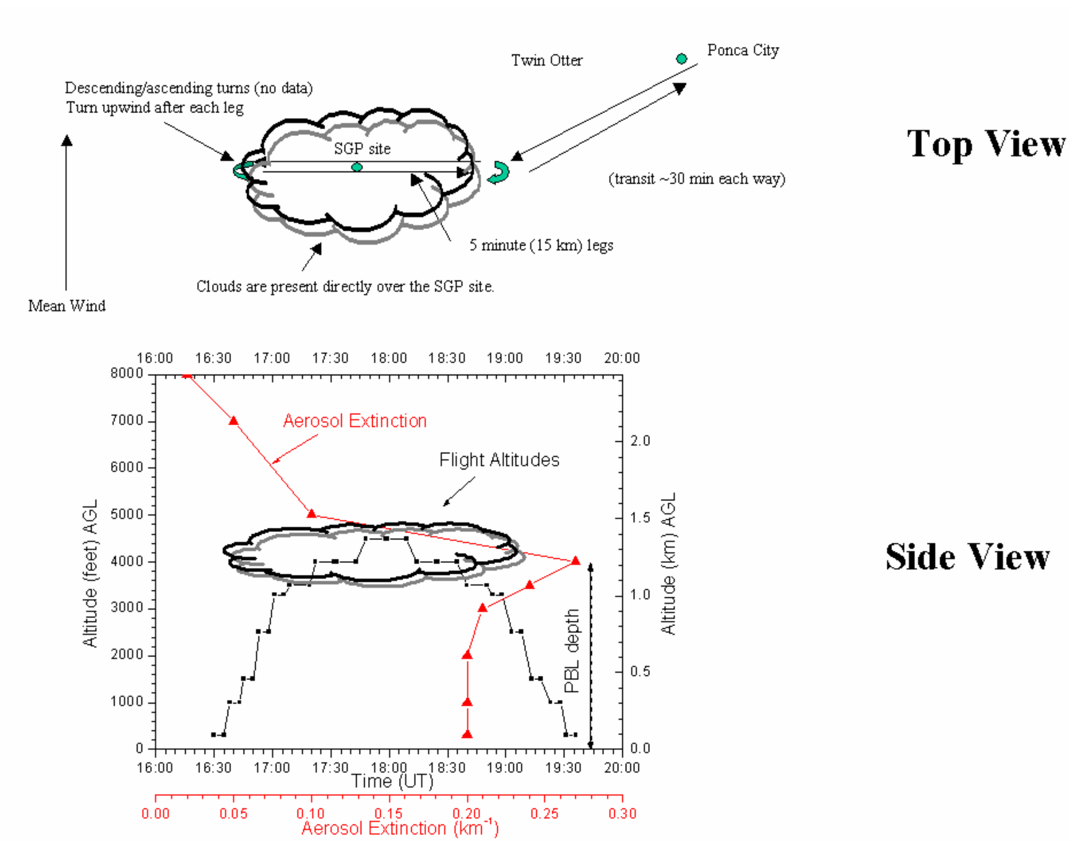

Figure 5b. Top and side views of flight plan 4b.

Experiment 5 – Aerosol Indirect Effect

Objective(s):

a. Investigate the relationship between sub-cloud aerosol parameters, cloud base turbulence, and cloud drop size for clouds with similar amounts of condensed water (liquid water path). Address problem in both a process-oriented sense and a statistical sense by looking at probability distribution functions of subcloud aerosol, turbulence, and cloud drop concentration. (Note, similar goals to Experiment 4, Objective c);

b. Evaluate the extent to which subcloud aerosol extinction measured by Raman lidar is an adequate proxy for the aerosol effects on drop size;

c. Evaluate the extent to which ground-based radar remote sensing of cloud drop size is adequate for quantifying the aerosol indirect effect;

d. Evaluate ground-based retrievals of drop size against airborne, downward looking radiance retrievals of drop size.

Advocate: Feingold

Measurement strategy: These flights prefer low overcast (statocumulus conditions) but would be willing to settle for low cloud coverage as low as 20%. It is desirable to contrast scattered cumulus conditions with overcast stratocumulus conditions. The ideal case would be to have these flights occur over the SGP site during cloudy conditions. A second, less desirable option that could be pursued is when clouds are present not directly over the SGP site, but a relatively short (<180 km or < 1 hr) distance away from Ponca City and the SGP site. The flight strategies for these two cases are described below. There is no preference for the time of day for these flights, although the required presence of cumulus or stratocumulus suggests that these flights would most likely occur late morning or afternoon. It would be desirable to launch a sonde at the beginning of the flight and also at the end.

Critical Instruments:

Surface-based: Raman lidar, MMCR radar, microwave radiometer, accumulation mode aerosol size distribution, CCN, *f*(RH), state parameters;

Airborne (Twin Otter): CCN, aerosol size distribution, aerosol composition (or proxies such as absorption, scattering, humidification factor), drop size distribution, liquid water content, gust probe (updraft, turbulence), radiances for downward-looking retrieval of drop size, state parameters.

Flight Strategy: For both scenarios below, the target cloud conditions are shallow, nonprecipitating boundary layer clouds with cloud tops at or below 7000 ft. These clouds can be either cumulus or stratocumulus where soundings indicate convective activity. The cloud base height must be greater that the minimum allowed flight altitude. The flight levels indicated in the scenarios below can be adjusted according to cloud base and cloud top heights. The lowest leg should be as low as permissible and preferably in a region where the relative humidity is below 70%. Flight legs should be flown at about 1500 and 500 ft below cloud base. Legs should also flown at 300 ft above cloud base, 1000 ft above cloud base and/or 300 ft below cloud top, and at about 1000 ft above cloud top. This top altitude is for designed for downward looking TO retrievals of drop size and measurement of reflectance. The scenarios below assume a cloud base of 3500 ft and a cloud top of 5000 ft.

Flight Strategy 5a (*Cloudy conditions at SGP):* Focused overflights of the SGP CF during cloudy conditions to avail ourselves of the ground-based remote sensors. The Twin Otter would takeoff from Ponca City and transit to the SGP vicinity (~30 min). TO will then perform a series of level leg flights at several altitudes oriented perpendicular to the wind direction. These level legs are centered at the SGP site. The TO would fly level legs at 1000 ft (10 min), 3000 ft (10 min), 3800 ft (25 min), and 4500 ft (25 min), 6000 ft (20 min). Time permitting, this pattern would then proceed downward, with legs at 4500 ft (25 min), 3800 ft (25 min), 3000 ft (10 min), and 1000 ft (10 min). If time does not permit, the descent pattern would fly legs at 4500 ft (15 min), 3800 ft (15 min), 3000 ft (10 min), and 1000 ft (10 min). In order to keep legs at 15 km (~5 min) length to maximize overpasses of CF, and to keep the preferred leg orientation of perpendicular to the mean wind, 180° turns would be executed at the end of each 5 min leg. Turns are either level, ascending, or descending (after 6000 ft leg). Turn upwind. Total flight time would be about 04:50.

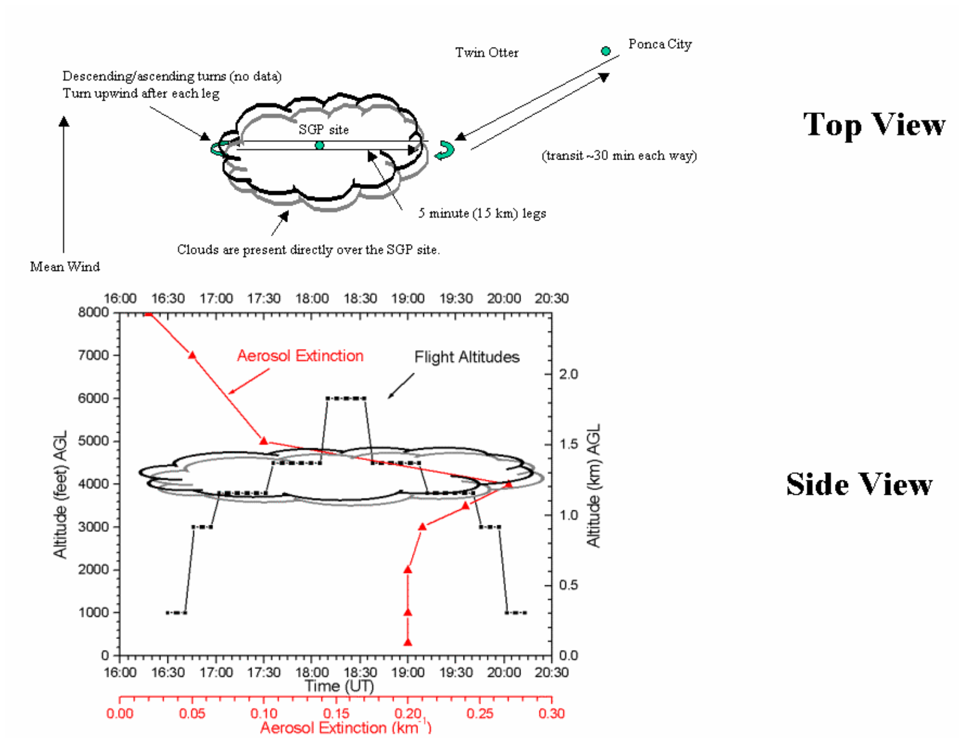

Figure 6a. Top and side views of flight plan 5a.

Flight Strategy 5b (*Cloudy conditions in the vicinity of but not directly above SGP):* This pattern would be very similar to the pattern described above, except that the legs would not be flown directly over the SGP site but rather at the location of the clouds. Here the assumed transit time would be longer (up to 1 hr each way) so that the time allotted for the level legs would be shortened to keep total flight time within the Twin Otter restraints. The TO would take off from Ponca City and transit to the location of clouds (< 60 min). TO will then perform a series of level leg flights at several altitudes oriented perpendicular to the wind direction. The TO would fly level legs at 1000 ft (10 min), 3000 ft (10 min), 3800 ft (30 min), and 4500 ft (30 min). This pattern would then proceed downward, with legs at 3800 ft (30 min), 3000 ft (10 min), and 1000 ft (10 min). In this case the legs would be 30 km (~10 min) in length. In order to keep the preferred leg orientation perpendicular to the mean wind, 180° turns would be executed at the end of each 10 min leg. Turns are either level, ascending, or descending (after 4500 ft leg). Turn upwind. Total flight time would be about 04:45.

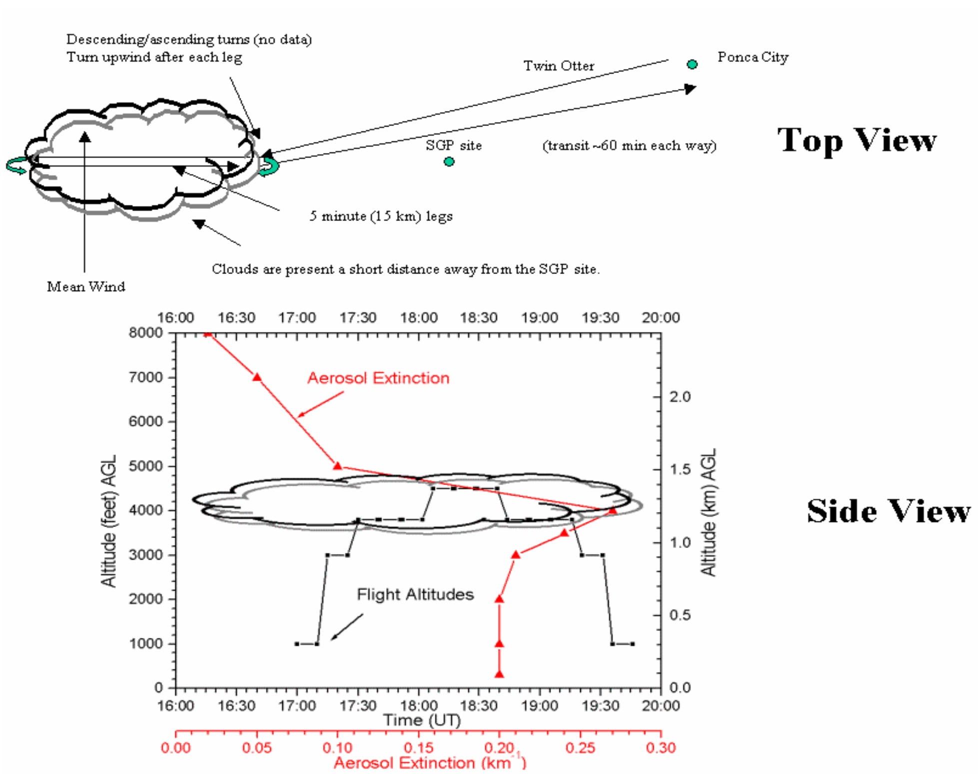

Figure 6b. Top and side views of flight plan 5b.

Experiment 6 – Spatial aerosol variability flights

Objective(s):

a. Assess satellite sub-pixel/scene variability in aerosol optical depth to determine how representative the SGP site point observations are for a larger scene.

b. Validate over-land aerosol optical depth retrievals of various satellite sensors, including MODIS, MISR, etc. and investigate the mutual consistency between suborbital and space-based assessments of aerosol variability.

c. Determine vertical distribution of aerosol extinction and particle types to validate aerosol models that are used in or retrieved from satellite sensor data inversion.

Advocates: Schmid, Redemann, Ferrare, Alexandrov

Measurement Strategy: Fly a TO profile to assess vertical distribution of aerosol extinction near satellite overpass time. Fly low-level Twin Otter horizontal legs between MFRSR sites to assess spatial variability in aerosol optical depth around satellite overpass time. Fly 1-2 horizontal legs at various altitudes to assess particle size distribution and type (chemical composition) around satellite overpass. The six (6) MISR local mode observations for SGP (#009 SGP-Lamont, 36.605N, -97.485W) during the month of May 2003 are May 06 (17:28 UT), May 08 (17:16 UT), May 15 (17:22 UT), May 22 (17:28 UT), May 24 (17:16 UT) and May 31 (17:22 UT). There are about 20 Terra overpasses suitable for MODIS validation. Both predictions likely will change due to satellite maneuvers between now and the IOP. However, the general number of validation opportunities and the approximate Terra overpass time between 16:30 and 17:30 UT will still be correct. A similar number of Aqua MODIS validation opportunities will arise. If there is suitable interest, there could be validation opportunities for CERES derived flux measurements. These flights should occur under generally cloud free skies to maximize airborne Sun photometer measurements of aerosol optical thickness.

Critical Instruments: Twin Otter airborne sunphotometer, Twin Otter in situ extinction/absorption measurements, Twin Otter radiative flux sensors, Twin Otter aerosol size distribution and chemical composition samplers, MFRSR at CF and at selected extended facilities, Cimel Sun photometer, Raman and MPL lidars, AOS system

Flight Strategy: There are two scenarios listed. The first describes flight legs over the MFRSR generally north of the SGP site, and the second describes legs generally south of the site. The particular pattern chosen will depend upon anticipated cloud and aerosol conditions, flight clearances, etc.

Flight Strategy 6a (northern): The Twin Otter will take off from Ponca City (map reference 1) and transit to the SGP vicinity (map reference 2) (~30 min). TO will then ascend to maximum attainable altitude (~12000 ft) and fly a 500 ft/min descent profile to minimum allowable altitude (~300-500 ft) over the SGP Cloud and Radiation Testbed site. Assuming a transit altitude of 5,000 ft and a top of the profile at ~12,000 ft, the initial ascent/descent maneuver would take about (30 min). The Twin Otter will then fly two 10 min (~30 km) low level passes centered over the SGP site. It would be best to time the low-level flight leg in such a way that the TO is in the closest possible proximity to the SGP site at exact satellite overpass time. These legs should generally be oriented north to south, which is generally the orientation of the transit to and from the extended facilities. Each pass is separated by a 180° turn. The Twin Otter will then perform a climbing ascent to an altitude near the top of the boundary layer (assumed here to be about 5000 ft), where the maximum aerosol scattering/extinction was observed during the previous descent. The TO will then fly two 10 min (~30 km) legs at this altitude along the same line as the previous horizontal leg. If an elevated (above boundary layer) aerosol layer was observed during the initial descent, then the TO will then perform a climbing ascent to this altitude (here assumed to be about 7000 ft) and fly two additional 10 min (~30 km) legs along the same line as the previous. (If no significant elevated aerosol layers were observed, then the TO would proceed to extended facility EF-9 [map reference 3]). The TO will then descent to the lowest possible altitude (500-1000 ft) permitted to transit among the various sites, and the travel to extended facility EF-9 (map reference 3) (~15 min, 45 km), then to EF-5 (70 km, 23 min) (Map 4), then to EF-2 (60 km, 20 min) (Map 5), then to EF-4 (100 km, 33 min) (Map 6), then to the CF (120 km, 40 min) (Map 7), then to EF-12 (80 km, 27 min) (Map 8), then return to base at Ponca City. Each time the TO flies over facility, it should fly straight and level for at least 1 min after flying over the facility before turning to go on to the next point. Given a typical satellite overpass time of 17:00 UT (12:00 CDT), the TO would have to depart Ponca City at about 16:00 UT (11:00 CDT) to accommodate the coordination of this flight plan with satellite overpass time. Total TO flight time is estimated to be ~ 05:00 min. Note that TO will fly over or close by Wichita, Kansas when flying between EF-9 and EF-5 (Map 3 and 4). It is desired that the aircraft fly as close to city as possible to investigate urban impact on aerosol extinction and optical thickness. In addition, it is desired that the TO fly over or near the Sooner power plant (36.45N, 97.05W) during transit between CF and EF-12 or before returning to base. This plant may be a significant source of pollution transport to the CF.

Flight Strategy 6b (southern): The Twin Otter will take off from Ponca City (map reference 1) and transit to the SGP vicinity (map reference 2) (~30 min). TO will then ascend to maximum attainable altitude (~12000 ft) and fly a 500ft/min descent profile to minimum allowable altitude (~300-500 ft) over the SGP Cloud and Radiation Testbed site. Assuming a transit altitude of 5,000 ft and a top of the profile at ~12,000 ft, the initial ascent/descent maneuver would take about (30 min). The Twin Otter will then fly two 10 min (~30 km) low level passes centered over the SGP site. It would be best to time the low-level flight leg in such a way that the TO is in the closest possible proximity to the SGP site at exact satellite overpass time. These legs should generally be oriented northeast to southwest, which is generally the orientation of the transit to and from the extended facilities. Each pass is separated by a 180° turn. The Twin Otter will then perform a climbing ascent to an altitude near the top of the boundary layer (assumed here to be about 5000 ft), where the maximum aerosol scattering/extinction was observed during the previous descent. The TO will then fly two 10 min (~30 km) legs at this altitude along the same line as the previous horizontal leg. If an elevated (above boundary layer) aerosol layer was observed during the initial descent, then the TO will then perform a climbing ascent to this altitude (here assumed to be about 7000 ft) and fly two additional 10 min (~30 km) legs along the same line as the previous. (If no significant elevated aerosol layers were observed, then the TO would proceed to extended facility EF-19 [map reference 3]). The TO will then descend to the lowest possible altitude (500-1000 ft) permitted to transit among the various sites, and then travel to extended facility EF-19 (map reference 3) (~37 min, 112 km), then to EF-20 (85 km, 28 min) (Map 4), then to EF-18 (70 km, 23 min) (Map 5), then to EF-12 (112 km, 37 min) (Map 6), then to the CF (80 km, 27 min) (Map 7) then return to base at Ponca City. Each time the TO flies over facility, it should fly straight and level for at least 1 min after flying over the facility before turning to go on to the next point. Given a typical satellite overpass time of 17:00 UT (12:00 CDT), the TO would have to depart Ponca City at about 16:00 UT (11:00 CDT) to accommodate the coordination of this flight plan with satellite overpass time. Total TO flight time is estimated to be ~05:00. Note that TO will fly over or close by Oklahoma City, Oklahoma when flying between EF-19 and EF-20 (Map 3 and 4). It is desired that the aircraft fly as close to city as possible to investigate urban impact on aerosol extinction and optical thickness. In addition, it is desired that the TO fly over or near the Sooner power plant (36.45N, 97.05W) during transit between CF and EF-12 or before returning to base. This plant may be a significant source of pollution transport to the CF. In addition, it is desired that the TO fly over or near the Sooner power plant (36.45N, 97.05W) during transit between d EF-12 and CF or before returning to base. This plant may be a significant source of pollution transport to the CF.

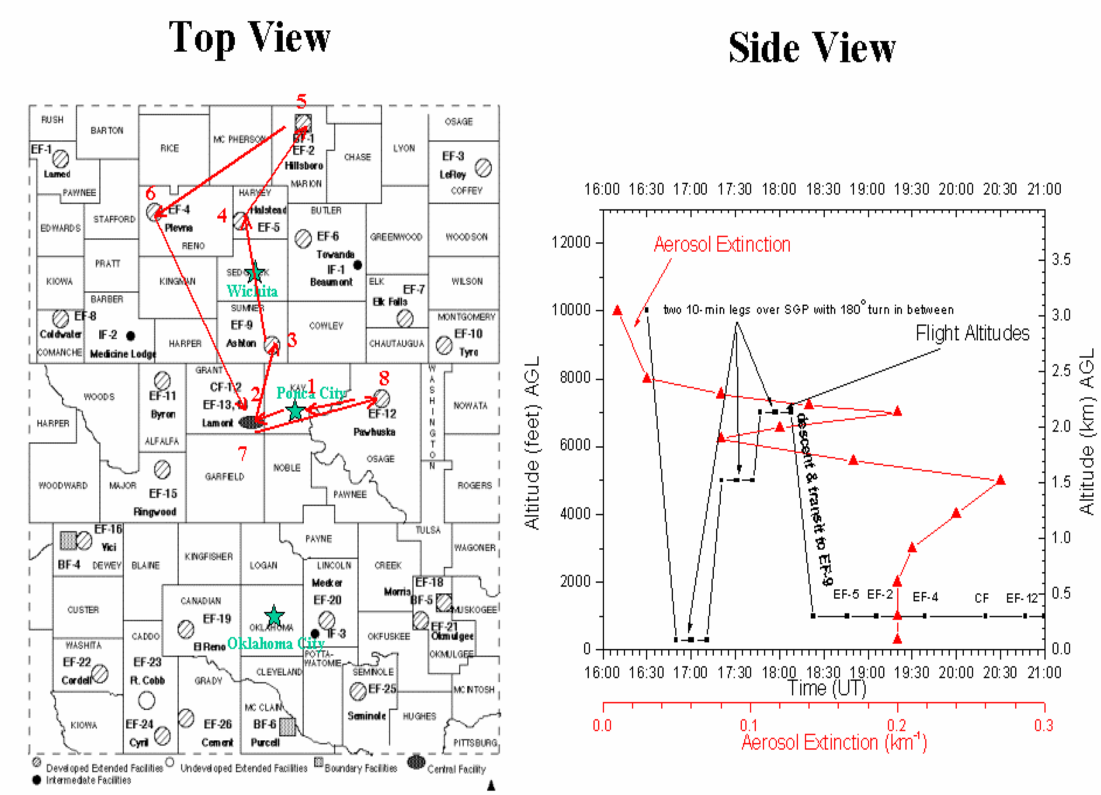

Figure 7a. Top and side views of flight plan 6a.

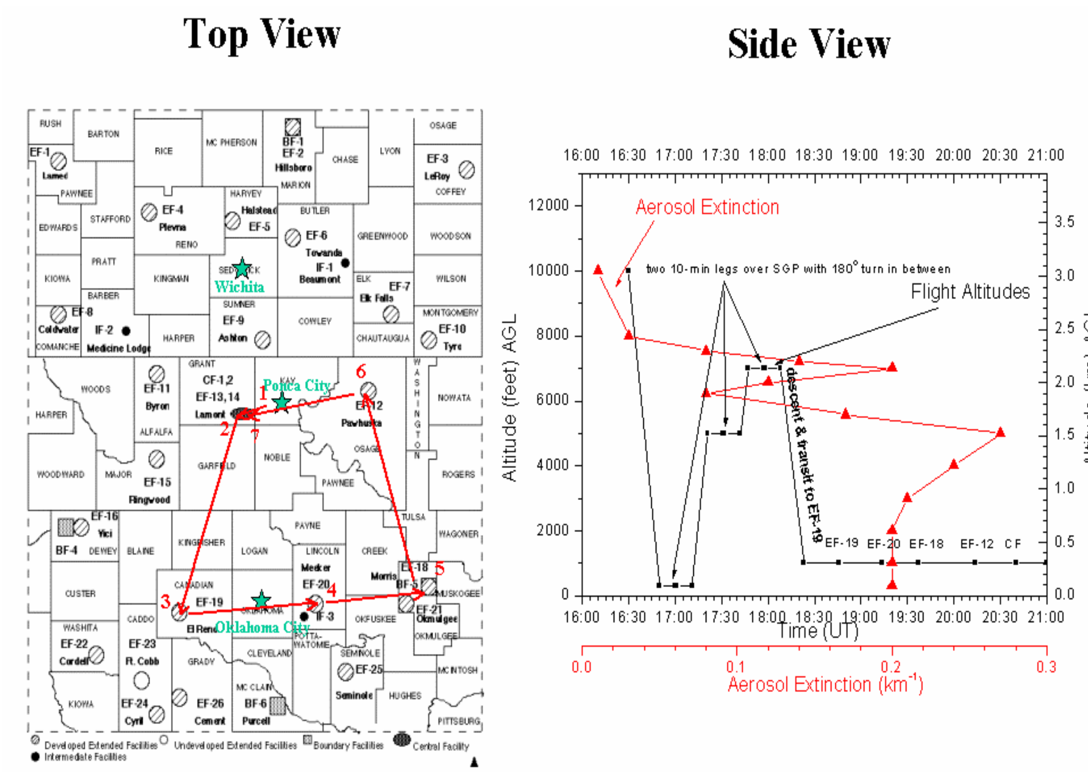

Figure 7b. Top and side views of flight plan 6b.

6.1 Alloocation of Flight Hours

There are 60 hrs total available for science flights. Of this total, about 40 would be available for aerosol related studies, and about 20 for cloud indirect/CCN studies. Since some of the flight patterns are similar (e.g. 1b and 3b; 4a, 1a, 1b), there is considerable overlap in achieving the science goals, so that a combination of these patterns would be similar to repeating the same pattern more than once.

Estimated breakdown:

Experiment #	Experiment	Hours/flight	# flights	Flight hours
2	Evaluation of IAP	3.5	3	10.5
3a	Layer absorption/Irradiance closure	3.5	2	7
1b	Raman, MPL evaluation/slow extinction closure	4	1	4

3b	In situ absorption closure	4	1	4
1a or 4a	Raman, MPL evaluation/fast extinction closure	4.33	1	4.33
1b or 3b or 4a	Lidar evaluation/absorption closure	4	1	4
6a or 6b	Spatial aerosol variability	5	1	5
			Subtotal:	39
4b	CCN (cloudy)	4	3	12
5a or 5b	Cloud indirect (cloudy)	4.75	2	9.5
			Subtotal:	21.5
			Grand Total:	60.5

7. Schedule

The Aerosol IOP will occur over the ARM SGP Cloud and Radiation Testbed site between May 5-30, 2003. A brief test flight of the Twin Otter will occur on May 5 or 6. Advance preparations for the site facilities will occur during April 2003.

7.1 Daily Schedule

Tentative daily schedule during Aerosol IOP is:

- Daily planning meeting at 7 a.m. at Ponca City airport. This meeting will cover:
  - Weather briefing and forecast discussion
  - Instrument and aircraft status reports
  - Discuss proposed flight plans
  - Final go/no-go decision
  - Pilot briefing 2 hrs before takeoff
  - Hands-off Twin Otter equipment 1 hr before takeoff
  - light duration ~ 5 hrs
  - Flight planning for next day during the day
  - Notify Vance AFB of proposed next day operations by 4 p.m.
  - After aircraft landing, pilot and science debrief, plan for next day operations (5 p.m.)

Note that radiosondes are launched at 0530 UT (0030 CDT), 1130 UT (0630 UT), 1730 UT (1230 CDT), 2330 UT (1830 UT). There is the potential for a few launches at 1430 UT (0930 CDT) or 2030 UT (1530 CDT) to support aircraft operations.

Status reports will be posted on a web page at http://iop.archive.arm.gov/iopaerosol2003/. Usernames and passwords have been distributed to IOP participants. Other documentation regarding the Aerosol IOP can be found at http://www.tap.bnl.gov/arm_acp_aerosol_iop/?M=D

8. Data Availability and Archival

The ability to compare measurements from different sources in near real-time (i.e. within 24 hrs) has been found critical during previous IOPs. Therefore, investigators are strongly encouraged to share preliminary data. These initial "quicklook" data sets are not intended for public consumption, and are intended to be used only by the IOP participants. During the IOP, investigators can preliminary data to ARM IOP Archive (http://iop.archive.arm.gov/). An FTP site has been established at this location to provide a central, backed-up location for data streams resulting from the Aerosol 2003 IOP and for ease of eventual assimilation of the data and metadata into the ARM Archive at the completion of the analysis/calibration period. Data files can be uploaded, modified, and downloaded only by IOP participants using usernames and passwords provided to individual participant. Instructions for accessing this site have been emailed to the individual participants.

IOP and campaign participants may release their own preliminary data to whomever they wish; preliminary data of other investigators will be shared only with consent from the data's originator. Investigators are to submit an initial version of quality controlled, calibrated data to ARM archive for use by only IOP participants by September 1, 2003. Final data are to be submitted to the ARM archive by December 31, 2003. These data will be publicly available January 1, 2004. Note that routine ARM data are available to all participants on a free and open basis and are publishable upon receipt with acknowledgment of ARM as the source. Data sources should be recognized either through co-authorship or acknowledgement.

9. Collaborations

9.1 DOE Atmospheric Chemistry Program

Aerosols exert a substantial influence on atmospheric radiation through direct light scattering and through modification of the microphysical properties of clouds. Description of these effects locally requires characterization of the optical and cloud nucleating properties of the aerosol, respectively, but questions remain regarding the ability of radiation transfer models and cloud microphysical models to accurately represent these aerosol influences. These aerosol properties and their influences will be examined during the Aerosol IOP. Extension of the applicability of these results to other locations and times, and ultimately into climate models, requires the ability to model the optical and cloud nucleating properties from the size distribution and size distributed composition of the aerosols. Recognition of this has motivated participation in this IOP by aerosol scientists in DOE's ACP. The objective of this component of the IOP will be to evaluate ability to calculate aerosol optical properties including scattering and absorption coefficients and backscatter fraction, and their relative humidity dependence, from measured aerosol composition and size distribution by comparison with measurements, and likewise for models of CCN concentration as a function of supersaturation. Instruments/measurements to be deployed for chemical and microphysical characterization include: Tandem Differential Mobility Analyzer (TDMA) with, rapid size distribution by Differential Mobility Analyzer*, particle refractive index*, particle hygroscopicity by Humidified TDMA*, total aerosol mass by Tapered Oscillating Element Microbalance, aerosol ionic composition and soluble organic carbon by Particle Into Liquid Sampler* with ion chromatography and Total Organic Carbon analysis, laboratory analysis of collected particles by Scanning Electron Microscopy/Energy Dispersive Xray analysis, Time-of Flight Secondary Ion Mass Spectrometry*, and analysis of carbonaceous particulate matter (elemental and organic) via quartz filters and thermal evolution analysis*. Together with the ARM measurements, these additional ACP measurements will provide an extraordinarily complete chemical, microphysical, optical, and radiative characterization of atmospheric aerosols.

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Appendix A

Acronyms

Appendix A

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
ACP	Atmospheric Chemistry Program
ADAM	Asian Dust Above Monterey
AERONET	Aerosol Robotic Network
AGL	above ground level
AI	aerosol index
AOD	Aerosol Optical Depth
AOS	aerosol observing system
AT	aerosol trailer
AWG	Aerosol Working Group
ARM	Atmospheric Radiation Measurement Program
BBHR VAP	Broad Band Heating Rate Profile Value Added Product
BORCAL	broadband outdoor radiometer calibration
CERES	Clouds and Earth's Radiant Energy System
CF	Central Facility
CIRPAS	Center for Interdisciplinary Remotely-Piloted Aircraft Studies
CLAMS	Chesapeake Lighthouse Aerosol Measurements for Satellites
CSPHOT	Cimel Sun/sky photometer
CMDL	Climate Monitoring and Diagnostics Laboratory
CPC	condensation particle counter
CW-CRD	Continuous Wave Cavity Ring-Down
CWV	Columnar Water Vapor
DNSI	direct-normal solar irradiance
DOE	Department of Energy
EF	extended facility
EOS	earth observing plan
ERBE	Earth Radiation Budget Experiment
GIF	guest instrument facility
GOES	geostationary operational environmental satellite
GSFC	NASA Goddard Space Flight Center
IAP	in situ Aerosol Profiles
IOP	Intensive Observation Period
IR	infrared
LES	large-eddy simulation
LWC	liquid water content
MFRSR	Multifilter Rotating Shadowband Radiometer
MISR	Multi-angle Imaging SpectroRadiometer
MOA	memorandum of agreement

MPL	micropulse lidar
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPS	Naval Postgraduate School
OEC	Optical Extinction Cell
OPC	Optical Particle Counter
PAPS	Programmable azimuth plane scanning
PCASP	passive cavity aerosol spectrometer probe
PI	Principal Investigator
PRIDE	Puerto Rico Dust Experiment
PSAP	Particle Soot Absorption Photometer
RCC	radiometer calibration and characterization
RCF	Radiometer Calibration Facility
RH	Relative Humidity
rms	root mean square
RSS	Rotating Shadowband Spectrometer
SAFARI-2000	Southern African Regional Science Initiative
SGP	Southern Great Plains
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
SSFR	Solar Spectral Flux Radiometer
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
TDMA	time division multiple access
TO	Twin Otter
TOA	top of the atmosphere
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
UV	ultraviolet ray
WRR	World Radiometric Reference
WVIOP	Water Vapor Intensive Observation Period

Appendix B

CIRPAS Twin Otter Aircraft

Appendix B

CIRPAS Twin Otter Aircraft

The Twin Otter aircraft, owned and operated by the Naval Postgraduate School's (NPS) Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS – http://web.nps.navy.mil/~cirpas/) will be used in the Aerosol IOP. The CIRPAS UV-18A Twin Otter (see Figure B1), the military version of the De Havilland DHC-6-300, is a robust aircraft well suited for atmospheric science field studies. It can carry a large payload (4500 lbs total in the cabin, nose, and wing pods), has plenty of power for instrumentation (>4500 W), can cruise at a range of speeds (65-165 KIAS), and has the ability to fly from near the surface (.100 ft) up to 18,000 ft. The maximum flight duration is typically 5 hrs (unless additional fuel tanks are added, but this will not be done for ADAM). The Twin Otter carries a crew of two to four: a pilot, co-pilot, and 1-2 (typically, only 1) mission scientists/payload operators.

In addition, CIRPAS has developed its own data acquisition/display system for the Twin Otter that controls, stores, and synchronizes the data from all of the facility sensors onboard. Guest research sensors can tie in to the CIRPAS Twin Otter data system for time synchronization and display of data. A limited bandwidth SATCOM is linked to this data system allowing researchers on the ground to view their data and/or instrument diagnostics in real-time, and to 'chat' with the mission scientist/payload operator on board through the data system.

Figure B1. The CIRPAS Twin Otter Aircraft.

Measurements and associated instruments to be acquired from the Twin Otter during the Aerosol IOP are listed in Table B1.

Table B1. Twin Otter Measurements and Instruments.

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) Stabilized platform	Kipp and Zonen CM-22 pyranometers	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	Photoacoustic Instrument	Pat Arnott/DRI
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. Flew in CRYSTAL-FACE	Caltech

Appendix C

ARM AOS Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003

Appendix C

ARM AOS Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003

(page 1 of 2)

Instrument	**Integrating Nephelometer**	**Humidified Integrating Nephelometer**	**Continuous Filter-based Light Absorption Photometer**	**Condensation Particle Counter**	**Optical Particle Counter**
	TSI Model 3563 Integrating Nephelometer (AOS)	TSI Model 3563 Integrating Nephelometer (AOS)	Radiance Research Model PSAP (AOS)	TSI Model 3010 Condensation Particle Counter (AOS)	Particle Measuring Systems Model PCASP-X optical particle counter (AOS)
Operator	John Ogren	John Ogren	John Ogren	John Ogren	John Ogren
Contact	John.a.ogren@noaa.gov	John.a.ogren@noaa.gov	John.a.ogren@noaa.gov	John.a.ogren@noaa.gov	John.a.ogren@noaa.gov
Quantities to be measured	Total and backwards hemispheric aerosol light scattering coefficient at 450, 550, 700 nm	Total and backwards hemispheric aerosol light scattering coefficient at 450, 550, 700 nm as a function of RH	Aerosol light absorption coefficient (565 nm)	Total particle concentration, 0.01 µm < Dp < 3 µm	Aerosol size distributions, 31 bins, 0.10 µm < Dp < 10 µm
Measurement Technique or Principle	Integrating nephelometry	Integrating nephelometry	Light attenuation through aerosol deposit on filter	Condensational particle growth and detection w/ laser optics	Particle counting and sizing
Time resolution	1 minute	1 minute	1 minute	1 minute	1 minute
Reference(s)	Sheridan et al., J. Geophys. Res., Vol. 106, 20735-20747, 2001	Sheridan et al., J. Geophys. Res., Vol. 106, 20735-20747, 2001	Sheridan et al., J. Geophys. Res., Vol. 106, 20735-20747, 2001	Sheridan et al., J. Geophys. Res., Vol. 106, 20735-20747, 2001	Sheridan et al., J. Geophys. Res., Vol. 106, 20735-20747, 2001
Flow rate	30 slpm	30 slpm	0.75 slpm	1 lpm	2 cc/sec
Pump[1]	A	A	A	A	A
Sample line[1]	A	A	A	A	A
duration	Continuous	Continuous	Continuous	Continuous	Continuous
Flow control[1]	A	A	A	A	A
Size µm	Dp < 1 µm and Dp < 10 µm alternating size cuts	Dp < 1 µm and Dp < 10 µm alternating size cuts	Dp < 1 µm and Dp < 10 µm alternating size cuts	0.01 – 3 µm	0.10-10 µm
Filter[1]	N	N	N	N	N
Power[1]	A	A	A	A	A
Data[1]	A	A	A	A	A
dimension	In AOS	In AOS	In AOS	In AOS	In AOS
Space feet	In AOS	In AOS	In AOS	In AOS	In AOS
Desk[1]	N	N	N	N	N
Internet[1]	N	N	N	N	N
Additional Requirements	None	None	None	None	None

[1]S=self; A=ARM supply; N=no

ARM AOS Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003

(page 2 of 2)

Instrument	Ozone Monitor	Aerosol Filters
	Dasibi Continuous Ozone Monitor Model 1008-RS (AOS)	NOAA/PMEL aerosol filters (permanent addition to AOS)
Operator	John Ogren	Trish Quinn
Contact	John.a.ogren@noaa.gov	Patricia.K.Quinn@noaa.gov
Quantities to be measured	Ozone mixing ratio	Aerosol ionic chemistry
Measurement Technique or Principle	UV absorption	Ion chromatography
Time resolution	1 minute	24 hours
Reference(s)	Sheridan et al., J. Geophys. Res., Vol. 106, 20735-20747, 2001	
Flow rate	2 lpm	30 lpm
Pump[1]	A	A
Sample line[1]	A	A
duration	Continuous	Continuous
Flow control[1]	A	A
Size μm	None	Dp < 1 μm
Filter[1]	N	S, changed once a week
Power[1]	A	A
Data[1]	A	A
dimension	In AOS	In AOS
Space feet	In AOS	In AOS
Desk[1]	N	N
Internet[1]	N	N
Additional Requirements	None	None

[1]S=self; A=ARM supply; N=no

ARM IOP Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003
(page 1 of 3)

Instrument	3-λ Light Absorption	Integrating Nephelometer	Integrating Nephelometer	Integrating Nephelometer
	Univ. of Washington modified PSAP (Aerosol Trailer)	DRI integrating sphere nephelometer (GIF Trailer)	Radiance Research Model M-903 integrating nephelometer (GIF Trailer)	TSI Model 3563 Integrating Nephelometer
Operator	Dave Covert	Pat Arnott	Pat Arnott	John Ogren
Contact	dcovert@u.washington.edu	pat@dri.edu	pat@dri.edu	John.a.ogren@noaa.gov
Quantities to be measured	Aerosol light absorption coefficient at 3 visible wavelengths (466, 530, 660 nm)	Aerosol light scattering coefficient at 532 nm	Aerosol light scattering coefficient at 530 nm	Total and backwards hemispheric aerosol light scattering coefficient at 450, 550, 700 nm
Measurement Technique or Principle	Light attenuation through aerosol deposit on filter	Integrating nephelometry	Integrating nephelometry	Integrating nephelometry
Time resolution	1 minute	1 minute	1 minute	1 minute
Reference(s)				Anderson and Ogren, Aerosol Sci. Technol., Vol. 29, 57-69, 1998.
Flow rate	2 lpm	10 lpm	3 lpm	30 slpm
Pump[1]	A	S	S	S
Sample line[1]	A	S	S	S
duration	Continuous	Continuous	Continuous	Continuous
Flow control[1]	A	S	S	S
Size µm				Dp < 1 µm and Dp < 10 µm alternating size cuts
Filter[1]	S, changed daily	N	N	N
Power[1]	A			<100W @ 120 VAC
Data[1]	A			S
dimension	In AOS		12"x12"x24"	12"x12"x46"
Space feet	In AOS			12"x12"x46"
Desk[1]	N			N
Internet[1]	N			N
Additional Requirements	None			None; In GIF

[1]S=self; A=ARM supply; N=no

ARM Measurements at SGP Central Facility during
ARM ACP Aerosol IOP, May 2003
(page 2 of 3)

Instrument	Photoacoustic Light Absorption	7-λ Aethalometer	Cavity Ringdown Extinction	TEOM	Dusttrak
	DRI photoacoustic instrument (GIF)	Model XXXX Aethalometer (GIF)	DRI cavity ring-down instrument (GIF)	Tapered Element Oscillating Microbalance (GIF)	(GIF)
Operator	Pat Arnott	Pat Arnott	Pat Arnott	Pat Arnott	Pat Arnott
Contact	pat@dri.edu	pat@dri.edu	pat@dri.edu	pat@dri.edu	pat@dri.edu
Quantities to be measured	Aerosol light absorption coefficient at 532 nm	Aerosol light absorption coefficient at 7 wavelengths	Aerosol light extinction coefficient at 532 nm	Total aerosol mass concentration	
Measurement Technique or Principle	Photoacoustic light absorption	Light attenuation through aerosol deposit on filter	Extinction of light through ring-down cell	Based on oscillation frequency dependence on aerosol mass loading	
Time resolution	1 minute	2 minutes	1 minute		
Reference(s)					
Flow rate	1 lpm	1 lpm	10 lpm	3 lpm	
Pump[1]	S	S	S	S	
Sample line[1]	S	S	S	S	
duration	Continuous	Continuous	Continuous	Continuous	
Flow control[1]	S	S	S	S	
Size µm					
Filter[1]	N	N	N	N	
Power[1]					
Data[1]	S	S	S	S	
dimension					
Space feet	3' x 3' floor space	Can sit in rack or on desk	3' x 5' floor space	Can sit in rack or on desk	
Desk[1]	A	N	N	N	
Internet[1]	A	N	N	N	
Additional Requirements					

[1]S=self; A=ARM supply; N=no

ARM IOP Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003
(page 3 of 3)

Instrument	CCN Measurement	CCN Measurement	Size segregated composition	
	DRI CCN spectrometer (GIF Trailer)	CalTech CCN instrument (GIF Trailer)	DELTA Drum sampler, eight size cuts (GIF)	
Operator	Jim Hudson	Tracey Rissman	Tom Cahill	
Contact	hudson@dri.edu	rissman@its.caltech.edu	tacahill@ucdavis.edu	
Quantities to be measured		CCN concentration at a still-to-be-determined supersaturation		
Measurement Technique or Principle		N/A		
Time resolution		~ 1 Hz		
Reference(s)		N/A		
Flow rate	12 lpm	0.8-0.9 lpm	~ 17 lpm	
Pump[1]	S	S	S	
Sample line[1]	S	S	S	
duration	Continuous	Continuous		
Flow control[1]	S	S	S	
Size µm	Dp < 2 µm	N/A		
Filter[1]	N	S		
Power[1]	40A (max) @ 120VAC	5A @ 120VAC, 2 outlets		
Data[1]	S	S	S	
dimension	3 racks of 24”x24”x40” plus a couple of pumps	15” vertical rack space, plus column that hangs on side of rack		
Space feet	8’ x 8’	6’ x 8’	2’ x 2’	
Desk[1]	A	A	N	
Internet[1]	A	A	N	
Additional Requirements		Room for a rack-mounted calibration system to be wheeled in occasionally		

[1]S=self; A=ARM supply; N=no

ACP IOP Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003
(page 1 of 3)

Instrument	**PCASP**	**DMA**	**DMA / TDMA**[3]
	Passive Cavity Aerosol Spectrometer Probe	Differential Mobility Analyzer (	Texas A&M high flow tandem differential mobility analyzer
Operator	Jian Wang	Jian Wang	Don Collins
Contact	jian@bnl.gov	jian@bnl.gov	dcollins@tamu.edu
Quantities to be measured	Particle size distribution		10 – 1000 nm size distribution / 10 – 700 nm hygroscopic growth
Measurement Technique or Principle			Separation based on electrical mobility
Time resolution	1 second		~ 30 minutes
Reference(s)			
Flow rate	0.06 l/min	7 l/m	1 – 3 lpm
Pump[1]	N	A[2]	S
Sample line	A	A	S
duration	Continuous	Cont	Continuous
Flow control	S	S	S
Size µm	0.12-3	0.0035-1	0.01 – 1.0
filter	N	N	N
power		5A 120v 3out	4 A @ 120 VAC 1 outlet
data	S		S
dimension		19 x 23	3' L x 2' W x 4‘ H mobile cart
Space feet		6 X 8	5' x 4'
desk	N	Y	A
internet	Y	Y	A
Additional Requirements			
Location	GIF	GIF	GIF

[1]S=self; A=ARM supply; N=no

[2] Please provide: 6 LPM critical flow vacuum source

[3] Not ACP

ACP IOP Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003

(page 2 of 3)

Instrument	PILS-IC	PILS-TOC	filter	TEOM
	Particle into Liquid Sampler: Ion Chromatograph	Particle into Liquid Sampler: Total Organic Carbon (	Quartz filter to collect 12-hr integrated sample	Tapered Element Oscillating Microbalance
Operator	Yin Nan Lee	Yin Nan Lee	Yin Nan Lee	Yin Nan Lee
Contact	ynlee@bnl.gov	ynlee@bnl.gov	ynlee@bnl.gov	ynlee@bnl.gov
Quantities to be measured	major cations and anions	total organic carbon	major cations and anions	total aerosol mass concentration
Measurement Technique or Principle	sampling using PILS followed by on-line IC analysis	sampling using PILS followed by on-line TOC analysis	filter collection followed by batch IC analysis	based on oscillation frequency dependence on aerosol mass loading
Time resolution	8 min	4 min	12 hr	30 min
Reference(s)	A particle-into-liquid collector for rapid measurement of aerosol bulk chemical composition. Weber et al. Aerosol Sci. Technol, 35, 718-727, 2001.	http://www.ionics.com/products/division/Instruments/sievers_instruments.htm#1	The BNL filter pack system for collection and determination of air pollutants, Leahy et al, BNL report -61730, 1995.	http://www.rpco.com/products/ambprod/amb1400/index.htm
Flow rate	5 l/min	5 l/min	5 l/min	3 l/m
Pump[1]	A	A	A	A
Sample line	A	A	A	A
duration	7am-7pm	7am-7pm	7am-7pm	7am-7pm
Flow control	S	S	S	S
Size µm	PM2.5 or PM1.0	PM2.5 or PM1.0	PM2.5 or PM1.0	PM2.5 or PM1.0
filter	N	N	S	N
power	3A 120v 2out	3A 120v 2out	1A 120v 2out	1A 120v 2out
data	S	S	S	
dimension	23" w x 18" d	23" w x 18" d	18" w x 12"	18" w x 12"
Space feet	6' X 8'			
desk	Y			
internet	N			
Location	GIF	GIF	GIF	GIF

[1]S=self; A=ARM supply; N=no

ACP IOP Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003
(page 3 of 3)

Instrument	**EC-OC**[6]	**SP-2**		
	Elemental and Organic Carbon (aerosol trailer)	Particle Absorption by Incandescence **TENTATIVE**		
Operator	Tom Kirchstetter	Darrel Baumgardner[4]		
Contact	TWKirchstetter@lbl.gov	darrel@servidor.unam.mx		
Quantities to be measured	TC/OC/BC and 330-900 nm light-transmission			
Measurement Technique or Principle	thermal analysis and light spectrometer			
Time resolution	6 hour			
Reference(s)				
Flow rate	30 std L per min	100 cc/s		
Pump[1]		S		
Sample line		A		
duration		Continuous		
Flow control	mass flow controller	S		
Size µm		0.1-10		
filter		N		
power	ARM (backup pump is 12A, 120V)	5A 120V 4 outlets		
data		S		
dimension		66 lb 30" x 30"		
Space feet		6' X 8'		
desk	need small workspace to change filters	Y		
internet	No	N		
	No PVC. Data logger to record flows, technician to log filter changes			
Location	This experiment will be housed in the Aerosol Trailer	GIF		

[1]S=self; A=ARM supply; N=no

[4] Not ACP; tentative.

Other ARM Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003
(page 1 of 2)

Instrument	SMART trailer (Surface Measurements for Atmospheric Radiative Transfer)	S^3 photometer	Shadowband radiometer	Broadband radiometers	Micopulse lidar
	NASA GSFC	NASA GSFC	Yankee Environmental Systems, Inc.	Eppley, Yankee, Kipp&Zonen, NILU-UV	NASA GSFC
Operator	SMART team	Jack Ji	Jack Ji	Jack Ji	Jack Ji
Contact	Jack Ji, ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov
Quantities to be measured	Solar, terrestrial radiation	Solar radiance at 340, 380, 440, 500, 615, 675, 870, 870p1, 870p2, 936, 1030, 1240, 1640, 2130 nm	Solar irradiance at 414, 498, 614, 672, 866, 939, and 300~1000 nm (Global, Diffuse, and Direct radiance)	Solar irradiance at, 0.3~3, 0.4~3, 0.7~3 um (Global and Diffuse); 0.3~3 um (Direct); 4~50 um, also 302, 308, 315, 336, 377, 400~700 nm (Global)	Normalized Relative Backscatter
Measurement Technique or Principle	Remote sensing			Eppley PSP, PIR, NIP; Kipp and Zonen CM21, CG4, CH1	
Time resolution	Up to 1 min	15 min	1 min	1 min	1 min
Reference(s)	http://smart-commit.gsfc.nasa.gov		http://www.yesinc.com/products/data/mfr7/index.html	http://www.eppleylab.com http://www.kippzonen.com/product/index.html http://alomar.rocketrange.no/nilu-uv.html	http://virl.gsfc.nasa.gov
Flow rate	No				
Pump[1]	N				
Sample line[1]	N				
Duration	Continuous				
Flow control[1]	N				
Size µm	N				
Filter[1]	N				
Power[1]	A, 100A@220V				
Data[1]	S				
Dimension	20x17x9 ft				
Space feet	25x9 ft				
Desk[1]	N				
Internet[1]	A				
Additional Requirements	Whole sky view				

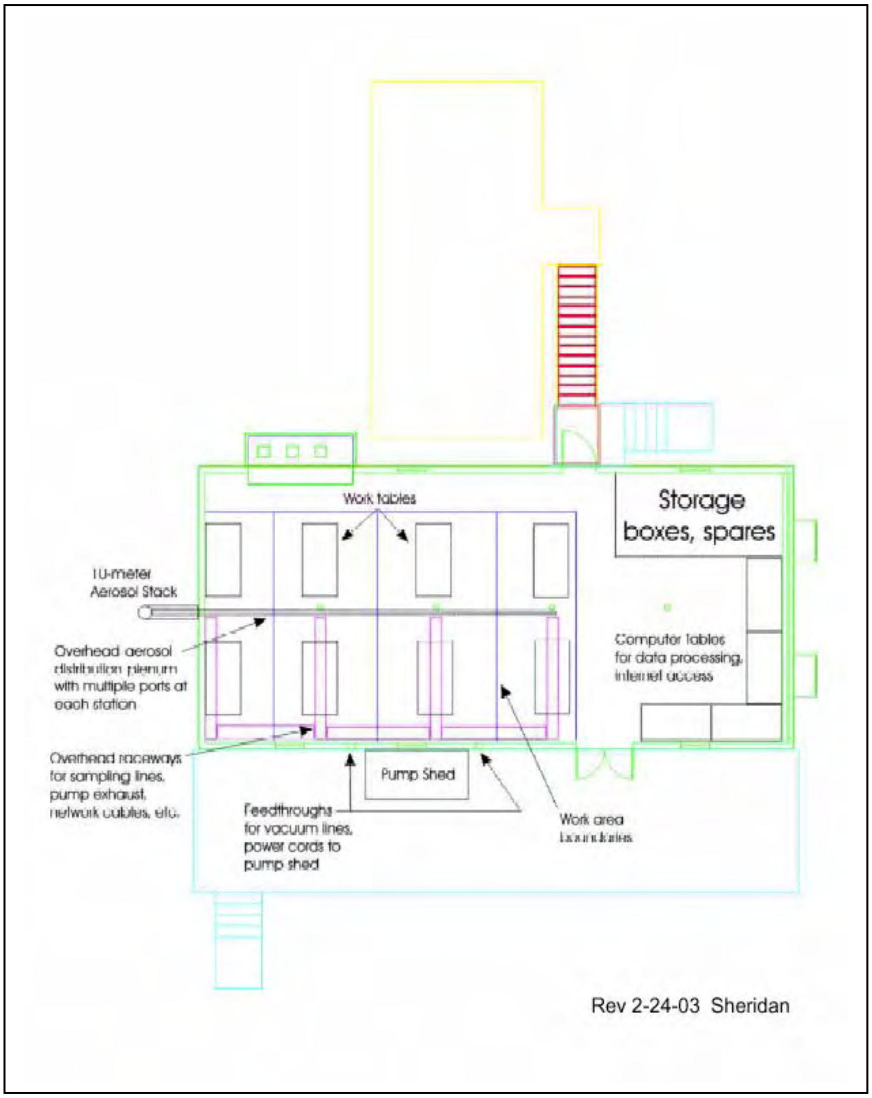
[1]S=self; A=ARM supply; N=no

Other ARM Measurements at SGP Central Facility during ARM ACP Aerosol IOP, May 2003
(page 2 of 2)

Instrument	**Sky imager**	**Spectro-radiometer**	**Interferometer**	**Scanning microwave radiometer**	**Rain gage**
	Yankee Environmental Systems, Inc.	Analytical Spectral Devices, Inc.	ABB Bomem	NASA GSFC	Optical Scientific Inc.
Operator	Jack Ji	Jack Ji	Jack Ji	Jack Ji	Jack Ji
Contact	ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov	ji@climate.gsfc.nasa.gov
Quantities to be measured	Sky image	Solar spectral irradiance 0.4~2.5 um, Sampling Interval 2nm	AERI, Sky spectral radiance 500~3000 cm-1, 1 cm-1 resolution	Sky radiance at 23, 23.8, and 36 GHz	Rain rate, measures from .1 to 500 m/hr
Measurement Technique or Principle					
Time resolution	1 min	1 min	5 min	5 min	5 min
Reference(s)	http://www.yesinc.com/products/data/tsi440/index.html	http://www.asdi.com/asdi_t2_pr_sp_fsp.html	http://www.abb.com/global/abbzh/abbzh251.nsf!OpenDatabase&db=/global/seapr/seapr035.nsf&v=6312A&e=us&m=9F2&c=C1E6CB3C346573A385256C61005B3D44		http://www.opticalscientific.com/Org.htm
Flow rate					
Pump[1]					
Sample line[1]					
Duration					
Flow control[1]					
Size µm					
Filter[1]					
Power[1]					
Data[1]					
Dimension					
Space feet					
Desk[1]					
Internet[1]					
Additional Requirements					

[1]S=self; A=ARM supply; N=no

Schematic showing GIF trailer



Appendix D

MISR Overpass Dates/Times

Appendix D

MISR Overpass Dates/Times

Report generated 08Jan2003 lm_sites, version 1.9
ID# Site Name Latitude Longitude 009 SGP_Lamont 36.6050 -97.4850

Requested date range: April 01, 2003 to June 30, 2003

Overpass date(s) for #009 SGP_Lamont, Path 27, Block 61

	Df_camera		Extent	View	Sun	Sun	MISR Prediction	
Date	Orbit#	GMT	(km)	Angle	Azimuth	Elevation	Azimuth	DOY
Apr 06, 2003	17553	2003/096/17:16:00	122.0W	10.0	146.8	55.6	190.1	Est
Apr 22, 2003	17786	2003/112/17:16:00	122.0W	10.0	143.4	61.2	190.1	Est
May 08, 2003	18019	2003/128/17:16:00	122.0W	10.0	138.6	65.6	190.1	Est
May 24, 2003	18252	2003/144/17:16:00	122.0W	10.0	132.9	68.5	190.1	Est
Jun 09, 2003	18485	2003/160/17:16:00	122.0W	10.0	127.7	69.8	190.1	Est
Jun 25, 2003	18718	2003/176/17:16:00	122.0W	10.0	125.2	69.5	190.1	Est

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Overpass date(s) for #009 SGP_Lamont, Path 28, Block 61

	Df_camera		Extent	View	Sun	Sun	MISR Prediction	
Date	Orbit#	GMT	(km)	Angle	Azimuth	Elevation	Azimuth	DOY
Apr 13, 2003	17655	2003/103/17:22:00	8.0E	1.0	148.0	58.8	190.1	Est
Apr 29, 2003	17888	2003/119/17:22:00	8.0E	1.0	144.3	64.0	190.1	Est
May 15, 2003	18121	2003/135/17:22:00	8.0E	1.0	139.2	67.9	190.1	Est
May 31, 2003	18354	2003/151/17:22:00	8.0E	1.0	133.5	70.2	190.1	Est
Jun 16, 2003	18587	2003/167/17:22:00	8.0E	1.0	129.1	70.8	190.1	Est
Jul 02, 2003	18820	2003/183/17:22:00	8.0E	1.0	128.1	70.0	190.1	Est

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Overpass date(s) for #009 SGP_Lamont, Path 29, Block 61

	Df_camera		Extent	View	Sun	Sun	MISR Prediction	
Date	Orbit#	GMT	(km)	Angle	Azimuth	Elevation	Azimuth	DOY
Apr 04, 2003	17524	2003/094/17:28:00	147.0E	12.0	152.0	56.1	190.2	Est
Apr 20, 2003	17757	2003/110/17:28:00	147.0E	12.0	149.3	61.9	190.2	Est
May 06, 2003	17990	2003/126/17:28:00	147.0E	12.0	145.3	66.6	190.2	Est
May 22, 2003	18223	2003/142/17:28:00	147.0E	12.0	140.0	69.9	190.2	Est
Jun 07, 2003	18456	2003/158/17:28:00	147.0E	12.0	134.6	71.5	190.2	Est
Jun 23, 2003	18689	2003/174/17:28:00	147.0E	12.0	131.4	71.5	190.2	Est

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Times are shown for the start of Local Mode acquisition for Df camera, duration of Local Mode is 7:35 minutes, therefore overpass of An camera is 3:47 minutes after Df. Extents and view angles are with respect to the latest orbit track, not the block center.

Appendix E

MODIS Overpass Dates/Times

Appendix E

MODIS Overpass Dates/Times

Date	The date of the predicted passes
Time of Rise/Peak/Set	The time for each pass's start, maximum (peak) elevation, and end.
Azimuth at Ris/Pk/Set	The azimuth (direction the observer must face) to the spacecraft, in degrees, when the pass begins, when the spacecraft reaches maximum elevation, and when the pass ends. 0 corresponds to north, 90 east, 180 south, and 270 west.
Peak Elev	The spacecraft's maximum elevation above the horizon, in degrees, for this pass. This will be at the time and azimuth specified in the previous columns. Passes with a peak elevation of 40.0 degrees or more are marked with an asterisk (*) at the end of this field.
Height at Pk	The spacecraft's altitude above the ground in kilometers at the time of peak elevation. Note that this is NOT the distance from the spacecraft to the observer.
Vis	A three-letter indicator of the spacecraft's visibility at the beginning of the pass (spacecraft rise), maximum elevation, and at the end of the pass (spacecraft set). The letters used are: **N** spacecraft is in the night portion of the orbit **D** spacecraft is in the day portion of the orbit **V** spacecraft is in the day portion of the orbit and the ground site is in nautical twighlight (sun at least 6 degrees below the horizon), making the spacecraft visible
Orbit	The spacecraft's orbit number for this pass, counting from launch

```
Satellite #25994   : TERRA
Element Set Number: 922 (Orbit 17867)
Element Set Epoch : 28Apr03  06:09:14.511 UTC   (1.4 days ago)
Orbit Geometry    : 698.85 km x 700.11 km at 98.187 deg
Propagation Model : SGP4
Ground Location   : Lat/Long 36.616700N 97.500000W
Time is shown in  : UTC (+0.00 h)

OVERPASS SUMMARY:
```

Date (UTC)	Time (UTC) of Rise	Peak	Set	Azimuth at Ris	Pk	Set	Peak Elev	Height at Pk	Vis	Orbit
Sun 04May03	02:24:41	02:27:11	02:29:41	77	55	34	1.9	689	NVV	17953
	03:56:55	04:03:38	04:10:29	148	72	356	40.5*	692	NNV	17954
	05:35:28	05:41:32	05:47:44	205	267	329	18.0	694	NNV	17955
	15:59:30	16:05:02	16:10:42	38	92	146	12.7	695	DDD	17962
	17:36:13	17:43:04	17:50:03	7	286	204	57.0*	693	DDD	17963
	19:16:06	19:19:47	19:23:37	335	302	268	4.5	690	DDD	17964

Mon	05May03	03:03:52	03:09:08	03:14:32	114	63	12	11.5	691	NNV	17968
		04:39:16	04:46:15	04:53:22	172	258	345	69.9*	693	NNV	17969
		06:20:51	06:24:40	06:28:37	238	272	308	4.5	694	NNV	17970
		16:41:20	16:48:03	16:54:54	22	98	174	35.9	694	DDD	17977
		18:19:22	18:25:33	18:31:53	356	292	229	21.0	692	DDD	17978
Tue	06May03	03:44:54	03:51:21	03:58:04	141	71	359	30.4	692	NNV	17983
		05:22:40	05:29:07	05:35:34	197	265	333	24.1	694	NNV	17984
		15:47:37	15:52:38	15:57:46	43	90	138	8.8	695	DDD	17991
		17:23:56	17:30:47	17:37:54	10	287	198	77.8*	693	DDD	17992
		19:03:09	19:07:38	19:12:23	341	300	257	7.1	690	DDD	17993
Wed	07May03	02:52:14	02:56:59	03:01:51	105	61	17	8.2	690	NVV	17997
		04:26:59	04:33:58	04:40:57	165	66	348	86.4*	693	NNV	17998
		06:07:31	06:12:15	06:17:00	227	271	315	7.6	694	NNV	17999
		16:29:11	16:35:38	16:42:21	26	95	167	26.7	694	DDD	18006
		18:06:57	18:13:16	18:19:51	359	292	222	27.5	692	DDD	18007
Thu	08May03	03:32:52	03:39:12	03:45:31	133	68	3	23.1	692	NNV	18012
		05:10:07	05:16:42	05:23:25	189	262	336	32.2	694	NNV	18013
		15:36:00	15:40:05	15:44:26	51	88	127	5.5	695	DDD	18020
		17:11:31	17:18:30	17:25:37	14	104	191	78.2*	694	DDD	18021
		18:50:29	18:55:37	19:00:45	346	297	249	10.2	691	DDD	18022
Fri	09May03	02:40:53	02:44:50	02:49:03	95	59	22	5.4	689	NVV	18026
		04:14:42	04:21:41	04:28:40	158	73	352	63.8*	693	NNV	18027
		05:54:18	05:59:43	06:05:15	217	268	321	11.2	694	NNV	18028
		16:17:01	16:23:21	16:29:40	30	96	159	20.0	695	DDD	18035
		17:54:24	18:01:07	18:07:50	2	288	215	36.4	693	DDD	18036
		19:35:44	19:37:34	19:39:25	320	305	289	1.2	689	DDD	18037
Sat	10May03	03:20:59	03:27:03	03:32:59	126	65	7	17.6	691	NNV	18041
		04:57:34	05:04:25	05:11:16	182	263	340	43.6*	693	NNV	18042
		06:42:03	06:42:59	06:44:10	267	275	285	0.5	694	NNN	18043
		15:24:38	15:27:40	15:30:50	60	87	114	2.7	695	DDD	18049
		16:59:14	17:06:13	17:13:12	17	104	184	56.9*	694	DDD	18050
		18:37:48	18:43:28	18:49:08	350	295	240	13.9	691	DDD	18051
Sun	11May03	02:29:47	02:32:49	02:35:58	83	57	29	3.0	689	NVV	18055
		04:02:33	04:09:24	04:16:15	151	72	355	46.7*	692	NNV	18056
		05:41:22	05:47:18	05:53:21	208	267	327	15.5	694	NNV	18057
		16:05:00	16:10:48	16:16:52	35	92	151	14.8	695	DDD	18064
		17:41:59	17:48:50	17:55:49	6	286	208	49.1*	693	DDD	18065
		19:22:15	19:25:25	19:28:51	331	303	273	3.4	689	DDD	18066
Mon	12May03	03:09:14	03:14:46	03:20:26	118	65	10	13.2	691	NVV	18070
		04:45:09	04:52:00	04:58:59	175	259	344	60.1*	693	NNV	18071
		06:27:16	06:30:34	06:33:52	245	274	303	3.1	694	NNV	18072
		16:47:05	16:53:49	17:00:48	21	99	177	41.5*	694	DDD	18079
		18:25:15	18:31:11	18:37:23	354	294	232	18.4	692	DDD	18080
Tue	13May03	02:19:20	02:20:40	02:22:14	66	55	41	0.8	688	VVV	18084
		03:50:31	03:57:07	04:03:50	144	71	358	34.7	692	NNV	18085
		05:28:33	05:34:53	05:41:12	200	265	331	21.0	694	NNV	18086
		15:53:07	15:58:23	16:03:47	40	91	142	10.6	695	DDD	18093
		17:29:42	17:36:33	17:43:32	9	283	201	67.2*	694	DDD	18094
		19:09:11	19:13:16	19:17:37	338	301	262	5.8	690	DDD	18095
Wed	14May03	02:57:36	03:02:37	03:07:45	109	62	14	9.7	690	NVV	18099

		04:32:44	04:39:43	04:46:42	168	271	347	81.9*	693	NNV	18100
		06:13:40	06:18:01	06:22:30	232	272	312	6.0	694	NNV	18101
		16:34:48	16:41:24	16:48:15	24	96	170	30.7	694	DDD	18108
		18:12:42	18:19:02	18:25:29	357	291	225	24.2	692	DDD	18109
Thu	15May03	03:38:30	03:44:50	03:51:25	137	70	1	26.3	692	NNV	18114
		05:15:53	05:22:28	05:29:11	193	263	335	28.1	694	NNV	18115
		15:41:22	15:45:58	15:50:43	47	90	133	7.0	695	DDD	18122
		17:17:17	17:24:16	17:31:15	12	180	194	87.9*	694	DDD	18123
		18:56:22	19:01:15	19:06:07	343	298	253	8.7	691	DDD	18124
Fri	16May03	02:46:07	02:50:28	02:54:56	100	60	20	6.7	690	NVV	18128
		04:20:27	04:27:18	04:34:25	161	80	350	73.9*	693	NNV	18129
		06:00:28	06:05:28	06:10:44	222	269	319	9.4	694	NNV	18130
		16:22:39	16:28:59	16:35:34	28	94	163	22.9	695	DDD	18137
		18:00:10	18:06:45	18:13:28	1	290	218	31.9	693	DDD	18138
Sat	17May03	03:26:29	03:32:41	03:38:52	130	66	5	20.0	691	NVV	18143
		05:03:20	05:10:03	05:16:54	185	261	339	37.8	694	NNV	18144
		15:29:44	15:33:26	15:37:15	55	87	121	4.0	695	DDD	18151
		17:05:00	17:11:51	17:18:58	16	100	187	66.2*	694	DDD	18152
		18:43:42	18:48:58	18:54:30	348	297	244	12.1	691	DDD	18153
Sun	18May03	02:34:45	02:38:19	02:42:00	90	58	26	4.1	689	NVV	18158

Satellite #27424 : AQUA
Element Set Number: 358 (Orbit 5223)
Element Set Epoch : 27Apr03 22:19:13.319 UTC (1.7 days ago)
Orbit Geometry : 698.11 km x 701.36 km at 98.208 deg
Propagation Model : SGP4
Ground Location : Lat/Long 36.616700N 97.500000W
Time is shown in : UTC (+0.00 h)

OVERPASS SUMMARY:

Date (UTC)		Time (UTC) of			Azimuth at			Peak	Height	Vis	Orbit
		Rise	Peak	Set	Ris	Pk	Set	Elev	at Pk		
Sun	04May03	06:33:04	06:36:46	06:40:43	54	87	122	4.3	696	VNN	5317
		08:08:21	08:15:12	08:22:19	15	98	188	68.7*	696	VNN	5318
		09:47:02	09:52:19	09:57:51	348	297	245	11.7	693	VVN	5319
		17:38:07	17:41:49	17:45:30	90	57	25	4.4	689	DDD	5324
		19:11:33	19:18:24	19:25:23	155	77	353	56.2*	693	DDD	5325
		20:50:54	20:56:26	21:02:14	214	267	324	12.8	694	DDD	5326

Mon	05May03	07:14:03	07:20:07	07:26:18	32	94	156	17.8	696	VNN	5332
		08:51:18	08:58:01	09:04:52	4	287	212	41.1*	695	VNN	5333
		10:31:58	10:34:29	10:37:07	326	304	282	2.1	691	VVN	5334
		18:18:11	18:23:59	18:29:54	123	65	8	15.8	691	DDD	5339
		19:54:22	20:01:13	20:08:12	179	257	341	49.4*	693	DDD	5340
		21:37:41	21:39:55	21:42:18	255	275	295	1.5	694	DDD	5341
Tue	06May03	06:22:16	06:24:38	06:27:00	66	86	106	1.7	697	VNN	5346
		07:56:21	08:03:12	08:10:11	19	101	181	50.3*	696	VNN	5347
		09:34:47	09:40:27	09:46:23	351	295	237	15.6	693	VVN	5348
		17:27:27	17:29:57	17:32:43	78	56	32	2.1	689	DDD	5353
		18:59:41	19:06:32	19:13:15	148	70	356	41.6*	692	DDD	5354
		20:38:23	20:44:19	20:50:30	206	265	328	17.4	694	DDD	5355
Wed	07May03	07:02:19	07:07:59	07:13:47	37	92	148	13.1	697	VNN	5361
		08:39:10	08:46:01	08:53:00	7	286	205	55.4*	695	VNN	5362
		10:19:03	10:22:44	10:26:26	335	302	269	4.3	692	VVN	5363
		18:06:42	18:12:07	18:17:31	115	63	12	11.8	691	DDD	5368
		19:42:22	19:49:14	19:56:20	173	256	345	67.6*	693	DDD	5369
		21:23:58	21:27:40	21:31:29	240	272	306	4.1	694	DDD	5370
Thu	08May03	07:44:21	07:51:12	07:58:03	22	100	175	37.1	696	VNN	5376
		09:22:31	09:28:35	09:34:54	355	293	230	20.4	694	VNN	5377
		18:47:57	18:54:32	19:01:15	142	71	359	31.4	692	DDD	5383
		20:25:51	20:32:19	20:38:46	197	265	332	23.2	694	DDD	5384
Fri	09May03	06:50:43	06:55:51	07:01:07	42	90	139	9.3	697	VNN	5390
		08:27:10	08:34:01	08:41:08	10	289	198	75.1*	696	VNN	5391
		10:06:32	10:10:52	10:15:29	340	300	259	6.8	692	VVN	5392
		17:55:30	18:00:15	18:05:15	106	62	16	8.6	690	DDD	5397
		19:30:23	19:37:14	19:44:21	166	151	348	88.6*	693	DDD	5398
		21:10:55	21:15:32	21:20:16	228	271	314	7.1	694	DDD	5399
Sat	10May03	07:32:37	07:39:04	07:45:47	26	96	167	27.8	696	VNN	5405
		09:10:23	09:16:43	09:23:18	358	291	222	26.6	694	VNN	5406
		18:36:21	18:42:40	18:49:08	134	68	2	24.0	692	DDD	5412
		20:13:36	20:20:11	20:27:02	190	262	336	30.9	694	DDD	5413
Sun	11May03	06:39:23	06:43:43	06:48:12	49	88	129	6.0	697	VNN	5419
		08:15:10	08:22:09	08:29:08	13	116	192	81.3*	696	VNN	5420
		09:54:08	09:59:08	10:04:17	345	298	250	9.8	693	VVN	5421
		17:44:26	17:48:31	17:52:44	96	59	21	5.8	690	DDD	5426
		19:18:23	19:25:22	19:32:21	159	71	351	67.1*	693	DDD	5427
		20:58:08	21:03:24	21:08:56	218	268	321	10.6	694	DDD	5428
Mon	12May03	07:20:45	07:27:04	07:33:32	29	95	160	21.0	697	VNN	5434
		08:58:16	09:04:51	09:11:42	2	289	215	34.9	695	VNN	5435
		10:39:43	10:41:18	10:42:53	319	305	292	0.9	691	VVV	5436
		18:24:53	18:30:48	18:37:00	127	67	5	18.5	692	DDD	5441
		20:01:28	20:08:11	20:15:10	183	259	340	41.4*	694	DDD	5442
Tue	13May03	06:28:18	06:31:36	06:35:01	57	86	116	3.2	697	VNN	5448
		08:03:18	08:10:10	08:17:16	17	101	185	60.3*	696	VNN	5449
		09:41:52	09:47:24	09:53:04	349	295	241	13.3	694	VVN	5450
		17:33:29	17:36:47	17:40:12	86	57	27	3.4	690	DDD	5455
		19:06:39	19:13:22	19:20:21	152	76	354	49.5*	693	DDD	5456
		20:45:36	20:51:24	20:57:20	210	267	326	14.7	694	DDD	5457
Wed	14May03	07:09:09	07:15:05	07:21:08	34	93	153	15.7	697	VNN	5463

		08:46:16	08:52:59	08:59:58	5	288	209	46.4*	695	VNN	5464
		10:26:32	10:29:34	10:32:44	330	304	276	3.0	692	VVN	5465
		18:13:24	18:19:04	18:24:44	119	64	9	14.1	692	DDD	5470
		19:49:20	19:56:19	20:03:18	176	261	343	56.2*	694	DDD	5471
		21:31:51	21:34:53	21:37:55	248	274	300	2.6	695	DDD	5472
Thu	15May03	06:18:17	06:19:36	06:20:55	74	85	97	0.7	697	VNN	5477
		07:51:26	07:58:10	08:05:09	20	97	178	44.3*	696	VNN	5478
		09:29:45	09:35:32	09:41:44	353	295	234	17.5	694	VVN	5479
		17:23:12	17:25:10	17:27:09	72	55	38	1.3	689	DDD	5484
		18:54:55	19:01:38	19:08:21	146	70	357	37.0	693	DDD	5485
		20:33:13	20:39:24	20:45:44	202	266	330	19.7	695	DDD	5486
Fri	16May03	06:57:33	07:03:05	07:08:37	39	92	144	11.5	697	VNN	5492
		08:34:16	08:41:07	08:48:14	8	287	202	62.8*	696	VNN	5493
		10:13:53	10:17:58	10:22:03	337	301	264	5.3	692	VVN	5494
		18:02:12	18:07:20	18:12:36	111	62	13	10.5	691	DDD	5499
		19:37:28	19:44:19	19:51:26	170	248	346	76.2*	694	DDD	5500
		21:18:40	21:22:45	21:26:58	235	272	310	5.3	695	DDD	5501
Sat	17May03	07:39:34	07:46:18	07:53:09	23	98	172	33.0	697	VNN	5507
		09:17:37	09:23:48	09:30:16	356	292	227	22.7	695	VVN	5508
		18:43:18	18:49:46	18:56:21	139	70	0	28.2	693	DDD	5514
		20:20:57	20:27:24	20:34:00	195	263	334	26.1	695	DDD	5515
Sun	18May03	06:46:12	06:51:05	06:55:57	45	90	135	7.9	697	VNN	5521

Appendix F

Aerosol IOP Participants

Appendix F

Aerosol IOP Participants

Name	E-mail Address	IOP Username	Role
Tom Ackerman	Tom.Ackerman@arm.gov	a03acker	ARM Infrastructure
Betsy Andrews	betsy.andrews@noaa.gov	a03andre	Participant
Pat Arnott	pat@dri.edu	a03arnot	Participant
Chad Bahrmann	cbahrmann@psu.edu	a03bahrm	Site Scientist/Manager
Don Bond	dbond@ou.edu	a03bond	Site Scientist
Anthony Bucholtz	bucholtz@nrlmry.navy.mil	a03bucho	Participant
Thomas Cahill	tacahill@ucdavis.edu	a03cahil	Participant
James Campbell	campbell@virl.gsfc.nasa.gov	a03campb	Participant
Ric Cederwall	rcederwall@llnl.gov	a03ceder	ARM Infrastructure
Bill Clements	clements@lanl.gov	a03cleme	Site Scientist/Manager
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Appendix G

Aerosol IOP Planning Meeting Participants, December 2002 at NASA Ames

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