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Science and Experiment Plan Fall 2002 Flight Series

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Arm-Uav

Atmospheric Radiation Measurement - Unmanned Aerospace Vehicle

Science and Experiment Plan

Fall 2002 Flight Series

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Introduction

Objectives

The ARM-UAV (Atmospheric Radiation Measurement - Unmanned Aerospace Vehicle) Program is a multi-agency, multi-laboratory program funded by the Department of Energy. The program emphasizes the use of UAVs as a remotely piloted platform for making important climate measurements, but has also used manned aircraft when these provide an operational advantage. The UAVs that are used are a variant of a UAV originally developed for defense surveillance. Using a UAV to make these measurements offers the significant advantage of high-altitude and long-endurance operations, two features that are very important when studying evolving cloud fields and their effect on the solar and thermal radiation balance in the atmosphere, a major goal of the ARM-UAV program. Additionally, the program is seeking to exploit the high altitude flight capability of UAVs to provide measurements to calibrate satellite radiance products and validate their associated flux retrieval algorithms.

A corollary to these scientific goals is the technical objective of using improved measurement techniques and instruments for radiative fluxes, cloud properties, and *in situ* water vapor that were developed earlier in this program, as well as state-of-the-art instruments developed by the science community at large. The demonstration of this objective was a feature of the eight previous flight campaigns flown in the spring of 1994, fall of 1995, spring of 1996, fall of 1996, fall of 1997, spring of 1999, summer of 1999, and spring of 2000 and will be continued in the fall 2002 campaign discussed herein.

The primary focus for this campaign is to improve understanding of solar and thermal fluxes at the top of the Single Column Model (SCM) column centered at the SGP ARM site. These data will improve the use of SCMS and Cloud Resolving Models (CRMs) as parameterization test beds. The secondary focus is to improve understanding of mid-latitude cirrus clouds, and the remote sensing of them. This is important for at least two principal reasons. First, cirrus clouds have a direct effect, through their optical properties, on both thermal and solar radiative transfer (this broad affect is referred to as cloud-climate forcing). Second, they are a stage in the circulation of water from cumulus towers into the upper troposphere. The feedback between the density of water vapor in the upper troposphere and other changes in the physical climate is a crucial issue. The third focus is to provide a point test of the solar flux retrieval from GOES radiance data. These retrievals are used by the climate modeling community for TOA input to radiative heating calculations.

Science Questions

As with the ARM program the primary scientific focus of the ARM-UAV program is on radiation-cloud interactions. Uncertainties in how clouds interact with the earth's solar and thermal radiation account for almost the entire factor of three variation in the predicted temperature rise for a doubling of atmospheric CO₂. While some of these uncertainties can be addressed by the ground-based measurements being made in the ARM program, others require measurements from within the atmosphere. For example, the measurement of atmospheric heating in a slab requires the measurement of the net fluxes at the top and bottom of the slab as well as the relevant cloud properties and water vapor profiles. Satellite based measurements are a natural way of extending these process measurements to larger scales but would benefit from the additional calibration and validation that carefully controlled high altitude aircraft measurements can provide.

The ARM program has been collecting active and passive ground based remote sensor data for many years at several sites. These data streams are contributing substantially to our understanding of how clouds are coupled to the meteorology on multiple scales and how they ultimately interact with the climate system. The ground-based data consist of information pertaining to the macroscale cloud properties (occurrence, boundaries, fraction, layering, etc.) and, by combining multiple data streams and assumptions, the microphysical properties of the clouds can be derived (water content, particle size, concentration, optical depth, etc.). While these data streams have been mature for several years, our ability to validate the results of algorithms applied to the data to infer the microphysical and even the macro scale characteristics of the clouds continues to be sparse. A recent analysis of all available aircraft profiles of cirrus layers observed at the ARM site in 4 IOP's resulted in approximately 12 events (Figure 1). These events, while useful, are too few for rigorous validation of algorithms. The upcoming deployment discussed in this document and scheduled for the November 2002 timeframe provides a substantial opportunity to conduct a set of experiments that will expand our library of well-documented cirrus cases and will address important issues regarding the development and validation of cloud property retrieval algorithms.

This science plan outlines an experiment using a manned Scaled Composites Proteus aircraft as a platform for collecting measurements that will shed some insight on these broad issues. It will further the basic long-term goal of improving our understanding the effects of clouds on the radiation budget at the tropopause and of cirrus clouds on the radiative and water budgets of the upper troposphere. Specifically, this campaign seeks to contribute toward answering the following critical science questions.



Figure 1. Comparison of IWP derived from aircraft with that calculated from combined radar reflectivity and AERI radiances.

Experiment 1 seeks to measure

cirrus cloud microphysical and optical properties and link them to the bulk radiative properties as a basis for evaluating the parameterization of cloud optical properties in terms of cloud physical properties, and evaluating the parameterization of radiative transport through cirrus clouds. Both airborne methods and methods developed to analyze surface CART data will be compared with the in situ observations to ascertain their accuracy.

The objective of Experiment 2 is to characterize the structure of cirrus layer tops using a combination of in situ and remote observational techniques. Cirrus layers often exhibit a gradual decrease in particle size and radar reflectivity toward the layer top, and the reflectivity often decreases below the radar detection threshold at ranges below the actual hydrometeor layer top. Unfortunately, lidar can attenuates completely below these upper layers and then it is impossible to ascertain whether the layer top reported by the radar coincides with the actual layer top. This experiment will aid in placing uncertainty bounds on the layer top estimation of cirrus and determining how much this error biases our estimate of such parameters as the OLR and albedo.

The objectives of Experiment 3 are to assess the errors in the narrowband calibrations of selected channels on satellite imagers and to determine the uncertainties in fluxes derived from both narrow- and broadband fluxes.

Experiment 4 will assess the accuracy of the radiative fluxes at the top of the SCM column. The Proteus measurements will provide the fine-scale spatial and temporal variability of upwelling irradiance at the top of the SCM column that can be compared with CRM output and used to better interpret temporally-averaged and spatially-averaged radiation quantities used by the CPM WG.

Approach

As noted above, the programmatic approach is to use UAVs because of their promise for sustained endurance at altitudes up to 20 km. However, national priorities associated with the war against terrorism have made the airframe of choice, the General Atomics Aeronautical Systems, Inc. Altair UAV, unavailable for this campaign. Therefore the Scaled Composites manned Proteus aircraft will be used instead. The Proteus is a well matched substitute and will be able to accomplish the flight profiles required for the research described herein.

An ARM-UAV Science Team has provided guidance for the preparation of this science plan, and its members are responsible for the usage and analysis of data from all instrumentation. Team members are identified in the descriptions of the various experiments and their contact information can be found in Appendix A.

Campaign History and Resources

Since its initial flight in the fall of 1993 the ARM-UAV program has utilized five aircraft types in eight separate campaigns with payloads comprised of a subset of twenty-two different instruments. The aircraft and their payload complements are discussed below. Six of the campaigns were flown at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) Site in north central Oklahoma in the spring of 1994, fall of 1995, spring of 1996, fall of 1996, fall of 1997, and spring of 2000. The other two were flown from the Pacific Missile Test Range on the island of Kauai, Hawaii in the spring of 1999 and from Monterey, California in the summer of 1999.

The first campaign used the General Atomics Gnat 750, a midsize UAV capable of carrying a 100-kg payload to a maximum altitude of 7 km. The Gnat was first operated in a checkout flight at Edwards Air Force Base with a basic radiometric payload in November, 1993, and again at the SGP CART site in April, 1994, for a seven flight science mission, called UAV Development Flight (UDF). The operable payload contained four broadband radiometers plus a downwelling Total Direct Diffuse Radiometer (TDDR) developed by Francisco Valero — the radiometers were the four combinations of upwelling and downwelling, solar and thermal. Valero, Gore, and Giver, 1982; Valero, Ackerman, and Gore, 1989; and Valero and Pilewskie, 1992 describe these instruments. Additionally the payload included an *in situ* package with total temperature, pressure, and dew point sensors. Newer UAVs have superceded the Gnat 750.

The General Atomics Altus, capable of carrying a 150-kg payload to a 10 km altitude, was utilized in the fall 1996 and fall 1997 campaigns. Its payload

included the Gnat 750 instruments (with a frost point hygrometer instead of the dew point sensor) plus a Scanning Spectral Polarimeter (SSP), Cloud Detection Lidar (CDL), and a Multispectral Pushbroom Imaginge Radiometer (MPIR). A derivative of this aircraft, the Altus II was flown in the spring 1999 campaign. The Altus II has a reciprocating engine with a dual stage turbocharger which increases its service ceiling to 16 km. In that campaign, the Altus II additionally mounted a Solar Spectral Flux Radiometer (SSFR) although only two of the following three instruments could be flown simultaneously – CDL, MPIR, and SSFR. Neither Altus will be flown in this campaign.

A DHC-6 Twin Otter manned aircraft was flown during all previous campaigns as a chase plane for the various UAVs and as a low level instrumented platform in all but UDF, It was the only aircraft flown during the summer 1999 and spring 2000 campaigns. The Twin Otter instrument suite included four Valero radiometers covering various broad spectral bands for both upwelling and downwelling fluxes, two TDDRs for upwelling and downwelling spectral fluxes, and an *in situ* package with total temperature, total pressure, differential pressure, and dew point sensors. In the two 1996 campaigns and the fall 1997 one the Otter also carried a microwave radiometer to determine total cloud water and columnar water vapor. For the spring 1999 campaign in Hawaii a SSP, Millimeter Wave Cloud Radar (MMCR), and SSFR were added. During the summer 1999 campaign the Twin Otter carried the *in situ* package, SSP, SSFR, and MMCR, and was used to test a prototype Compact Millimeter Wave Radar (CMR). Since the focus of the spring 2000 campaign, also known as ARM Enhanced Shortwave Experiment II (ARESE II), was precision radiometry, the payload was modified to include not only the Valero radiometers but also Kipp and Zonen radiometers provided by the Japanese Meteorological Research Institute (CM-21s) and Sandia National Laboratories (CM-22s), as well as the standard *in situ* package, a DFC prototype, SSFR, and two SSPs. The Twin Otter will not be flown in this campaign.

A Grob Egrett manned aircraft, capable of carrying a 200-kg payload to greater than 16 km altitude, was flown in the fall 1995 and spring 1996 campaigns. Its instrument suite is the same as that mentioned for the Altus UAV without the SSFR. The Egrett will not be flown in this campaign.

The Proteus manned aircraft, to be used in this campaign, can carry a 800 kg payload to 17 km, and flies between Mach 0.3 and 0.6 which is faster than the UAVs previously utilized. This additional speed makes *in situ* sampling more difficult. Sandia National Laboratories has implemented a new payload that incorporates some of the instruments previously flown (CM-22, CMR, CDL, SSFR, DFC, and *in situ* package) and some additional ones (CG-4, CAPS, SRP, VIPS, CIN, Nevzorov probe, and S-HIS). The zenith pointing radiometers will be mounted on a new precision stabilized platform. The CMR, DFC, and *in situ* package have been significantly upgraded from the previously flown versions. All Proteus payload instruments are described in detail in the next chapter. All

data will be recorded on board and only sample data will be transmitted to the ground station during any flight; this allows over-the-horizon operation for the first time in ARM-UAV campaigns.

Document Structure

The bulk of this document describes Proteus instrumentation suite and the five experiments that have been proposed for the fall 2002 campaign. Since most of these experiments require specific meteorological conditions, the experiment suite actually flown during the campaign will be a subset of these, with the details of the subset depending on the conditions encountered during the course of the deployment. The appendices provide contact information, a glossary of acronyms, revision history for this document, and a list of references.

The ARM-UAV Proteus Instrument Suite

Part A – Science Instruments

Broadband Hemispheric Radiometers

Kipp and Zonen CM-22 pyranometers and CG-4 pyrgeometers modified by Sandia populate the broadband hemispheric radiometer suite. There are four CM-22s: (1) zenith looking mounted on the stabilized platform described below, (2) nadir viewing mounted to the payload pod deck, (3) nadir viewing mounted to the payload pod deck with an affixed dark cover, and (4) zenith looking mounted to the aircraft fuselage. There are three CG-4s: (1) zenith looking mounted on the stabilized platform, (2) nadir viewing mounted to the payload pod deck, and (3) nadir viewing mounted to the payload pod deck with an affixed dark cover. The four radiometers labeled (1) and (2) provide the primary measurement of downwelling and upwelling fluxes respectively. The two radiometers labeled (3) will be used to measure dark offsets in the extreme temperature conditions at the tropopause. Pyranometer (4) provides an unstabilized comparison measurement to pyranometer (1) on the stabilized platform.

The CM-22 pyranometer is a high precision hemispheric broadband shortwave flux radiometer. Its spectral range, as defined by its 50% transmission points, is 200 to 3600 nm. The excellent thermal path from the 4 mm quartz domes to the body and proprietary Kipp and Zonen compensation electronics result in a thermal stability better than $\pm 0.5\%$ between -20° C and 50° C, its normal ground based operating temperature range. Unfortunately, the temperature at the tropopause can range downward to -60° C requiring a temperature dependent calibration. All the CM-22s are mounted to allow a wash of external air around the dome and body to maintain thermal equilibrium between components and the atmosphere. The Sandia modification is the inclusion of a very low power, and hence low heating, electronics package within the aft pyranometer body that amplifies, digitizes, and serializes the measurement signal as well as that of three PRTs which measure the temperature of the fore-body, aft-body, and electronics module. Data logging is accomplished via standard computer serial port.

The CG-4 pyrgeometer is a precision hemispheric broadband longwave flux radiometer. Its spectral range, as defined by its 50% transmission points, is 4.5

to 40 μ m. The thermal path between the diamond coated aspheric silicon dome and the radiometer body is excellent resulting in minimal offset corrections when operated between -20° C and 50° C, its normal ground based operating temperature range. Unfortunately, the temperature at the tropopause can range downward to -60° C requiring additional calibration verification. As with the CM-22s, all the CG-4s are mounted to allow a wash of external air around the dome and body to maintain thermal equilibrium. The Sandia modification is similar to that of the CM-22s. Data logging for these is also accomplished via standard computer serial port.

Considerable effort has been applied to the calibration of the radiometer suite. The absolute calibration of the pyranometers has been through the comparison of each to the same absolute cavities used by the ARM program and using the same procedure as that program. The comparison was accomplished in May, 2002, at the National Renewable Energy Laboratory (NREL) facilities in Golden, Colorado, by Ibriham Reda and Tom Stoffel. The optical axis of each pyranometer was measured at Sandia using a rotary table scheme and the mounting fixtures adjusted with angle plates to insure perpendicularity, especially for the zenith mounted instruments. A temperature compensation for each pyranometer was also determined at Sandia by mounting the instruments in a cold chamber for illuminated and dark measurements. The absolute calibration of the pyrgeometers was by black body immersion, and was accomplished both at NASA Ames Research Center, Moffet Field, California, and at the above mentioned NREL facilities using ARM procedures. Both optical axis and low temperature measurements were also performed on the pyrgeometers.

Cloud, Aerosol, and Precipitation Spectrometer (CAPS)

The cloud, aerosol, and precipitation spectrometer (CAPS) is a relatively new airborne particle spectrometer developed by Droplet Measurement Technologies, Boulder, Colorado, that measures particles from 0.35 to 1550 μ m in diameter and liquid water content from 0.01 to 3 gm⁻³ (Baumgardner, et al., ????). Thus it has the same measurement capabilities as the combined grouping of five oft used instruments: (1) the PMS forward scattering spectrometer probe, model 100 (FSSP-100), (2) the PMS FSSP-300, (3) the two-dimensional optical imaging probe (2D-OAP), (4) the hot wire probe, and (5) the multiangle aerosol spectrometer probe (MASP). The first three of these measured size and concentration of atmospheric aerosol and cloud particles larger than 0.3 μ m, the next measured liquid water content, and the latter aerosol size and particle composition in the upper troposphere.

The CAPS consists of five sensors: the cloud and aerosol spectrometer (CAS: $0.35 - 50 \ \mu m$), the cloud imaging probe (CIP: $25 - 1550 \ \mu m$), the liquid water content detector (LWCD: $0.01 - 3 \ gm^{-3}$), and air speed sensor, and a temperature probe. The CAS measures forward ($4^{\circ} - 13^{\circ}$) and backward ($5^{\circ} - 13^{\circ}$)

14°) scattered light from single particles illuminated by a focused 45 mW 0.685 µm diode laser. Particle size is determined from the scattered light using Mie scattering theory and assuming spherical particles of known refractive index. A comparison of sizes predicted by forward scattering and backward scattering provides a check on the spherical assumption and calculational errors. The CIP measures particle images by capturing the shadow of particles that pass through a collimated laser beam from a diode laser similar to that mentioned above on a linear array of 64 photodiodes. The LWCD hot wire probe that measures LWC has an improved geometry and heating circuit to overcome some problems encountered by previous hot wire probes. Finally the CAPS has a Pitot tube and temperature sensor integrated into its case to measure air speed and temperature, two parameters needed to reduce data from the other components.

Past experience with this instrument in other field experiments has shown some problems with bringing a new CAPS instrument on line and with a new instrument's calibration. Therefore since the instrument flown in this campaign will be newly made, we will thoroughly review its operation during the precursor engineering flights.

Cloud Detection Lidar (CDL)

The Cloud Detection LIDAR, or CDL, was developed by Lawrence Livermore National Laboratory (LLNL) for the ARM-UAV program based on technology from the Clementine moon mapping mission for the profiling of aerosols, profiling of optically thin clouds, and determining cloud top or base height of optically thick clouds. It features a fully eye safe 58 μ J/pulse 5 kHz ND:YLF laser with a divergence of 53 μ rad, a wavelength of 1.053 μ m, and a pulse width of 20 ns. The receiver telescope has a 20 cm aperture and 75 μ rad field of view. The detector is a single-photon counting Geiger mode avalanche photodiode and is attached to multichannel scalar set for 100 m binning. The entire system is designed to be rotated in flight for either nadir or zenith viewing, but is constrained to viewing either straight to the nadir or at a 3° lateral offset from nadir. The CDL is contained inside the payload pod and senses through a heated window coated for maximum transmission at the laser wavelength. No special calibrations have been applied to the CDL for this campaign.

Cloud Integrating Nephelometer (CIN)

The Cloud Integrating Nephelometer (CIN) contains four photomultiplier modules that measure 635 nm laser light scattered by cloud particles (reference ???). One module measures forward scattered light (F), nominally between 10° and 90°; and a second module measures backscattered light (B), nominally between 90° and 175°. The third module measures forward scattered light $[\cos(F)]$ weighted by the cosine of the scattering angle, and the fourth module measures backscattered light $[\cos(B)]$ weighted by the cosine of the scattering angle.

Calibration of the CIN consists of a first laboratory part where the sensitivities of the four photomultiplier modules are equalized. All modules are exposed to the same amount of irradiance to generate scaling constants (C) given by

$$C_1 = F/F$$
$$C_2 = F/B$$
$$C_3 = F/cos(F)$$
$$C_4 = F/cos(B)$$

The second part of the laboratory calibration is to collocate the CIN with a Particulate Volume Monitor (PVM) in a cloud chamber, and to compare the output of the CIN with the PSA (total particle surface area) measured with the PVM. The PSA of the PVM has been calibrated previously against a standard in the Petten, The Netherlands, continuous-flow cloud chamber (see Gerber et al, 1994). The comparison of the CIN and PVM yields a scaling constant (C5) that makes the CIN measurements absolute with respect to the calibration at Petten. The equation for C5 is given by Gerber et al. (2000) as:

$$C_5 = [0.05 (1 - f) PSA(cm^2/m^3)]/[(F \times C_1) + (B \times C_2)]$$

where f approximately equals 0.52.

The field calibration of the CIN consists of placing a ND 2 attenuating filter across the laser beam, and placing a bar diffuser against the spacer that separates the split ellipsoidal wings. The field calibration is referenced against the laboratory calibration, and can thus be considered a secondary standard.

The outputs of the CIN are the asymmetry parameter (g) and the extinction (scattering) coefficient (E) measured in clouds for a wavelength of 635 nm. Their equations are given by:

$$E = C_5[(F \times C_1) + (B \times C_2)]/(1 - f)$$

$$g = f \{[(F \times C_1) + (B \times C_2)] + (1 - f)[(\cos(F) \times C_3) - (\cos(B) \times C_4)]\}/[(F \times C_1) + (B \times C_2)]$$

Experience with this instrument in other flight experiments indicates that it is not sensitive to cirrus with an optical depth less than 1 km⁻¹ — relatively thick for experiment 2 below.

Compact Millimeter Wave Radar (CMR)

The Compact Millimeter Wave Radar (CMR) is much-improved version of the device test flown in the ARM-UAV 1999 summer campaign in Monterey, California (also known as CAVEX). The performance and characteristics of the initial unit are documented in Bambha 1999, and are summarized here. The system utilized a solid-state W-band amplifier to produce a 100 nsec transmit pulse centered at 95.04 GHz with a peak power of 38 W providing Doppler velocity and radar reflectivity profiles with a range resolution of 15 m (1000 range gates) and a sensitivity of –20 dBZ at 1 km. The sensitivity was deemed inadequate and the ARM-UAV program funded the University of Massachusetts to produce the current upgraded version with a sensitivity of –42 dBZ at 1 km.

The 38 W solid-state pulsed transmitter has been replaced with a 1 W continuous-wave (CW) solid-state amplifier. A direct digital synthesizer (DDS) has been added to generate FM chirp transmit waveforms and a digital I&Q matched filter receiver/processor has been incorporated to allow the current unit to operate with different transmit chirp waveforms and bandwidths and to also provide real-time processing. An internal calibration loop measures lowlevel transmitter and receiver gain fluctuations. This loop couples a portion of the transmitted signal into the receiver providing a continuous measure of the transmitter power and receiver gain. The accuracy of this measurement depends on the ratio of the coupled power to the transmitter leakage power through the latching circulators. This ratio is greater than 40 dB which will result in a precision of better than 0.1 dB. Similar accuracy has previously been achieved in the ACR (Sadowy 1999). The transmitter uses four reasonably low cost 300 mW amplifiers in series to achieve the 1 W peak power. If one amplifier fails the radar will continue to operate, but its sensitivity will be reduced by 1.25 dB. This feature reduces deployment risk considerably.

The reduction in peak power from 38 W to 1 W in moving to the upgraded unit results in a loss of 15.8 dB in sensitivity. However, the use of a 40 μ sec 2 MHz chirp waveform increases sensitivity by 19 dB. The rest of the sensitivity gain is from the use of improved dual antennae (4 dB), the incorporation of advanced W band low noise amplifiers (3 dB), the reduction of range resolution to 75 m (10.5 dB), and the reduction of front-end loss (1.3 dB) — thus a net 22 dB gain.

The radar's processor and accelerator represent a considerable improvement over the original CMR. The 200 complex coefficients in the matched filter are programmable, allowing the radar to operate with varying chirp waveforms (different pulse lengths and bandwidths) to best match the observed scene and sensitivity requirements. The processor will perform pulse-pair averaging in real-time. This reduces the output data rate and provides Doppler velocity and reflectivity profiles via serial output in real-time for health and status verification during flight as well as permitting the storage of each profile to an internal solid-state disk for the data set of record.

Since this instrument is a new development, we will pay particular attention to its operation during the precursor engineering flights, and will endeavor to test it in those flights against several different cloud fields.

Diffuse Field Camera (DFC)

The Diffuse Field Camera (DFC) is actually a pair of nadir mounted moderate resolution calibrated digital cameras and associated hemispheric field-of-view lenses, one with a 620–670 nm pass band filter and the other with a 1580–1640 nm pass band filter. They have been developed by the Scripps Oceanographic Institute Marine Physics Laboratory (MPL) specifically for the ARM-UAV program. The pass bands were chosen to allow comparison of DFC data with that taken by the imager aboard the GOES series satellites used for cloud cover retrievals. DFC data is also useful in mapping the uniformity of the observed radiance field over a cloud deck and for recording the cloud situation to aid in the interpretation of data from other instruments.

The visible half of the camera pair is based on a DVC Company model 1312M camera. This camera has a 1300×1030 pixel CCD detector array that is cooled by a TEC to 45° C below ambient to insure low noise figures. An antireflectance coated Coastal Optical Systems lens with 183° field-of-view is used with this camera yielding ~7 µsteradian angular resolution. The data will be summed on a four pixel basis to ~30 µsteradian resolution to reduce file size. The near infrared half of the pair is based on a Indigo Company Alpha camera with a 320×256 pixel InGaAs detector array that is cooled via TEC to a stabilized 0°C. The same lens is used with this camera as with the visible one, except the lens is not coated. The near infrared angular resolution is ~150 µsteradians. Both cameras have 12 bit signal resolution, electronic shutters, and variable gains. They view the nadir scene from the payload pod through heated glass domes that protect the lens from the cold conditions at altitude and condensation during descent.

The DFC cameras have been carefully calibrated by MPL, and will be checked for calibration drift after the flight campaign is concluded. The calibration includes the following features: (1) absolute, the comparison of nadir signal to NIST standard lamp radiance, (2) roll off, the change in signal for constant radiance as a function of nadir angle, (3) flat field, pixel to pixel variance in gain, (4) linearity, gain linearity with signal level and setting, (5) exposure, the conformance of exposure time to setting, (6) temperature, the change in gain with detector temperature, and (7) angular, nadir and azimuth viewing angle relative to the camera mounting plane as a function of pixel position.

An unfiltered prototype DFC was flown on the spring 2000 campaign. The data produced during that campaign were roughly calibrated by comparison to broadband hemispheric radiometric data. This DFC is a much improved system.

In Situ State Parameters

The Proteus payload will measure in situ total pressure, static pressure, static temperature, total temperature, dew point, and frost point using a BF Goodrich Model 2014M Micro Air Data Transducer with Model 0101F Total Air Temperature Probe, General Eastern Model 1011B Dew Point Hygrometer, and a Buck Research CR-2 Cryogenic Hygrometer. The dew point and frost point temperatures will be compared to verify instrument accuracy in their sensing region overlap.

The air transducer is designed for use in high performance military and flight test aircraft requiring precise measurement of total pressure, static pressure, static temperature, and total temperature. It reports the following derived data in the ranges indicated: static pressure (1 to 38 in Hg), pressure altitude (– 2000 to 75000 ft), climb rate (–30000 to 30000 ft/min), total air temperature (–99° C to 250° C), static air temperature (–99° C to 60° C), Mach number (0.1 to 2.0), total pressure (1 to 80 in Hg), differential pressure (0.12 to 65 in Hg), indicated air speed (50 to 950 kts), and total air speed (70 to 1310 kts). Of course, these ranges far outstrip the performance of the Proteus which has a cruise speed of 160 kts indicated.

The General Eastern hygrometer is a chilled mirror instrument, cooled by a thermoelectric cooler. This hygrometer can measure dew points down to -25° C. The hygrometer samples outside air onto to chilled mirror, controlled to maintain a certain amount of dew on it, by an optical sensor and electronic circuitry. One can calculate relative humidity from this dew point temperature, pressure, and static temperature.

The Buck Research hygrometer is also a chilled mirror instrument, cooled by a Sterling cycle cryocooler. It has a very fast response time of 10 to 20 seconds and can operate to 25 km altitude and -40° C air temperature. Buck Research claims sensitivity to 5 ppbv at sea level, and a dew / frost point measurement range of -105° to $+30^{\circ}$ C. The readings may be converted other humidity and moisture units in a straightforward manner, as with the General Eastern hygrometer.

Nevzorov Probe

The Nevzorov liquid water content (LWC) and total water content (TWC) probe is described in Korolev (1998). It is a constant-temperature, hot-wire probe

designed for aircraft measurements of the ice and liquid water content of clouds. The probe consists of two separate sensors for measurements of cloud liquid and total (ice plus liquid) water content. Each sensor consists of a collector and a reference winding. The reference sensors are shielded from impact with cloud particles, specifically to provide an automatic compensation for convective heat losses. Intercomparison of Nevzorov LWC, TWC, a King LWC prove, and two PMS forward scattering spectrometer probes show good agreement in liquid clouds, although the Nevzorov probe displays distinct advantages in low-LWC situations due to a more stable baseline. The sensitivity of the probe is estimated to be approximately 0.003-0.005 g m⁻³. The accuracy of LWC measurements in non-precipitating liquid clouds is estimated as 10%-15%. Tests at a high-speed icing tunnel have provided verification of the TSC measurement for small frozen droplets to an accuracy of approximately 10%–20%, but verification in snow and natural ice crystals has not yet been possible due to the absence of any accurate standards. The TWC measurement offers not only the possibility of direct measurements of ice content but also improved liquid water contents in drizzle situations.

Experience with this instrument in other flight experiments indicates that it is not sensitive to cirrus with density less than 1 mg/m^3 — relatively thick for experiment 2 below.

Scanning High-Resolution Interferometer Sounder (S-HIS)

The Scanning High-Resolution Interferometer Sounder (S-HIS) is a scanning interferometer that measures emitted thermal radiation at high spectral resolution (0.5 cm^{-1}) between 3.3 and 18.0 µm. It is an advanced version of the HIS ER-2 instrument (Smith et. Al. 1987/89, Revercomb et al. 1988) developed between 1996 and 1998 with the combined support of the US DOE, NASA, and the MPOESS Integrated Program Office at the Space Science and Engineering Center (SSEC) at the University of Wisconsin. It has flown in eight field campaigns beginning in 1998 and has proven to be very dependable and effective. The measured emitted radiance is used to obtain temperature and water vapor profiles of the Earth's atmosphere. Also algorithms are currently being developed to retrieve remotely sensed sea surface skin temperature, land surface temperature and emissivity, cloud top temperature and emissivity, and trace gas total column amounts.

The spectral coverage is divided into three bands with separate detectors (two photoconductive HgCdTe and one InSb) to achieve the required noise performance. The bands use a common field stop to ensure accurate spatial co-alignment. The longwave band provides the primary information for temperature sounding for cloud phase and particle size. The midwave band provides the primary water vapor sounding information and further cloud property reflectance and augments sounding information. The shortwave band ???.

The optical design is very efficient, providing useful signal-to-noise performance from a single 0.5 second dwell time. This allows imaging to be accomplished by cross-track scanning. Onboard reference blackbodies are viewed as part of each cross-track scan providing updated calibration information every 20-30 seconds. The cross-track imaging resolution is \sim 1.5 km (at nadir) across a 32 km ground swath from a nominal altitude of 16 km. The instrument may also be operated in staring only mode with overlapping fields of view. As mounted on the Proteus the S-HIS views either toward the zenith or nadir.

Solar Spectral Flux Radiometer (SSFR)

The Solar Spectral Flux Radiometer (SSFR), a NASA Ames instrument, SSFR is used to measure solar spectral irradiance at moderate resolution to determine the radiative effect of clouds, aerosols, and gases on climate, and also to infer the physical properties of aerosols and clouds. The version flown in this campaign represents an upgrade from early 2000. It was designed primarily for airborne platforms and has no moving parts.

The SSFR spectral range is 300 nm to 1700 nm with 8–12 nm resolution. It has zenith and nadir viewing hemispherical field-of-view light collectors. The zenith collector has a cosine response diffuser and the nadir an integrating sphere. The signal is transmitted by high-grade optical fibers to the rack-mounted instrument system. The heart of the instrument is the monolithic diode array spectrometer-pair (visible and near-infrared) employed for each viewing direction (zenith and nadir). Light at the entrance slit is dispersed by a concave imaging grating onto a diode array (Si or InGaAs) producing a complete spectrum within a fraction of a second. The output is collected at a 1 Hz sampling rate and then processed by dedicated electronics. The data acquisition and control system is a 266 MHz Pentium-class embedded controller in a PC104 format. Data are recorded on a compact 220 MB PCMCIA flash memory card. The visible spectrometer is temperature regulated by a heater control circuit while the InGaAs detector array is cooled by a thermo-electric cooler for optimum performance.

Spectral Radiance Package (SRP)

The Spectral Radiance Package (SRP) contains three separate miniature spectrometers, separate optical heads and an autonomous data acquisition system. The two visible spectrometers, with spectral bands of 400–1050 nm and 710–800 nm, use a 2048 element cooled CCD linear array, the infrared spectrometer, with a spectral band of 1300–1500 nm, uses a cooled 512 element InGaS linear array. The field-of-view will be limited to one degree and will be nadir viewing. The data rate can vary from DC to 10 spectra per

second and time stamps will be applied at the beginning of the scan with millisecond resolution. The spectrometers are calibrated with an integrating sphere and by comparison to other high-resolution spectrometers.

Data from the new spectrometers will be used in combination with data from other sensors of the Proteus payload to obtain key cloud physical and radiative properties. Specifically,

Spectrally resolved reflectances in the 400–1050 nm region will be studied to examine and check models that include the weak gaseous features that occur in this spectral region. These data will also be used to derive the cloud optical depth.

Spectrally resolved reflectances in the 1300–1500 nm region will be used to study the scattering processes in the presence of strong water vapor absorption. This spectral region overlies the region of the 1.38 um channel of MODIS. We propose to determine other cloud properties in this region, including particle sizes as well as the in-cloud water vapor path.

Spectrally resolved reflectances in the 710–800 nm region at high resolution will be used to derive entirely new properties of cirrus, including photon path statistics, and will be used to cross check optical properties derived from the other channels. The effects of 3D transport on optical depth retrievals can also be quantitatively assessed using the photon path information. Careful analyses of these spectral data will be required to assess overall calibration. This will include signal calibration outside the absorption bands as well as the spectral registration of lines and line depths to determine the spectral properties of the instrument.

Video Ice Particle Sampler (VIPS)

The Video Ice Particle Sampler (VIPS) uses a standard technology video camera to capture images of ice cloud crystals that have been captured on a continuously moving oiled tape. The video camera images an area that is approximately 3 mm by 3 mm. This area differs from the size of the VIPS aperture, with dimensions 7 mm wide by 4 mm high. The VIPS sampling volume is given by the product of imaged area and the distance the aircraft flies during the time the imaging surface moves a distance equal to the imaged width. At an aircraft true airspeed of 100 m/sec, the sample volume is about 3 l/sec in the VIPS' current configuration. The collection efficiency of the VIPS is close to unity for particles above 10 μ m in size and hence a collection efficiency of unity is assumed.

The VIPS has an exact size and sample volume calibration indicator in every image. One sprocket hole on the moving tape, which is the standard size for a 16 mm movie camera, appears in every second or third image and each hole has the same dimensions. We therefore have an exact calibration of the size and rate of movement of the imaging surface for virtually all collection periods.

Following data collection, the images are digitized. On the Proteus aircraft, each image (at a rate of 2 Hz) will be digitized and put in a jpeg format. We will use the National Institute of Health software package "Image" to size, count, and determine the shapes of particles during key periods of in-cloud sampling by the Proteus aircraft.

Part B – Supporting Instruments and Systems

Proteus Aircraft

The Proteus piloted aircraft was designed and built by Scaled Composites, Inc., and is currently also operated by them. It is a twin turbofan high altitude platform with a crew of two and a seat for one additional person. It has a

wingspan of 78 ft, gross weight of 12,500 lb, fuel capacity of 5500 lb, can carry a 6900 lb podded payload, and supply 20 kW payload power. With the ARM-UAV payload pod, the Proteus has a service ceiling in excess of 50 kft and endurance in excess of 20 hrs. The maximum mission indicated air speed is 160 kts or Mach 0.6 true air speed yielding a potential mission radius or 3000 nm.



C-Migit II GPS/INS

The C-MIGITS II is an integrated Global

Positioning System / Inertial Navigation System (GPS/INS) composed of two basic elements: the Digital Quartz Inertial Measurement Unit (DQI IMU) and the MicroTracker LP GPS receiver. The DQI provides angular rate and linear acceleration information at a 600 Hz rate, and delta-velocity and delta-theta information about three axes at a 100 Hz rate. The MicroTracker LP GPS receiver has a five parallel channel L1 only Coarse / Acquision (C/A) code GPS engine which can track up to nine satellites.

In normal operation, a three-dimensional navigation solution (including attitude and heading) is computed based on integrated inertial data. This

inertial solution is corrected using a Kalman filter, which processes GPS range and range rate measurements at a 1 Hz rate. This results in a robust navigation solution that reduces inertial sensor errors. This solution remains accurate during periods of GPS signal loss due to satellite obscuration or high dynamics.

The C-MIGITS II unit is attached to the main deck of the Proteus payload pod, and thus shares the mount to which all nadir sensing instruments are anchored. Its accuracy re the zenith viewing instruments atop the aircraft depends on airframe and pod mount flexure.

Data System

A unique system has been developed to control and provide data support for the various instruments. All instruments have an associated PC-104 format computer that collects the instruments data and provides control signals as needed. Each instrument computer is connected to an IRIG time bus for synchronized time stamping of data, and to an internal network. An air gateway system (AGS) serves as a traffic cop on this network by distributing commands received from the mission controller via an Iridium satellite link to the various instrument computers and collecting from them messages and health and status data files for transmission to the mission controller. A payload power system provides separate switchable power feeds to each instrument, and measures the current draw on each circuit for instrument operation diagnostic purposes.

Stabilized Platform

A ruggedized highly stable gimbaled platform to mount the three zenith viewing hemispheric radiometers is attached to the top of the Proteus fuselage. The radiometers are a CM-22, a CG-4, and the zenith head of the SSFR, The platform was designed and built for the ARM-UAV program by the Sonoma Design Group; this campaign is its maiden flight series. The gimbaled mounting plate is stable within $\pm 0.04^{\circ}$ of the axis between the aircraft and the center of the Earth and normally is maintained within $\pm 0.02^{\circ}$, as long as the aircraft pitch and roll angles do not exceed $\pm 5.0^{\circ}$. This stability is achieved by actively moving the plate to compensate for aircraft motion as detected by an integrated inertial navigation system (INS) with a associated high resolution global positioning system (GPS) receiver.

The necessity of correcting downwelling irradiance for sun angle shifts caused by nonzero aircraft attitude is eliminated by mounting the radiometers on such a stable platform. Since these corrections involve several complex calculations and sky uniformity assumptions, their elimination will considerably improve the quality of the archived calibrated irradiance data. Additionally, the platform makes it possible to measure downwelling radiance under nonuniform layers and through non-optically thick clouds — measurements that are impossible otherwise without a full radiance map of the sky.

Experiment 1 — Mid-Latitude Cirrus Optical, Radiative, and Microphysical Properties

Part A – Science Issues

Science Objective

The objectives of this experiment are:

(a) To measure cirrus cloud microphysical (ice water paths, particle size) and optical properties (optical depth, effective radius) and subsequently link them to the bulk radiative properties (albedo and emittance), and

(b) To evaluate the remote sensing methods for obtaining cloud properties (such as ice water content and path, bulk particle size, number concentrations).

The comparisons between microphysical properties and optical plus bulk radiative properties serve as a basis for (i) evaluating the parameterization of cloud optical properties in terms of cloud physical properties, and (ii) evaluating the parameterization of radiative transport through cirrus clouds. The desired objective b is to compare both airborne methods and methods developed to analyze surface CART data with the in situ observations to ascertain their accuracy.

Advocate

The champions for this experiment are Graeme Stephens and Jay Mace.

Measurement Strategy

In this experiment, the Proteus aircraft will be primarily used as an above cloud remote sensing tool, although occasional in situ sampling forays into the cloud deck may be performed as well as remote sensing from below the cloud deck. The instrument compliment on the Proteus will closely match the capabilities of the Aqua train of satellites consisting of the MODIS instrument on Aqua, the cloud profiling radar (CPR) on CloudSat, and the lidar on Calipso. In this experiment we will also often utilize a second aircraft for in situ measurements, the SPEC Learjet operated by Paul Lawson. With the second aircraft flown in situ and the Proteus above the layer, the remote sensing measurements from the radar, lidar, and NFOV down looking radiometry along the flight track combined with collocated in situ observations will greatly improve our understanding of 1) the cirrus layer structure in general, and 2) our ability to retrieve the microphysical structure of the layer. Furthermore, concentration of the aircraft near the SGP central facility will allow us to use the validated Proteus remote sensing retrievals to compare various algorithm results with those derived from the ground based remote sensors.

Cloud fields selected for this experiment should include some with optical depth less than 1 km⁻¹. Flight tracks for this experiment should be flown primarily along the wind vector, either racetracks or legs with lengths on the order of 100 km with the Proteus remaining primarily above the cirrus layer top at a single altitude. The Learjet will conduct stepped legs collocated with the Proteus track. Due to the airspeed differences between the Proteus and Learjet, the Learjet should extend its legs far enough up wind and down wind so that the two aircraft are crossing the SGP central facility at approximately the same times. The Learjet should also begin either near cloud top or at cloud base and then profile the layer stepping up or down in vertical increments so that the layer is profiled during the course of the Learjet flight. When the Proteus is flown without the Learjet it will alternate between above and within cloud flight legs.

Required and Supporting Measurements

Proteus

The Proteus will be used primarily for measurements made from above and occasionally below the targeted cloud field. When flown in the context of this experiment it will also be flown within the cloud field. These measurements include (a) cloud optical properties, e.g., extinction, asymmetry parameter, and optical depth effective radius, based on the SRP and SSFR instruments, (b) radiation, e.g., spectral and broadband solar and IR fluxes, based on the CM-22, CG-4, and SSFR instruments, and (c) remote sensing, e.g., radar reflectivities, lidar backscatter, and solar and IR spectral radiances, based on the CMR, CDL, S-HIS, DFCs SRP, and SSFR instruments.

When the Proteus is flown through the target cloud, it will additionally measure cloud physical parameters, specifically ice water content and cloud particle size and habit using the CAPS, VIPS, CIN, and Nevzorov probes.

Learjet

The Learjet will measure cloud physical parameters, specifically water content and cloud particle size and habit, as well as atmospheric state parameters, such as temperature and dew point. Specific instruments are detailed in the instrument list below; since these are not discussed elsewhere in this document the list includes supporting instrumentation as well, e.g., aircraft attitude. The Learjet 25 has a service ceiling of 45 kft in an aerodynamically clean configuration. The ceiling with attached probes as flown in this experiment will be somewhat less, and will constrain the choice of target cirrus fields.

Satellite

Supporting, but not required, data products from MODIS (Moderate Resolution Imaging Spectroradiometer) aboard Terra and Aqua, AIRS (Atmospheric Infrared Sounder) aboard Aqua, and MISR () aboard Terra will be used to supplement aircraft data. Relevant products from MODIS include cloud particle phase, effective cloud particle radius, cloud optical thickness, cloud-top temperature, cloud-top height, cloud-top effective emissivity, and cloud-top phase. Relevant products from AIRS include water vapor mass mixing ratio, water vapor saturation mass mixing ratio, total water, total cloud water, cloudtop temperature, and cloud-top pressure. Relevant products from MISR include cloud heights and winds, top-of-atmosphere albedos and bidirectional reflectance factors.

Data Analysis Strategy

During the course of the campaign, Jay Mace will perform day to day comparison and review of the collected data for consistency and quality.

(Jay Mace description of post flight strategy.)

Relation to Other Experiments

This experiment is independent of all others.

Part B – Experiment Details

Flight Strategy

The Proteus will fly in a linear pattern aligned with the wind vector at cirrus altitude. Ideally, the pattern would have 100 km legs, although these may need to be shortened if the cloud field is of lesser extent; ideally, the pattern would center over the SGP CF (central facility), although this may need to be moved if the cloud field location is shifted. If the only cirrus in the region drift away from the SGP CF, then the pattern may drift as well. If the only cirrus in the region are well away from the SGP CF, then the entire experiment may be flown where the cirrus is located. There is, however, a strong preference for performing this experiment near the SGP CF.

The Proteus will fly at 160 knots indicated air speed approximately 500 meters above cloud top, for maximum radar performance. A higher separation is permissible if air space controls necessitate such. When the Learjet is not flown, the Proteus will fly every other leg within the cloud field at an altitude near the cloud center of mass. Other in-clouds altitudes may be flown as well at the discretion of the mission scientist. On occasion the Proteus may be flown 500 m or more below the cloud field to measure downwelling radiation through the clouds.

The Learjet, when flown, will profile the cloud field below the Proteus. Since the Learjet speed is greater than the Proteus, the leg length of its track must be adjusted so that the planes are horizontally collocated near the center of the Proteus track. The Learjet will profile the cirrus cloud deck in 300 meters increments, starting 1 km below the cloud top; the increment may be increased to 1000 meters for an exceptionally thick cirrus deck. An alternative Lagrangian profiling strategy that can be invoked at the discretion of the mission scientist is to drift downward in altitude at the fall rate of the cloud ice crystals.

At least once during the campaign the Proteus and Learjet should be flown through the same cloud mass to intercompare their in situ instruments.

Constraints

This experiment as written will utilize considerable air space, both horizontally and vertically. Since commercial aviation makes considerable usage of the airspace in the region, the flight tracks and altitude may need to be adjusted to stay within FAA preferences. The CDL and CMR are critical instruments for the experiment and must be operational for each flight. The Proteus mounted Nevzorov probe, VIPS, CPAS, and CIN are of low importance when the Learjet is flying.

Jay Mace, Jennifer Comstock, or Roger Marchand will be available during the campaign to provide direction on Learjet operations. Jay Mace will handle all Learjet coordination prior to the campaign.

Special Needs

It is highly desired, but not mandatory, to be sensing and sampling the targeted cirrus field during the over crossing of the Terra and Aqua satellites. Terra has a descending crossing of the equator at 1030 hours local standard time; Aqua an ascending crossing at 1330 hours. Given the 99 minute orbital period of these satellites, the over crossing at the SGP CF has an approximate offset of 10 minutes. It is further desirable to have the ARM-UAV aircraft flying at the nadir points during the over crossings, although this may prove challenging as it presupposes cirrus at those points.

Instrument and Data List

Proteus

Instrument 1: CDL — 100 meter range bins with intensity of reflected 1.053 μ m laser light plus one background bin; range bins provide information on the location and density of aerosols and clouds; background bin for data correction

<u>Instrument 2:</u> CMR — 1 W chirped CW 95 GHz cloud radar; –42 dBZ at 1 km; Doppler velocity and radar reflectivity profiles with a rang resolution of 15 m (1000 range gates)

<u>Instrument 3:</u> S-HIS — zenith or nadir viewing; spectral range $3.3-18.0 \ \mu m$ with 0.5 cm⁻¹ resolution; cross track scanning resolution is ~1.5 km (at nadir) across a 32 km ground swath from a nominal altitude of 16 km

<u>Instrument 4</u>: DFCs — two hemispheric nadir viewing cameras; pass bands of 620–670 nm and 1580–1640 nm with resolutions of 1300×1030 and 320×256 pixels respectively

Instrument 5: SRP — three 1° field-of-view nadir spectrometers; 400–1050 nm, 710–800 nm, and 1300–1500 nm; up to 10 spectra per second

<u>Instrument 6:</u> SSFR — zenith and nadir hemispherical field-of-view; 300–1700 nm with 8–12 nm resolution; 1 Hz sampling rate

<u>Instrument 7:</u> CM-22s — hemispheric broadband shortwave 200–3600 nm flux radiometers; two nadir and two zenith viewing; one zenith is stabilized against aircraft motion; one nadir is covered

<u>Instrument 8:</u> CG-4s — hemispheric broadband longwave $4.5-40 \mu m$ flux radiometers; two nadir and one zenith viewing; zenith is stabilized against aircraft motion; one nadir is covered

<u>Instrument 9:</u> Nevzorov probe — ice and liquid water content measured by constant-temperature, hot-wire probe

Instrument <u>10</u>: VIPS — video camera image capture of ice cloud crystals captured on an oiled tape; collection efficiency near unity for particles above 10 μ m

Instrument 11: CAPS — $0.35-50 \ \mu m$ cloud and aerosol spectrometer, 25–1550 μm cloud imaging probe, 0.01–3 gm⁻³ liquid water content, air speed, and temperature

<u>Instrument 12:</u> CIN — four measurements of cloud particle scattered 635 nm light: 10° – 90° forward scattered; 90° – 175° backscattered, cosine weighted forward scattered, cosine weighted backscattered

Learjet

Instrument 1: Rosemount Model 102 and 510BH Amplifier — temperature

<u>Instrument 2:</u> Buck Research Cryogenic Model CR-1A Dew Point Hygrometer — dew point temperature

Instrument 3: Rosemount 1201 — altitude

Instrument 4: Rosemount 1221 — airspeed

Instrument 5: PMS-CSIRO KLWS-100 — cloud liquid water

Instrument 6: Cloud Tech Nevzorov LWC Probe — cloud liquid water

Instrument 7: Cloud Tech Nevzorov Twc Probe — cloud total water

Instrument 8: Garmen Model GPS-92 — aircraft position

Instrument 9: Learjet Sperry Directional Gyro — aircraft heading

Instrument 10: PMS Model OAP-2D-C — 2D-C optical array spectrometer; 32 photodiode array with 33 μ m resolution

Instrument 11: SPEC Model 2D-S — 2D-S optical array spectrometer; dual 128 photodiode arrays with 10 μ m resolution

Instrument 12: PMS Model FSSP-100 — forward scattering spectrometer

Instrument 13: SPEC Model 230-x — cloud particle imager

Instrument 14: SPEC (0.4 to 2.3 µm) — cloud extinctioneter

Ground

<u>Instrument 1: radiosonde</u> — balloon borne instrument measuring temperature, pressure, water vapor, and winds from its surface launch point into the stratosphere

<u>Instrument 2:</u> Raman lidar — 355 nm laser system providing profiles of water vapor, aerosols, and optically thin clouds with 40 meter resolution; maximum altitude for water vapor is 4 km daytime and 10 km night time; maximum altitude for aerosols and clouds is 15 km

<u>Instrument 3:</u> MPL — several cloud-related parameters including cloud height, extinction coefficient, cloud layers, and time/date reference information

<u>Instrument 4:</u> SIRS — downwelling shortwave $(0.3-3.0 \ \mu\text{m})$: direct normal 5.7° field of view, diffuse hemispheric, and total hemispheric; downwelling longwave $(4.0-50 \ \mu\text{m})$: total hemispheric; upwelling shortwave $(0.3-3.0 \ \mu\text{m})$: total hemispheric; upwelling longwave $(4.0-50 \ \mu\text{m})$: total hemispheric

<u>Instrument 5:</u> AERI — two data for wave numbers between 520 and 1800 cm⁻¹: mean infrared radiance spectral ensemble and the standard deviation for that ensemble; three data for the six bands of 675-680, 700-705, 985-990, 2295-2300, 2282-2287, 2510-2515 cm⁻¹: mean radiance, standard deviation of that radiance, and brightness temperature

Instrument 6: MMCR — 35 GHz cloud radar for for profiling cloud particle size and density up to 20 km

Satellite — Aqua

<u>Instrument 1:</u> MODIS — 36 spectral bands (21 within 0.4–3.0 μ m and 15 within 3.0–14.5 μ m); cross track swath 2300 km; cross track resolution 250 m to 1000 m depending on band

<u>Instrument 2:</u> AIRS — upwelling radiation at 0.4–1.0 μ m and 3.7–15.4 μ m; cross track swath 1650 km; cross track resolution 13.5 km at nadir; 1°K accuracy per 1 km atmospheric layer; 0.05 emissivity accuracy

Satellite — Terra

<u>Instrument 1:</u> MODIS — 36 spectral bands (21 within 0.4–3.0 μ m and 15 within 3.0–14.5 μ m); cross track swath 2300 km; cross track resolution 250 m to 1000 m depending on band

<u>Instrument 1:</u> MISR — 4 spectral bands centered at 446, 558, 672, and 867 nm; cross track swath 360 km; cross track resolution ~275 m; 9 viewing angles at 0° , $\pm 26.1^{\circ}$, $\pm 45.6^{\circ}$, $\pm 60.0^{\circ}$, $\pm 70.5^{\circ}$ along orbit track

Experiment 2 — Cirrus Microphysical Properties: Retrieved versus In Situ

Part A – Science Issues

Science Objective

The objective is to characterize the structure of cirrus layer tops using a combination of in situ and remote observational techniques.

Many cloud layers exhibit layer boundaries that are clearly identifiable with either millimeter cloud radar (MMCR) or lidar. Using lidar, identification of even the most tenuous hydrometeor layers is often unambiguous. In most cases, the last range resolution volume containing significant non-molecular signal can be considered the hydrometeor layer top. Often, however, with the low-power micro pulse lidar (MPL) at the ARM CART sites, the laser signal attenuates even in moderately thick ice clouds. The MMCR, on the other hand, is not sensitive to molecular backscatter, and in cases where the laser is completely attenuated, the layer top must be identified by examining only the radar signal returned from hydrometeors. Identification of layer top using only the signal return from hydrometeors is complicated by the typical vertical structure of cirrus. Cirrus layers often exhibit a gradual decrease in particle size and radar reflectivity toward the layer top. In these situations, the radar reflectivity often decreases below the detection threshold of the radar at ranges below the actual hydrometeor layer top. Especially when the MPL attenuates completely or is not available, it is impossible to ascertain whether the layer top reported by the MMCR coincides with the actual layer top. More importantly, since we have no extensive measurements of cirrus layer top in conjunction with remote sensing and in situ observations, it is impossible to place uncertainty bounds on the layer top estimation of cirrus or on how much this error biases our estimate of such parameters as the OLR and albedo.

Advocate

Jay Mace is the advocate for this experiment.

Measurement Strategy

The Proteus will conduct missions near and above the layer tops. The payload's active remote sensors (radar and lidar) are key instruments since they will compliment the ground-based measurements that may or may not be sensitive enough to sense the layer tops. The in situ probes will measure the particle size distribution of the layer top region and its optical path. The experiment will be flown in close proximity to the ARM CART site so that coincident measurements with the ground based remote sensors can be made. However, since the Proteus will carry a compliment of active remote sensors, the flight pattern can be flexible. Optimally the legs will be flown along the wind centered on the SGP central facility. Following an above-cloud leg, the Proteus will conduct legs incrementally descending into the upper portion of the layer to characterize the thermodynamic and microphysical properties. Each leg should step roughly 250 meters further into the layer until the radar reflectivity of the layer is fully within the detection threshold of the MMCR. Since the characteristics of the layer top region will likely be a function of meteorological parameters, this experiment will need to be conducted in at least 3 separate cirrus systems during the deployment.

Required and Supporting Measurements

Proteus

The CMR and CDL will measure the radar optical reflectivity of the cirrus cloud top layer. The microphysical probes VIPS, CIN, and CAPS will be used to characterize the particle size distribution of the layers top region. The Nevzorov probe will supplement these measurements, to the extent the lower limit of its detection range. The CIN will allow us to ascertain the optical path of the tenuous layer top, to the extent of its detection range. The Scanning HIS will determine water vapor above the aircraft altitude and the frost point hygrometer CR-2 will be used to determine water vapor at sample altitude.

Learjet

The Learjet will optionally measure cloud physical parameters, specifically water content and cloud particle size and habit, as well as atmospheric state parameters, such as temperature and dew point. Specific instruments are detailed in the instrument list below; this list does not include supporting instrumentation that is listed in Experiment 1, e.g., in situ static pressure for aircraft attitude. The Learjet 25 has a service ceiling of 45 kft in an aerodynamically clean configuration. The ceiling with attached probes as

flown in this experiment will be somewhat less, and will constrain the choice of target cirrus fields.

Ground

The active SGP CF cloud remote sensing instruments will provide essential data for this experiment; these include the two LIDARS (CARL and MPL) and the millimeter wave radar (MMCR). Because of signal level limitations, the best CARL data will be collected during hours of darkness. Additionally the AERI and radiosondes, as well as CARL, will provide supporting water vapor profile retrievals.

Data Analysis Strategy

This experiment will produce five and possibly seven data sets that predict cloud top height — (1) ground based measurements from CARL, MPL, and MMCR, (2) ground based relative humidity profiles from radiosondes and, during hours of darkness, CARL, (3) Proteus based remote sensing measurements from CDL and CMR, (4) Proteus based relative humidity profiles from the CR–2 and S–HIS, (5) Proteus based in situ cloud measurements from VIPS, CAPS, CIN, and potentially the Nevzorov probe, (6) Learjet based relative humidity profiles from the CR–1A, (7) Learjet based in situ cloud measurements from the Nevzorov TWC probe, PMS Model OAP-2D-C, SPEC Model 2D-S, PMS Model FSSP-100, SPEC Model 230-X, and SPEC cloud extinctiometer. The various cloud top height retrievals will be compared, along with their known sensitivity and errors to determine their utility and reliability.

Relation to Other Experiments

Both this experiment and experiment 1 are concerned with cirrus clouds, but are independent because of differing flight path considerations. This experiment is also independent of all others.

Part B – Experiment Details

Flight Strategy

The Proteus will fly in a linear pattern aligned with the wind vector at cirrus altitude. Ideally, the pattern would have 10 minute legs and be centered over

the SGP CF. The turns at the end of each leg should be as tight as reasonably achievable.

The Proteus will fly at 160 knots indicated air speed approximately 1000 meters above the highest estimate of cloud top, for maximum radar performance. A higher separation is permissible if air space controls necessitate such. When the Learjet is not flown either because of unavailability or because the cirrus cloud top is above the Learjet service ceiling, the Proteus will fly profiles through the cloud mass after two complete legs above; the profiles legs will each be at constant altitudes with 180 m (two 90 m MMCR range bins) between altitude steps and one leg per step. The profiling will continue until well below the lowest estimate of cloud top. The entire pattern will be repeated at the discretion of the mission scientist until the cirrus clouds drift from the CF.

The Learjet, when flown, will profile the cloud field below the Proteus. Since the Learjet speed is greater than the Proteus, the leg length of its track must be adjusted so that the planes are horizontally collocated near the SGP CF. The Learjet will profile the cirrus cloud deck in 180 m increments, starting at the highest estimate of cloud top and continuing until well below the lowest estimate of cloud top. As in the case above, the entire pattern will be repeated at the discretion of the mission scientist until the cirrus clouds drift from the CF.

It is desired that this experiment be repeated three times during the course of the campaign — twice during hours of daylight and once during hours of darkness. The latter sortie will be flown as a Proteus only case.

Constraints

This experiment as written will not utilize as much air space as Experiment 1, but still consideration must be given to commercial aviation usage of the airspace in the region. The flight tracks and altitudes may need to be adjusted to stay within FAA preferences.

The CDL, CMR, S–HIS, and VIPS are critical instruments for the experiment and must be operational for each flight.

Special Needs

One sortie for this experiment must be flown during hours of darkness to maximize the utility of CARL data.

Instrument and Data List

Proteus

<u>Instrument 1:</u> CDL — priority 1; 100 meter range bins with intensity of reflected 1.053 μ m laser light plus one background bin; range bins provide information on the location and density of aerosols and clouds; background bin for data correction

<u>Instrument 2:</u> CMR — priority 1; 1 W chirped CW 95 GHz cloud radar; – 42 dBZ at 1 km; Doppler velocity and radar reflectivity profiles with a rang resolution of 15 m (1000 range gates)

<u>Instrument 3:</u> VIPS — priority 1; video camera image capture of ice cloud crystals captured on an oiled tape; collection efficiency near unity for particles above 10 μ m

<u>Instrument 4:</u> S-HIS — priority 1; zenith or nadir viewing; spectral range $3.3-18.0 \ \mu\text{m}$ with 0.5 cm⁻¹ resolution; cross track scanning resolution is ~1.5 km (at nadir) across a 32 km ground swath from a nominal altitude of 16 km

Instrument 5: CR-2 — priority 1; cryocooled chilled mirror hygrometer

<u>Instrument 6:</u> CAPS — priority 2; 0.35–50 μ m cloud and aerosol spectrometer, 25–1550 μ m cloud imaging probe, 0.01–3 gm⁻³ liquid water content, air speed, and temperature

<u>Instrument 7:</u> CIN — priority 3; four measurements of cloud particle scattered 635 nm light: 10° – 90° forward scattered; 90° – 175° backscattered, cosine weighted forward scattered, cosine weighted backscattered

<u>Instrument 8:</u> Nevzorov probe — priority 3; ice and liquid water content measured by constant-temperature, hot-wire probe

Learjet

Instrument 1: Buck Research Cryogenic Model CR-1A Dew Point Hygrometer — dew point temperature

Instrument 2: Cloud Tech Nevzorov Twc Probe — cloud total water

Instrument 3: PMS Model OAP-2D-C — 2D-C optical array spectrometer; 32 photodiode array with 33 μ m resolution

Instrument 4: SPEC Model 2D-S — 2D-S optical array spectrometer; dual 128 photodiode arrays with 10 μ m resolution

Instrument 5: PMs Model FSSP-100 - forward scattering spectrometer

Instrument 6: SPEC Model 230-X — cloud particle imager

Instrument 7: SPEC (0.4 to 2.3 µm) — cloud extinctioneter

Ground

<u>Instrument 1: radiosonde</u> — balloon borne instrument measuring temperature, pressure, water vapor, and winds from its surface launch point into the stratosphere

<u>Instrument 2:</u> Raman lidar — 355 nm laser system providing profiles of water vapor, aerosols, and optically thin clouds with 40 meter resolution; maximum altitude for water vapor is 4 km daytime and 10 km night time; maximum altitude for aerosols and clouds is 15 km

<u>Instrument 3: MPL</u> — several cloud-related parameters including cloud height, extinction coefficient, cloud layers, and time/date reference information

<u>Instrument 4:</u> AERI — two data for wave numbers between 520 and 1800 cm⁻¹: mean infrared radiance spectral ensemble and the standard deviation for that ensemble; three data for the six bands of 675-680, 700-705, 985-990, 2295-2300, 2282-2287, 2510-2515 cm⁻¹: mean radiance, standard deviation of that radiance, and brightness temperature

Instrument 5: MMCR — 35 GHz cloud radar for for profiling cloud particle size and density up to 20 km

Experiment 3 — Satellite Calibration and Flux Retrieval Validation

Part A – Science Issues

Science Objective

The objectives of this group of experiments are to assess the errors in the narrowband calibrations of selected channels on satellite imagers and to determine the uncertainties in fluxes derived from both narrow- and broadband fluxes.

Spectral or broadband radiances are the fundamental quantities observed from satellites. Retrieval of surface and cloud properties from spectral radiances requires a quantitative understanding of the absolute and relative calibrations of similar channels on different satellites. Although many satellites maintain onboard calibration systems, it is essential to assess periodically the imager calibrations with a reference source having a known absolute calibration. Such assessments can be used to independently verify or adjust the imager calibrations.

Radiances are also used to estimate the fluxes exiting the top of the atmosphere (TOA). The TOA broadband shortwave (SW) and longwave (LW) fluxes constitute the basic quantities for determining the Earth radiation budget (ERB), a fundamental climate parameter. Flux is nominally computed by hemispherical integration of radiances exiting the TOA. Typically, radiance can only be measured by a satellite radiometer from only one direction at a given time, although a few research scanners can view the same area from several different angles during a given overpass. The radiance field at the TOA is often anisotropic, so that it cannot be assumed that the observed radiance is representative of radiances at all other exiting angles. For narrowband and broadband sw radiation, bidirectional reflectance distribution functions (BRDFs) are used to account for the radiances exiting in directions unseen by the imager or scanning radiometer that observes the radiance. Likewise, a limb-darkening function (LDF) is used to correct for the anisotropy of the TOA broadband longwave (LW) or narrowband infrared (IR) radiance field. Corrections for anisotropy of the radiance field are the greatest source of uncertainty in the estimation of fluxes. The most direct way of determining

the error in TOA fluxes derived from measured radiances is to compare the derived values fluxes measured simultaneously with a well-calibrated hemispherical radiometer over the same area viewed by the satellite.

This experiment will provide a set of well-calibrated radiances and fluxes that can be compared directly to a variety of radiances and derived fluxes from several different satellite platforms. These measurements should provide the basis for assessing the calibrations of several imagers and the fluxes derived from both broadband and narrowband radiometers. The results of the experiment will include uncertainties for fluxes derived from several different scene types and for the calibrations for several different imager narrowband SW channels. If sufficiently out of range of the expected calibrations, the results may be used to recalibrate the imager channels in question.

Advocate

The NASA Langley Research Center Satellite Analysis Group advocates these measurements. Individuals desiring to use these measurements include Pat Minnis.

Measurement Strategy

Ideally, measurements for all of the experiments should be taken at altitudes as high as possible to maximize the viewed area for matching with the relatively large footprints (0.25 - 25 km) of the satellite instruments and to minimize the atmospheric corrections required to adjust the measurements to the TOA. Flight segments should be flown parallel or orthogonally to the satellite instrument scan direction. Flights should be performed in conjunction with as many different satellite overpasses as possible. Highest priority for calibration flights should be reserved for overpasses when the imagers have near-nadir views to facilitate alignment of the aircraft and satellite sensor viewing angles. A mix of scenes is desirable including clear land, overcast cirrus and stratus, and broken cloud fields to obtain a variety of signal strengths, spectral combinations and anisotropic fields. These measurements are useful only if all cloud cover is well below the aircraft.

Required and Supporting Measurements

Proteus

The primary instruments on this platform for flux assessments are the zenith and nadir CM-22, CG-4, SSFR, and SRP. For the calibration experiments,

primary instruments are the DFCs, SRP, and the SSFRs. Secondary instruments for both experiment portions include the CDL, S-HIS, and CMR.

Ground

The supporting instruments are the MFSR for estimating the aerosol optical depth.

Satellite

The required instruments for the calibrations are the infrared and visual imagery from GOES-8 or GOES-10. These instruments view the SGP domain every 15 minutes and can be used for every flight. Each flight, however, should give priority to one or more precessing or sun-synchronous satellite including the Terra, Aqua, NOAA-15, NOAA-16, and TRMM. Because the Clouds and the Earth's Radiant Energy System (CERES) broadband scanners fly on Terra and Aqua, each high-altitude flight for flux validation should attempt to match the respective overpasses near 1030 and 1330 LT, respectively. Calibration experiments can be performed simultaneously for the Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua. Flight paths can also be aligned with Advanced Very High Resolution Radiometers (AVHRR) on NOAA-15/16 and the Visible Infrared Scanner (VIRS) on TRMM.

From the ARM perspective, the most important calibrations are for the Terra and Aqua satellites. The GOES satellites are next, but since they are always viewing the SGP CF region, the needed measurements to calibrate them have no special time considerations and thus data from other experiments will serve. The next most important is TRMM, and the NOAA satellites have the lowest ARM priority.

Data Analysis Strategy

Data from the CM-22, CG-4, and the SSFR will be averaged to match the relevant GOES-8/10 and CERES pixels. The measurements will corrected to the top of the atmosphere using radiative transfer models (RTM) and appropriate gaseous loading in the stratosphere. Similarly, the DFC, S-HIS, and SRP radiances will be averaged to match the nearly co-aligned GOES and one or more of the other satellite imagers. RTMs will be used to adjust the radiances to the TOA. When the satellite scan and aircraft instrument angular alignments are not possible or for comparison with the SSFR data, BDRFs will be applied to the measurements as accurately as possible to account for the different viewing conditions. Spectral integration of the S-HIS and the CDL and CMR will be used to determine the cloud boundaries for inclusion in the RTMs.

Relation to Other Experiments

The GOES portion of this experiment can be gleaned from data collect in conjunction with other experiments. In addition, it is possible to divert from another experiment to the nadir point for the over crossing of one of the polar orbiting satellites if such diversion will not consume much flight time and will not unduly impact the other experiment. The latter is of some importance re Experiment 1 and 2 since they require cirrus that may not occur often and this experiment can be flown for a much wider variety of cloud conditions.

Part B – Experiment Details

Flight Strategy

A single trial involves the Proteus flying level at high altitude for as long as possible to maximize the flight distance and number of matched satellite pixels during a given overpass.

Constraints

This experiment has no special constraints.

Special Needs

The instrument advocates must provide a list of relevant nadir points and over crossing times for all the listed polar orbiting satellites for the campaign period prior to the its start.

Instrument and Data List

Proteus

<u>Instrument 1:</u> CM-22s — hemispheric broadband shortwave 200–3600 nm flux radiometers; two nadir and two zenith viewing; one zenith is stabilized against aircraft motion; one nadir is covered

<u>Instrument 2:</u> CG-4s — hemispheric broadband longwave 4.5–40 µm flux radiometers; two nadir and one zenith viewing; zenith is stabilized against aircraft motion; one nadir is covered

<u>Instrument 3:</u> DFCs — two hemispheric nadir viewing cameras; pass bands of 620-670 nm and 1580-1640 nm with resolutions of 1300×1030 and 320×256 pixels respectively

Instrument 4: SRP — three 1° field-of-view nadir spectrometers; 400–1050 nm, 710–800 nm, and 1300–1500 nm; up to 10 spectra per second

<u>Instrument 5:</u> SSFR — zenith and nadir hemispherical field-of-view; 300–1700 nm with 8–12 nm resolution; 1 Hz sampling rate

<u>Instrument 6:</u> S-HIS — zenith or nadir viewing; spectral range $3.3-18.0 \,\mu\text{m}$ with 0.5 cm⁻¹ resolution; cross track scanning resolution is ~1.5 km (at nadir) across a 32 km ground swath from a nominal altitude of 16 km

Instrument 7: CDL — 100 meter range bins with intensity of reflected 1.053 μ m laser light plus one background bin; range bins provide information on the location and density of aerosols and clouds; background bin for data correction

<u>Instrument 8:</u> CMR — 1 W chirped CW 95 GHz cloud radar; –42 dBZ at 1 km; Doppler velocity and radar reflectivity profiles with a rang resolution of 15 m (1000 range gates)

Ground

<u>Instrument 1:</u> MFSFR —spectral measurements of direct normal, diffuse horizontal, and total horizontal solar irradiances; nominal wavelengths of 415, 500, 615, 673, 870, and 940 nm; 20 second sampling rate

Satellite — GOES 8

Instrument 1: visible imagery; 0.65 µm, 1 km

Instrument 2: infrared imagery; 3.9, 10.8, and 12.0 µm, 4 km

Satellite — GOES 10

Instrument 1: visible imagery; 0.65 µm, 1 km

Instrument 2: infrared imagery; 3.9, 10.8, and 12.0 µm, 4 km

Satellite — Terra

Instrument 1: MODIS — visible and SW imagery; 0.63 μ m, 0.25–1 km; 0.87, 1.38, 1.60, and 2.19 μ m

Instrument 2: MODIS - infrared imagery; 3.7, 8.4, 10.8, and 12.0 µm, 1 km

Satellite — Aqua

Instrument 1: MODIS — visible and SW imagery; 0.63 μ m, 0.25–1 km; 0.87, 1.38, 1.60, and 2.19 μ m

Instrument 2: MODIS - infrared imagery; 3.7, 8.4, 10.8, and 12.0 µm, 1 km

Satellite — NOAA 15

Instrument 1: AVHRR visible and SW imagery; 0.62, 0.87, and 1.6 μ m, 1 km

Instrument 2: near-infrared imagery; 3.9, 10.8, and 12.0 µm, 1 km

Satellite — NOAA 16

Instrument 1: AVHRR visible and SW imagery; 0.62, 0.87, and 1.6 µm, 1 km

Instrument 2: near-infrared imagery; 3.9, 10.8, and 12.0 µm, 1 km

Satellite — TRMM

Instrument 1: VIRS visible and SW imagery; 0.62 and 1.6 µm, 2 km

Instrument 2: VIRS infrared imagery; 3.7, 10.8, and 12.0 µm, 2 km

Experiment 4 — Spatial and Temporal Variability of Upwelling Irradiance at the Top of a SCM Column

Part A – Science Issues

Science Objective

The objective is to assess the accuracy of model-computer radiative fluxes at the top of the SCM column.

Measurements from the airborne platform will provide the fine-scale spatial and temporal variability of upwelling irradiance at the top of the SCM column that can be (1) compared with CRM output, and (2) used to better interpret temporally-averaged (on the order of an hour) and spatially-averaged (now over a 370-km wide domain) radiation quantities used by the CPM WG.

Advocate

The advocates for this experiment are Ric Cederwall and Minghua Zhang.

Measurement Strategy

The ARM SCM domain is quite large and is defined by a twelve-sided polygon about 370 km across, or equivalently twelve adjacent triangles with their vertices all located at the CF. The latitude and longitude pairs that define the outer boundary of the polygon are shown in Table 1. The intent of this experiment is to characterize the spatial and temporal variability. To accomplish this it would be ideal to fly the entire SCM domain continually, but it may necessary to fly a combination of long and short legs to capture both the spatial variability across the SCM domain while also remaining near the CF for periods to characterize the temporal variability where high frequency ARM observations are concentrated. Also, it will be valuable to time flight legs with GOES satellite overpasses, because of the relationship between this experiment and Experiment 3. The top of the SCM column depends on the vertical resolution of the variational analysis. The CPM WG currently performs a coarse analysis with 50 mb resolution. The top of this column is 115 mb, which leads to a geometric height of about 15750 m or 51660'. The top of the fine analysis (25 mb resolution) column is 40 mb, which leads to a geometric height of about 22270 m, or 73050' which is above the service ceiling of the Proteus aircraft.

Daytime flight legs would be of greatest interest, with an occasional nighttime flight leg to evaluate the longwave component at night.

Point	Latitude	Longitude
1	38°18'33" N	97°17'44'' W
2	38°13'15" n	98°18'59" W
3	37°39'08'' n	99°05'28'' W
4	36°53'19" n	99°19'44'' w
5	36°04'19" n	99°13'03" W
6	35°16'24" n	98°34'21'' W
7	34°58'47" n	97°31'07'' w
8	35°07'29" n	96°33'43" W
9	35°40'57" n	95°51'48" w
10	36°31'20" n	95°33'05" w
11	37°22'48" n	95°38'05" W
12	38°02'27'' N	96°18'08'' W

Table 1. SCM domain.

Required and Supporting Measurements

Proteus

The Proteus will measure upwelling and downwelling solar and thermal fluxes in the upper troposphere with the broadband hemispheric radiometer suite. The CDL will be used to document the underlying cloud field.

Data Analysis Strategy

Data from this experiment will be used by CPM WG in three ways. The first is to estimate the time-space averaged longwave and shortwave radiative fluxes for selected days and selected time periods. The estimated fluxes will be compared with the GOES fluxes that are currently used as an upper boundary in the ARM SGP variational analysis. The sensitivity of the variational analysis to the potential difference will be assessed. Second, we will use the instantaneous radiometric measurements to construct statistics to compare with CRM output. This includes the extremes, variances, spatial correlation scales, and other statistical measures that carry information of the parameterization of microphysical and radiative parameterizations in CRMs. Third, in situ meteorological measurements (winds, temperature etc.) will be

used to examine the small scale variability and assess the de-aliasing approach we currently use in the variational analysis.

Relation to Other Experiments

This experiment is related to Experiment 3: Support for GOES Radiation Retrieval as the Minnis products are the primary source of information for the TOA radiation in the CPM WG variational analysis. Any aspects of Experiment 4 that can work synergistically with Experiment 3 should be exploited. The night flights mentioned in the measurement strategy section are primarily for assessing the accuracy of GOES algorithm at night, so they are strongly linked to Experiment 3.

Part B – Experiment Details

Flight Strategy

The Proteus will fly a eight legged daisy pattern as illustrated in the accompanying figure and delineated in Table 2. The legs are 200 km in length and take approximately 20 minutes to traverse in wind free conditions. In similar conditions, an additional 6 minutes is needed to realign from the end of one leg to the beginning of the next. The flight altitude is to be 15.25 km (50 kft).

Five sorties with duration of 8 to 10 hours each should be flown, with the flight days chosen to represent different synoptic conditions. Ideally, an additional sortie will be flown at night, but that flight can be shortened in duration to a single iteration of the pattern.

Constraints

This experiment has no special constraints.

Special Needs

Point	Easting	Northing	Zone	Latitude	Longitude
CF	635136	4052339	14	36° 36' 25" n	97° 29' 20'' w
А	633546	4152326	14	37° 30' 30" n	97° 29' 20'' W
В	671931	4145324	14	37° 26' 20" n	97° 03' 24" w
С	704713	4124165	14	37° 14' 30" n	96° 41' 32'' W
D	726904	4092071	14	36° 56' 51" n	96° 27' 07'' w
Е	735123	4053929	14	36° 36' 06" n	96° 22' 17" w
F	728121	4015544	14	36° 15' 27" n	96° 27' 39" w
G	706962	3982762	14	35° 58' 01" n	96° 42' 17" w
Н	674868	3960571	14	35° 46' 24" n	97° 03' 55" w
Ι	636726	3952352	14	35° 42' 20" n	97° 29' 20'' w
J	598341	3959354	14	35° 46' 24" n	97° 54' 43" w
Κ	565559	3980513	14	35° 58' 01" n	98° 16' 23'' W
L	543368	4012607	14	36° 15' 27" n	98° 31' 02" w
М	535149	4050749	14	36° 36' 06" n	98° 36' 25" w
Ν	542151	4089134	14	36° 56' 51" n	98° 31' 36" W
Ο	563310	4121916	14	37° 14' 30" n	98° 17' 10'' W
Р	595404	4144107	14	37° 26' 20" n	97° 55' 18" w

Table 2. Experiment 4 data leg end points.

There are no special needs for this experiment.

Instrument and Data List

Proteus

<u>Instrument 1:</u> CM-22s — hemispheric broadband shortwave 200–3600 nm flux radiometers; two nadir and two zenith viewing; one zenith is stabilized against aircraft motion; one nadir is covered

<u>Instrument 2:</u> CG-4s — hemispheric broadband longwave 4.5–40 μ m flux radiometers; two nadir and one zenith viewing; zenith is stabilized against aircraft motion; one nadir is covered



Figure 1. Experiment 4 data collection region.

Instrument 3: CDL — 100 meter range bins with intensity of reflected 1.053 μ m laser light plus one background bin; range bins provide information on the location and density of aerosols and clouds; background bin for data correction

Instrument <u>4</u>: CR-2 — cryocooled chilled mirror hygrometer

Instrument 5: MADT — in situ temperature and pressure

Appendix A: Contact List

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Appendix B: Acronym and Symbol List

2D-OAP	two dimensional optical imaging probe
AERI	atmospherically emitted radiation interferometer
AGS	air gateway system
AIRS	atmosphere infrared sounter
ARESE	ARM Enhanced Shortwave Experiment
ARM	Atmospheric Radiation Measurement (program)
AVHRR	advanced very high resolution radiometer
Brdf	bidirectional reflectance function
CAPS	cloud, aerosol, and precipitation spectrometer
CART	Cloud And Radiation Testbed
CAS	cloud and aerosol spectrometer
CCD	charge coupled device
Cdl	cloud detection lidar
CERES	cloud and earth radiant energy system
CF	central facility
CG-4	Kipp and Zonen pyrgeometer model number
CIN	cloud integrating nephelometer
Сір	cloud imaging probe
См-21	Kipp and Zonen pyranometer model number
См-22	Kipp and Zonen pyranometer model number
CMR	compact millimeter wave radar
Cpr	cloud profiling radar

CRM	cloud resolving model	
DFC	diffuse field camera	
Erb	Earth radiation budget	
FSSP	forward scattering spectrometer probe	
GOES	geostationary operational environmental satellite	
GPS	global positioning system	
Ins	inertial navigation system	
Іор	intensive observing period	
Ir	infrared	
IRIG	???	
Ldf	limb darkening function	
Lidar	light detection and ranging	
LLNL	Lawrence Livermore National Laboratory	
Lw	long wave	
Lwc	liquid water content	
LWCD	liquid water content detector	
MADT	micro air data transducer	
MASP	multiangle aerosol spectrometer probe	
MFRSR	multifilter rotating shadowband radiometer	
MISR	???	
MMCR	millimeter-wave cloud radar	
Modis	moderate resolution imaging spectroradiometer	
Mpir	multispectral pushbroom imaging radiometer	
Mpl	Marine Physical Laboratory or Micropulse lidar	
Msl	mean sea level	

- NASA National Aeronautics and Space Administration
- **NOAA** National Oceanographic and Atmospheric Administration
- **NREL** National Renewable Energy Laboratory
- **PMS** Particle Measurement Sciences (Company)
- **PSA** total particle surface area
- **PVM** particulate volume monitor
- **RTM** radiative transfer model
- **SCM** single column model
- SGP southern great plains
- S-HIS scanning high resolution interferometer sounder
- SIRS solar infrared spectrometers
- SSFR solar spectral flux radiometer
- **SPEC** ???
- **SRP** spectral radiance package
- SSP spectrally scanning polarimeter
- Sw short wave
- **TDDR** total direct diffuse radiometer
- TEC thermoelectric cooler
- **TOA** top of atmosphere
- **TRMM** tropical rainfall measurement mission (satellite)
- TWC total water content
- UAV unmanned aerospace vehicle
- UDF UAV development flight
- VIPS video ice particle sampler
- VIRS visible infrared sensor

Appendix C: Revision History

June 16, 2002	Mark 1, initial draft release
July 15, 2002	Mark 2, input from science team added to the descriptions of all experiments
August 13, 2002	Mark 3, additional experimental details added, Experiment 5 dropped
September 20, 2002	Mark 4, input from Bob Ellingson added

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