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UAV Spring Flight Series Mission Summary

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ARM
CLIMATE RESEARCH FACILITY

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ARM-UAV Spring 1996 Mission Summary

The ARM UAV program concluded a very successful deployment to Oklahoma on May 6, 1996. The purpose of this three week long campaign was to conduct a series of instrumented flights to obtain data on the interaction of solar energy with clear and cloudy skies to test and develop new mathematical models of this interaction for use in climate studies. The mission activities centered on three classes of scientific experiments, namely :

1. radiative fluxes, in which aircraft are used to make high accuracy measurements (~1%) of the solar radiative transport throughout the troposphere under a variety of clear sky, cloud aerosol, and water vapor conditions,

2. cloud properties, in which remote sensing techniques are used to develop and validate techniques for obtaining cloud reflectivity, phase (ice or water), effective droplet size, etc., and

3. satellite calibration and validation, where the high altitude aircraft is used to indirectly calibrate sensors on operational satellites as well as to validate retrieval algorithms for such derived quantities as flux divergence, cloud properties and water vapor profiles.

Briefly, the experiments used a combination of satellite, aircraft, and ground platforms to make highly accurate measurements of up and downwelling solar radiance and flux at different altitudes throughout the atmospheric column. The aircraft used were the Twin Otter and Egrett, and they often flew a "cloud sandwich" pattern with the Otter below the clouds and the Egrett above. The instrumentation on the Egrett included a multispectral pushbroom radiometer (MPIR), a cloud detection lidar (CDL), a spectrally scanning polarimeter (SSP), a wide field of view (WFOV) camera, a frost-point hygrometer, and up- and down-looking "Valero" radiometers. The Twin Otter instrumentation included a microwave radiometer (MWR), a frost-point hygrometer, and up- and down-looking "Valero" radiometers identical to those on the Egrett. On occasions the aircraft operations were carried out simultaneous to radiance measurements from the GOES and NOAA polar orbiting satellites. On other occasions, coordinated flights were performed in conjunction with the NASA-sponsored SUCCESS program. Details concerning the instrumentation, scientific objectives, and flight plans associated with each of the classes are described in the ARM-UAV Science and Experiment Plan (http://info.arm.gov/~info/iops/uav/docs/science_plan.pdf).

All aircraft operations were performed in the immediate vicinity of the ARM CART site from April 15 through May 6. During that time seven scientific data flights were flown and in-flight data were accumulated under a variety of atmospheric conditions ranging from clear to solid overcast. These flights are detailed in Table 1 below and include: cloud forcing experiments under scattered, broken, and solid overcast conditions including low, mid-, and high-level cloud decks; clear sky column absorption and surface albedo measurements; clear sky flux profiling measurements; and in-flight, co-altitude intercomparisons of flux measurements made from the two aircraft. A summary of the individual missions follows Table 1. The data appear to be of excellent quality and comprise a unique data set for testing our understanding of the transfer of solar radiation in both clear and cloudy atmospheres.

The success of this deployment was the result of the tremendous efforts of a multi-laboratory multiagency team comprised of five DOE Laboratories, three NASA Centers, about a dozen universities and three aircraft companies. The ARM Program sponsored the ground-based measurements, ARM-UAV (Unmanned Aerospace Vehicle) the coordinated Egrett and Otter measurements, and ARM. Funding was provided through the DOE's ARM Program and through DoD's Strategic Environmental Research and Development Program (SERDP).

Table 1. - Spring 1996 Science Flights Summary

Date	Platform	Measurement Conditions and Experiments
04-18	Egrett	Clear-skies Satellite Narrowband Calibration (Experiment 1), Satellite Narrowband Radiances to TOA Fluxes (Experiment 2), Bi-directional reflectance functions (Experiment 10)
04-20	Egrett and Otter SUCCESS ER-2 and DC-2	Overcast to broken cirrus cover Cloud microphysics from various sensors (Experiment 7) Cirrus cloud optical properties (Experiment 9)
04-27	Egrett and Otter SUCCESS DC-8	Overcast to broken cirrus cover Cloud microphysics from various sensors (Experiment 7) Bi-directional reflectance functions (Experiment 10)
05-03	Egrett SUCCESS ER2, DC8, B757 and T39	Clear-skies Detection of contrails (Experiment 12) Satellite narrow band calibration (Experiment 1) Bi-directional reflectance functions (Experiment 10)
05-04	Egrett and Otter SUCCESS ER2, DC8, B757 and T39	Broken fair-weather cumulus clouds Three-dimensional cloud effects (Experiment 4) Cloud observation distance (Experiment 5) Satellite narrow band calibration (Experiment 1) Satellite narrow band radiances to TOA fluxes (Experiment 2) Bi-directional reflectance functions (Experiment 10) Contrail impact on local radiation field (Experiment 12)
05-05	Egrett and Otter	Overcast to broken fair-weather cumulus clouds Three-dimensional cloud effects (Experiment 4) Satellite narrow band calibration (Experiment 1)
05-06	Egrett	Overcast to broken stratocumulus clouds Angular corrections to the broadband radiometers

The remaining portions of the document contain individual Mission Summaries.

UAV Spring Flight Series Mission Summary

by R. G. Ellingson, UAV Mission Scientist

UAV-S96 Flight on April 18, 1996: Flt.960418.14

Summary of the First Science Flight of the Spring 1996 UAV IOP

Clear skies over the Oklahoma offered the possibility of obtaining crucial data for three science team experiments, namely:

Satellite Narrowband Calibration (Experiment 1),
Satellite Narrowband Radiances to TOA Fluxes (Experiment 2), and
Bi-directional reflectance functions (Experiment 10)

Following a mildly shaky preflight check, the Egrett took off at approximately 1600 UTC. After performing several 360 degree turns at different bank angles over the CART site for BDRF purposes, the aircraft lined up to perform a constant heading (55 degree) calibration segment with GOES 8 at approximately 1820. The planned point satellite-aircraft match point was met to within about 100 m and within 2 min of the planned time. This was accomplished under very strong flight level winds (45 m/s). Not bad for the first try!

Following the GOES run, the Egrett returned to the vicinity of the CART site to perform additional 360 banked turns for BDRF determinations while awaiting the opportunity to perform the NOAA 14 calibration run. The NOAA 14 calibration was carried out at about 1944 with a constant heading of 346 degrees - within 10 sec of the planned time and within 100 m spatially.

The Egrett returned to the vicinity of the CART site to perform several 360 turns at 30 degrees bank to complete the series of clear-sky BDRF runs. The aircraft then returned to the Ponca City Airport, and along the way flew constant level runs at 2500 ft over I35 to perform a MPIR instrument check.

Clear skies persisted over the region for the duration of the mission, thereby assuring uniform underlying conditions during the period of observations. As far as can be determined from in-flight analyses, all payload instrumentation performed as intended. Given the weather conditions, instrument performance, and the close match of the planned satellite calibration points, this first mission of the spring 1996 series must be regarded as an outstanding success.

UAV-S96 Flight on April 20, 1996: Flt.960420.14

Cirrus clouds studied during the second ARM-UAV Mission of the Spring IOP

The 19 April 12 UTC and the 20 April 00 UTC forecast runs of the of the Nested Grid Model (NGM) from the National Centers for Environmental Prediction (NCEP) showed that a region of high relative humidity in the 8 to 10 km layer would reach the vicinity of the SGP CART site at about 1300 local time. Believing that widespread cirrus would form, we scheduled a flight plan that would allow the collection of data according to plans specified in the UAV Science Plan for Experiments 9 and 7.

Experiment 9 has objectives (1) to develop and test methods for the retrieval of cirrus optical properties based on the use of airborne sensors and correlated surface and satellite sensors, (2) to relate these properties to atmospheric state parameters, and (3) to relate these properties to broadband flues and albedos.

Experiment 7 is designed to determine how well cloud effective particle size and water path independently derived from satellite, airborne, and surface sensors agree with one another.

The Egrett took off at approximately 1030 local to flight a level of about 45000 ft. The Otter followed at about 1230 to a flight level of about 18000 ft. The cirrus layer was located roughly between 21000 and 34000 ft. The aircraft executed the Experiment 9 pattern twice, beginning the first at about 1230. As if on cue, the cirrus arrived, with the maximum coverage as well as the maximum cloud thickness occurring at just about the 1300 time predicted by the NGM. Although the coverage was not 100%, the coverage was near 70-80% during parts of the runs.

The cirrus thinned and became more scattered during the second run of Experiment 9 and during Experiment 7. Nevertheless, the CDL and the WFOV showed the cirrus layer to be present in the 7 to 10 km layer during the entire mission. Examples from the CDL during the mission as well as some solar radiation data are shown on the home page.

On the return to the airport, the Egrett made a very slow profiling decent through the cloud layer.

Concurrent with the ARM-UAV flights, the NASA sponsored SUCCESS program carried out flights by the ER2 and the DC8 over the CART site simultaneous to ours. The DC8 flew profiles above, in and below the cirrus. Cloud samples were taken during the in-cloud legs.

Despite some minor difficulties with several instrument systems, the mission must be regarded as successful. Combined with the ARESE experiment in Fall 1995, this was one of the very few experiments that we've been able to run when the cloud forecast (other than clear skies) actually matched what was observed! More importantly, the combined flights by the two programs apparently obtained data to characterize the radiation field at different levels and the cloud microphysics. This data set is likely unprecedented.

UAV-S96 Flight on April 27, 1996: Flt.960427.16

ARM-UAV Aircraft Sample an Extended Cloud Layer

After a long preflight check, the aircraft were able to execute a flight in support of Experiment 7, which is designed to determine how well cloud effective particle size and water path independently derived from satellite, airborne, and surface sensors agree with one another. The cloud layer sampled extended from about 18,000 to 33,000 ft. At the start of the flight the clouds appeared to be quite uniform to both the eye as well as on satellite pictures. During the time of our mission, the SUCCESS aircraft flew within the cloud layer and took cloud particle samples.

The Egrett climbed to an altitude of 44 kft while the Otter flew its legs at 2500 MSL. While awaiting for the Otter to locate above the CART site, the Egrett flew 360 degree turns at a 40 degree bank angle in the vicinity of the CART site in support of Experiment 10 - the BDRF mission. After both aircraft reached the area of the central facility, they began their patterned flights along the crosses described in the ARM-UAV Science Plan. The first leg was executed very close to solar noon. The broad band radiometers showed an albedo of about 45%.

Following one crossing pattern, the Egrett practiced the set up for a NOAA 14 overflight. The patterned leg for the overflight was run at about 1447 local. Unfortunately, the cloud layer became thinner and broken just prior to the overflight. In fact the albedo fell to close to the clear-sky value during the overflight.

During the period the Egrett was setting up for the overflight, the Otter performed 360 degree turns in the vicinity of the CART site at 30, 40, 50, and 60 degree banks in support of the microwave radiometer.

After the satellite overflight, the aircraft again positioned themselves for another Experiment 7 pattern, but with the Otter bumped up to 3500 ft MSL. However, this experiment was canceled after one leg due to the cloud layer moving out of the sampling region.

Despite the lack of clouds during the satellite overflight, the experiment must be regarded as another success. Not only did we achieve our goal of obtaining radiometric data from an extensive cloud layer, we were also able to perform the experiment at the time of cloud particle sampling. The combined data should serve as an excellent set with which to study the radiation - cloud particle size problem.

UAV-S96 Flight on May 3, 1996: Flt.960503.16

ARM-UAV and SUCCESS Carry Out Joint Contrail Mission

Under fair weather conditions over Northern Oklahoma, the ARM-UAV and SUCCESS aircraft flew in patterned formation to sense different features of contrails generated by a Boeing 757. The SUCCESS aircraft, the ER2, DC8, B757 and the T39, flew in clear air and the B757 attempted to generate contrails with different type fuels at approximately 37 Kft. The ARM-UAV Egrett flew above at 45 Kft and looked for the contrails with various sensors, including the MPIR, the CDL and the broadband radiometers. Unfortunately, the atmosphere was quite dry, and the contrails generated were very short lived - less than about a mile. Nevertheless, the SUCCESS pilots reported they could see different type contrails depending upon the fuel used. The Egrett did fly over the contrails, and it appeared that the MPIR was able to sense one during an overpass.

At the beginning of the mission, a broken fair weather cumulus cloud covered the area. However, as the day progressed, clear air moved into the area from the west, and the entire region became clear. Following the completion of the contrail tests, the Egrett positioned itself in the vicinity of the CART site and performed several 360 degree, 30 degree banked, turns for a BDRF experiment (Experiment 10). This was followed by a GOES 8 calibration run along a 140 km track (Experiments 1 and 2) over clear skies. The relatively large solar zenith angle for this period (40 degrees) completed our goal of obtaining clear-sky GOES calibration data at low and high solar zenith angles.

Overall, the coordination between the two programs proved excellent, and data useful to the scientific goals were collected.

UAV-S96 Flight on May 4, 1996: Flt.960504.13

ARM-UAV Samples Three-Dimensional Cloud Effects

For the first time during this deployment, Mother Nature cooperated and produced a broken layer of fair weather cumulus with well defined bases and tops with no clouds above. The ARM-UAV aircraft duo of the Egrett and Otter flew patterned flight legs above and below the clouds close to the patterns described in the UAV Science Plan for experiments 4 and 5. The Otter legs were flown at 1500 ft AGL for the below cloud legs, and at 9000 ft MSL for their above cloud legs. Meanwhile the Egrett flew at 42000 ft MSL.

The Otter pilots reported that clouds were present during their runs below and above the clouds. They commented that during their check of the cloud top altitudes before the runs that the clouds were building faster than they were climbing - the order of 500 ft per min. However, when the clouds hit somewhere about 6000 ft, they stopped abruptly. The CART site soundings at 1130 and 1430 UTC show a very sharp inversion with the max potential temperature at about 800 mb or roughly 2000m. This corresponds very well with the pilot reports. Based on this description and discussions with the various instrument PIs, it appears that we accomplished our goal of obtaining simultaneous data from the microwave, MPIR, CDL, WFOV, and broadband radiation flux data above and below a cloud layer simultaneous to the multiple suite of observations at the CART site.

Prior to the cloud runs, the Egrett performed six 30 degree banked 360 degree BDRF runs in support of Experiment 10. This was followed by a GOES8 calibration run (Experiments 1 and 2).

Following the cloud study, the ARM-UAV aircraft participated in a contrail study with the SUCCESS program. The objective of today's SUCCESS mission was to attempt a measurement of the effect of contrails on the radiation fluxes. In support of this, the Otter flew a racetrack 1500 AGL whereas the Egrett flew at 45000 ft MSL in a patterned designed to cross and fly along the contrails. The Otter pilots reported that there were few clouds present during this run, but it was very hazy during the entire time.

After completing the contrail crossings, the Egrett performed six 30 degree banked 360 degree BDRF runs in support of Experiment 10. This was followed by a NOAA 14 calibration run (Experiments 1 and 2) over clear to widely scattered cloud conditions before returning to base.

UAV-S96 Flight on May 5, 1996: Flt.960505.17

ARM-UAV Completes a Successful Mission Above and Below Broken Cumulus

The ARM-UAV program concluded its Spring 1996 campaign today with a mission geared toward the collection of data for use in testing radiation models of three-dimensional cloud effects. A synopsis of the mission follows below.

The East-West oriented cold front that had been situated across central Kansas for the past two days passed through the Blackwell, Oklahoma region about 0800 local in conjunction with the eastward movement of a Mesoscale Convective System (MCS) in Kansas. The GOES 8 IR pictures showed a cirrus shield was present on the south and east edges of the MCS, but stratiform clouds were located behind the front. Thus, the launch of the mission was delayed until early afternoon, thereby allowing time for the stratiform deck to move into the CART operations area.

By noon, the stratiform clouds, now broken, were located in our area, and GOES 8 data showed no middle or cirrus clouds. The early morning soundings from the CART site again showed the presence of a strong capping inversion at about 6000 ft., and the GOES 8 IR temperatures showed the tops were at roughly 6000 ft. On takeoff, the Egrett pilot reported cloud base near 2500 AGL with uniform tops at 6000 ft MSL. Thus, we had excellent agreement between the sonde, satellite and aircraft estimates of cloud height. More importantly, we had almost ideal cloud conditions for obtaining data under and above an extensive broken clouds layer.

The mission was launched about 1400 local and the pilots assumed positions above (42000 Kft MSL) and below the clouds (1500 AGL) in support of Experiment 4 - Three Dimensional Cloud effects. The aircraft repeated their patterned runs twice, once with the Egrett at 42000 ft MSL, and once with the Egrett at 32000 ft MSL. The Otter maintained 1500 AGL throughout the mission. Data were gathered from about 1520 until about 1630, during which the cloud cover varied from 0.2 to 0.9. The Egrett pilot did report a few thin cloud layers at times. The CDL showed that the layer based at 2500 ft AGL was the predominant one. All systems appeared to be operational throughout the entire data collection period.

While waiting for the Otter to get on station, the Egrett performed a GOES 8 calibration run. Unfortunately, the cloud cover over the CART site was very small during this period - apparently the only period during the mission.

Given the unique cloud conditions and the apparent excellent performance of the instruments throughout the flight, today's mission must be rated as an outstanding success.

UAV-S96 Flight on May 6, 1996: Flt.960506.16

Egrett performs radiometer calibration flight

The use of the data collected by the Valero radiometers requires knowledge of the angular orientation of the radiometers. This information is provided by the c-midgets, but there are often corrections that need to be made. One method for locating the orientation is to fly the aircraft in a L-shaped pattern with legs toward, away, and parallel (at two headings) to the direction of the sun. During the Fall 95, this pattern was flow with both aircraft at the same flight level. Unfortunately, the Twin Otter could not participate on this date because of mechanical problems. Nonetheless, it looks as though we obtained a very good data set to look at the angular corrections on the broadband radiometers.