Atmospheric Radiation Measurement Program—Unmanned Aerospace Vehicle: The Follow-On Phase

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A companion paper ("Unmanned Aerospace Vehicle Workshop," this volume) discusses the initial unmanned aerospace vehicle (UAV) demonstration flights (UDF). These flights are designed to provide an *early* demonstration of the scientific utility of UAVs by using an existing UAV and instruments to measure broadband radiative flux profiles under clear sky conditions. UDF is but the first of three phases of ARM-UAV. The second phase significantly extends both the UAV measurement techniques and the available instrumentation to allow both multi-UAV measurements in cloudy skies and extended duration measurements at the tropopause. These activities build naturally to the third and final phase, that of full operational capability, i.e., UAVs capable of autonomous operations at 20-km altitudes for multiple days with a full suite of instrumentation for measuring radiative flux, cloud properties, and water vapor profiles.

The second phase of ARM-UAV will significantly extend both the UAV measurement techniques and the available instrumentation. Three UAV interim flight (UIF) missions will demonstrate the ability to use multiple UAVs for cloudy sky measurements and for satellite calibration:

- the cloudy skies/satellite calibration mission
- the sustained top of mid-latitude troposphere mission
- the tropical tropopause mission.

The cloudy skies/satellite calibration mission, now scheduled for the Oklahoma Cloud and Radiation Testbed (CART) site in fall 1994, uses two UAVs to measure the radiative fluxes above and below clouds *simultaneously*. The low altitude UAV is the Gnat 750-45 used in the clear sky mission, and the high altitude UAV is the Perseus-B now under development by Aurora Flight Sciences. Both will carry the baseline radiometric payload used in UDF. When combined with simultaneous ARM measurements of cloud properties, measurements from the two UAVs will allow us to validate and refine models of cloud heating. In addition, the high altitude UAV will allow calibration of radiative fluxes derived from the National Oceanic and Atmospheric Administration’s Polar Orbiting Environmental Satellite (POES) and Geostationary Operational Environmental Satellite (GOES), thereby greatly enhancing the utility of these measurements for climate studies. UAV objectives on this mission include the operation of multiple UAVs and the demonstration of in-flight intercalibration between sensors on different platforms.

The sustained top of mid-latitude troposphere mission is a “long endurance” mission scheduled for the Oklahoma ARM site in spring of 1995. It extends our flux measurement capabilities to multiple days at the mid-latitude tropopause, thus creating a “geostationary satellite” at the tropopause. Such long endurances are one of the principal advantages of UAVs and will allow study of the diurnal variations in the radiative flux, as well as the evolution of cloud fields, passage of fronts, and other synoptic events. Sustained high-altitude operation will serve to further test and refine the calibration of satellite-derived fluxes begun in the cloudy skies mission. This long endurance mission will also serve as the maiden scientific flight for the Cloud Detection Lidar.

The tropical tropopause mission is to be flown in the tropical Pacific and is scheduled for winter of 1995 to coincide with a major tropical experiment known as MCTEX, the Marine Continent Thunderstorm Experiment. By this time, industry expects to have a UAV capable of long endurance flights above the tropical tropopause (20 km—which is 6 km higher than required for the mid-latitude tropopause.)

By formation flying two of these high altitude UAVs to obtain various atmospheric profiles, we will demonstrate the ability to test key hypotheses related to the tropical warm pool, whose sea surface never exceeds 304 K. The tropical warm pool plays a major role in El Niño and is regarded by many as nature's greenhouse laboratory. The multiday UAV endurance will allow us to fly over the great distances (1000s km) characteristic of these phenomena, while the high altitude capability will allow measurements up to and above the tropical tropopause. This combination of endurance and altitude is significantly beyond the capabilities of manned aircraft.

In addition to the core radiometric payload used in UDF, we are currently developing several UAV-compatible instruments to accurately measure the *net* flux and cloud properties. These instruments are

- the hemispherical optimized net radiometer (HONER)
- the multispectral pushbroom imaging radiometer (MPIR)
- the cloud detection lidar (CDL)
- a miniaturized version of the ground-based Atmospheric Emitted Radiance Interferometer (AERI) (UAV-AERI).

HONER is a novel approach for accurately measuring the net radiative flux using an optical differencing technique. To accomplish this, HONER uses an integrating sphere with two apertures: one looking downward and the other upward. The radiation through each aperture is chopped at the same frequency but out of phase and then is incident on filtered pyroelectric detectors. If the phase difference between the chopped upward and downward radiation is 180 degrees, HONER will give a direct measure of the net flux. If this phase difference is selected to be 90 degrees, HONER will measure the absolute fluxes (in quadrature). By this method, HONER should be able to measure net fluxes with an accuracy of 3%. In practice, HONER will consist of two integrating spheres and will provide broadband, hemispherical flux and net flux measurements of both the solar and thermal fluxes. HONER is being developed by Los Alamos National Laboratories and is scheduled to be available in spring 1995.

MPIR is a well-calibrated multichannel cloud radiometer. It will have nine spectral channels between 0.58 and 11.5 microns (see below), with wavelengths carefully chosen for retrieving cloud reflectivity and cloud droplet phase (ice/water) and size and for providing radiometric calibration of satellite-borne sensors such as AVHRR. MPIR will form multispectral images by using linear detector arrays in a pushbroom imaging geometry. This allows a wide field-of-view (80 degrees), with a 6 mrad instantaneous field-of-view, in a compact physical package. MPIR is being developed by Sandia National Laboratories and is scheduled to be available in the summer of 1995.

MPIR Wavelengths (microns)

0.62-0.68	3.55-3.93
0.86-0.90	6.54-6.99
1.36-1.39	8.40-8.70
1.58-1.64 (tentative)	10.30-11.30
2.11-2.22	

CDL is a small backscatter lidar for detecting and profiling thin cirrus clouds and for accurately determining cloud top altitudes. CDL uses micropulse lidar technology to achieve a fully eye safe design while still obtaining excellent performance. It will be able to reliably detect thin cirrus clouds (optical density of 0.03) with along-track and vertical spatial resolutions of 100 m each. CDL is being developed by Lawrence Livermore National Laboratories and is scheduled to be available in the spring of 1995.

UAV-AERI, is a miniaturized version of the ground-based Atmospheric Emitted Radiance Interferometer (AERI) already in use in DOE climate programs. The UAV-AERI will measure up- and down-welling radiances over the spectral range of 3-20 microns with a resolution of 0.5 cm^{-1} or better and with a spatial footprint of 1 km at 10 km. On-board calibration will provide a radiometric accuracy better than 1% of full scale. The UAV-AERI is being developed by the University of Wisconsin and is scheduled to be available in the fall of 1995.