UAVs give clearer view of clouds

A well-known song lyric that says, "I really don't know clouds at all" may be closer to the truth than the singer realized. It turns out there are a lot of unknowns about clouds, even among scientists. At a meeting of the American Association for the Advancement of Science in Washington, D.C., Michael Janes of Sandia National Laboratories in Livermore, Calif., presented a brief summary of the Atmospheric Radiation Measurement-Unmanned Aerospace Vehicle (ARM-UAV) program. This Dept. of Energy (DOE) effort uses UAVs as well as manned aircraft to collect important data about clouds.

Since the project's inception in 1993, a group of dedicated scientists, currently spearheaded by Will Bolton, technical manager of the program at Sandia, has studied clouds—ice clouds, water clouds, clouds above Oklahoma, clouds above Alaska's North Slope, and clouds above the equator in an area around Darwin, Australia, among other places.

The ARM-UAV program seeks to demonstrate the use of UAVs for atmospheric research and to foster development of instruments and measurement techniques suitable for use on such aircraft. From the outset, the program has obtained important scientific data at various locales, in particular at DOE ARM sites in the Southern Great Plains, North Slope of Alaska, and Tropical Western Pacific. The program now conducts regular high-altitude airborne measurements at ARM sites.

The program's purpose is to improve our understanding of the role clouds play in global climate change. One element of the project emphasizes long-term ground-based measurements of cloud and atmospheric properties. The overall program emphasizes airborne measurement campaigns, primarily using UAVs but also using piloted aircraft when appropriate.

Flight campaigns

Making measurements at the top of the troposphere in the tropics requires a long-endurance UAV capable of carrying an instrumented payload to altitudes above 60,000 ft. ARM-UAV flights have used GNAT and Altus UAVs built by General Atomics Aeronautical Systems in San Diego, Calif., instrumented Egrett aircraft built by Grob in Germany, and Twin Otter piloted planes built by de Havilland Canada, now a part of Bombardier in Montreal, Quebec.

The ARM-UAV program has conducted a number of major field measurement campaigns. Most were run as part of intensive observing periods at the DOE Cloud and Radiation Testbed (CART) site in north-central Oklahoma. Other flight locations included Kauai, Hi., where a cirrus cloud campaign took place in 1999 at altitudes as high as 57,000 ft.

These activities have advanced the state of the art in airborne measurements and demonstrated the utility of UAVs. Accomplishments include the first science flights using a UAV, in 1994; the first use of an unescorted UAV in general-use airspace, in 1996; development of a GPS-based system that allows precise vertically stacked flight of a UAV and a piloted aircraft for cloud absorption measurements; a data-taking flight lasting over 26 hr over the CART site; and development of several compact instruments suitable for UAV applications.

The program encourages development of high-altitude UAV capabilities that should be useful for near-term and future atmospheric research.

The ARM-UAV has conducted nine major flight campaigns since the program began. Six of those flights took place at the CART site in Oklahoma. The combination of ground-based measurements from CART, airborne measurements from ARM-UAV and other aircraft, and satellite overflights yielded data that have added to scientists' understanding of cloud properties and effects.

Efforts at other locations achieved specific program or scientific goals. Flights

During the Alaska mission over the Brooks Range, the Proteus carried instrumentation attached to its canard.

at Edwards AFB, Calif., profiled clear sky flux. At Kauai, activities centered on subtropical cirrus cloud properties. At Monterey Bay, Calif., the focus was on maritime stratus cloud properties.

New instruments and UAV uses

Only instruments suited to the specific characteristics and requirements of UAV platforms can be used on unmanned aircraft. The ARM-UAV program developed several instruments to fly on UAVs, including the cloud detection lidar, atmospheric emitted radiance interferometer, hemispherical optimized net radiometer, multispectral pushbroom imaging radiometer, compact millimeter-wave radar, and frost point hygrometer.

The program also adapted instruments already under development for UAV use, including the scanning spectral polarimeter, radiation measurement system, solar spectral flux radiometer, modified commercial radiometers, and meteorological instruments. The combination of these devices, when flown on high-altitude, long-endurance UAVs, provides a powerful measurement suite.

From the outset, the ARM-UAV program encouraged the development of high-performance UAVs aimed at meeting the program's goals. These efforts include providing a visible, science-based flight program utilizing the best available UAV capabilities for atmospheric research.

In addition, the program has expanded the options for UAV use by helping to develop rules for FAA flight operation and airworthiness. The procedures developed under this program have also expanded options for use of UAVs in general-use airspace (outside of restricted or test-range areas).

Last October, the ARM-UAV program used the Proteus aircraft to collect data on clouds in Alaska.

Research activities

The chief scientist, working in conjunction with a science team, sets the research agenda for the ARM-UAV program. This agenda emphasizes remote and in-situ sensing of cloud radiometric properties. Several examples illustrate how the program has addressed various research questions.

Combining multispectral radiometer measurements with high vertical resolution cloud measurements improves capabilities for determining cloud optical depth. These capabilities were used during the spring 1999 ARM-UAV deployment at Kauai. The high-altitude Altus UAV carried broadband and spectrally resolving radiometers and in-situ meteorological instruments; the instrumented Twin Otter carried the same suite of radiometers, plus a 95-GHz cloud radar. These aircraft were operated in vertically stacked flight with the UAV at high altitude above the cirrus clouds and the Twin Otter below.

The long-endurance and altitude capabilities of the UAV allow it to remain aloft over a scene for extended periods. This in turn allows data to be obtained over a broader range of solar zenith angles. For example, bidirectional reflectance distribution function data taken during the fall 1996 ARM-UAV campaign enabled researchers to test the calibration of channel 1 of the GOES-8 imager.

The ARM-UAV program used the Altus UAV for nine science flights that studied the role of clouds in global climate change. Altus carried a payload of 390 lb to altitudes of 50,000 ft or more.

A flight campaign known as ARESE (ARM enhanced shortwave experiment) took place at the CART site in 1995. The goal was to obtain direct measurements of the absorption of solar radiation by the clear and cloudy atmosphere and to investigate the possible causes of any absorption in excess of model predictions. The experimental approach involved two aircraft with instrument payloads in vertically stacked formation in clear and cloudy skies. A follow-on experiment, ARESE II, conducted at the same site in 2000, refined the experimental approach and set new standards for pre- and post-test calibration and intercomparison of the suite of airborne and ground radiometers.

In October 2004, Will Bolton and a group of scientists associated with the ARM-UAV program spent a month studying clouds around Barrow, Alaska, on the North Slope of the Brooks Range. Bolton says that to really study clouds you have to fly aircraft, either manned or unmanned, to altitudes approaching 60,000 ft, where cirrus clouds are found. These clouds play an important role in the greenhouse effect, because they often contain ice crystals and are very cold. They also retain thermal radiation in the atmosphere. The biggest contributor to the greenhouse effect is water vapor.

Bolton says the UAVs they flew were commandeered for uses outside the cloud program. For several years scientists used an Altus UAV for the global climate cloud studies over Oklahoma. The plane came with a trailer-based command and control center. They have since been relying on the Proteus aircraft, manufactured by Scaled Composites in Mojave, Calif. The Proteus can be flown either remotely or by onboard pilots. It holds two pilots—an advantage, says Bolton, because a UAV is more difficult to control.

The DOE group's activities give scientists better data on cloud characteristics. This information needs improving, says Bolton, and is crucial to developing better models of global climate. Using questionable data on clouds impacts the reliability of predictions generated by the model. For example, if a weather model predicts a certain accumulation of greenhouse gases but uses faulty data on water-formed clouds, the prediction about the CO_2 buildup would be questionable.

The Sandia researchers examine cloud energies in the troposphere by flying over the three DOE sites. Bolton calls this the Grand Tour. They begin by flying over an instrumented site in Oklahoma. They then fly over the Alaska site, as they did last October. They plan to continue this effort in January 2006 with a flyover of a site near Darwin, Australia, located near the equator.

Bolton points out that the clouds are cold in Alaska and warm in the tropics. He also points out that the troposphere is thicker in the tropics, extending higher than 65,000 ft, and that it is thinner in the arctic region.

Bolton says the Oklahoma site area is heavily instrumented by other agencies interested in plotting the thunderstorms and tornadoes that frequently occur in that area. He notes, however, that his group's interest is confined to collecting data on clouds.

Clouds perform an important function in preserving human life. Without them there is drought. Living under an endless blue sky is not the preferred mode of existence for human beings. Clouds mitigate the impact of solar radiation absorbed by the Earth, reflecting some of that radiation back into space. In winter, they return infrared heat to the Earth. A blue sky at night allows the planet to radiate much of the day's heat into what is essentially a deep-space black body.

The researchers will take measurements of the optical and radiative properties of clouds using airborne radiometers and lidar. This information will contribute to a database from which broad trends and a global picture can be extracted over time.

For more information about the ARM-UAV program go to http://armuav.ca.sandia.gov.

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