DOE/SC-ARM-0606

Atmospheric Radiation Measurement
CLIMATE RESEARCH FACILITY
U.S. Department of Energy

ARM Annual Report 2006






Department of Energy
Washington, DC 20585

December 1, 2006

Subject: Annual Report for the Atmospheric Radiation Measurement (ARM) Program and ARM Climate Research Facility

The ARM Climate Research Facility continues to assist the global change research community by providing state-of-the-art scientific infrastructure for interdisciplinary studies of earth systems. Continuous data from permanent sites in Alaska, Oklahoma, and the Tropical Western Pacific, supplemented with data obtained from temporary ARM Mobile Facility deployments, are providing critical information for improving the treatment of cloud and radiative properties in both global and regional climate models.

Prominent leadership changes marked 2006, beginning with a new ARM Chief Scientist at the helm of the ARM Science Team. In June, a new ARM Science Program Director joined the program, providing needed oversight of ARM Science Team research activities as the trend for user facility access continues to escalate.

Noteworthy scientific and infrastructure accomplishments in 2006 include:

- Collaborating with the Australian Bureau of Meteorology to lead the Tropical Warm Pool-International Cloud Experiment, a major international field campaign held in Darwin, Australia
- Successfully deploying the ARM Mobile Facility in Niger, Africa
- Developing the new ARM Aerial Vehicles Program (AVP) to provide airborne measurements
- Publishing a new finding on the impacts of aerosols on surface energy budget in polar latitudes
- Mitigating a long-standing double-Intertropical Convergence Zone problem in climate models using ARM data and a new cumulus parameterization scheme.

Members of ARM's international science team are major contributors to advances in cloud and radiative research. In 2006, ARM scientists authored or co-authored 96 journal articles containing ARM research results. Notably, the *Journal of Geophysical Research-Atmospheres* devoted an entire issue to 18 papers containing ARM research examining the properties and radiative influences of aerosols on climate.

Thank you for interest in and support of DOE's important climate research efforts.

Wanda R. Ferrell, PhD
Program Director
ARM Climate Research Facility

Kiran Alapaty, PhD
Program Director
ARM Science Program

Rickey Petty
Program Director
ARM Aerial Vehicles Program

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On the cover: A setting sun provides the backdrop for a collection of radiometers recording data from the hazy desert sky in Niamey, the capitol of Niger, Africa. The ARM Mobile Facility was stationed there from January through December 2006 to obtain measurements of absorbing aerosols from desert dust in the dry season, and deep convective clouds and associated moisture loadings during the summer monsoon.

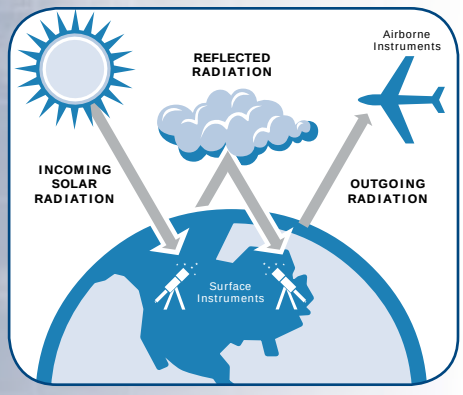
Program Overview

The Role of Clouds in Climate

Research has shown that cloud radiative forcing and feedbacks are one of the major sources of uncertainty in simulations of climate change over the next century. The ARM Program focuses on obtaining continuous field measurements of atmospheric properties and processes, and from these measurements, developing data products that promote the advancement of climate models.

Sophisticated computer models of the earth's climate system are the principal tools used by scientists for simulating climate and predicting its change. The credibility and validity of these models are dependent upon, among other things, their ability to correctly represent physical processes, such as the exchange of energy between Earth and the atmosphere. The representation of cloud processes and their impact on this energy exchange—referred to as Earth's radiation balance—has been recognized for decades as the source of much uncertainty surrounding the prediction of climate variability and change.

The U.S. Global Change Research Act of 1990 established an interagency program within the Executive Office of the President to coordinate U.S. agency-sponsored scientific research designed to monitor, understand, and predict changes in the global environment. To address the need for new research on clouds and radiation, the U.S. Department of Energy (DOE) established the **Atmospheric Radiation Measurement (ARM) Program**, managed through the Office of Science. As part of the DOE's overall Climate Change Science Program, a primary objective of the ARM Program is improved scientific understanding of the fundamental physics related to interactions between clouds and radiative feedback processes in the atmosphere.



ARM researchers use data collected from ground-based and airborne instruments to study the natural phenomena that occur in clouds, and how those cloud conditions affect incoming and outgoing radiative energy.

ARM Science Goals

A major emphasis of the DOE Climate Change Research program is on understanding climate forcing, especially the radiation balance from the surface of the Earth to the top of the atmosphere and how changes in this balance due to increases in the concentration of greenhouse gases in the atmosphere may alter climate. Much of the research is focused on improving the quantitative models necessary to predict possible climate change at global and regional scales.

Research in the ARM Program focuses on resolving the greatest scientific uncertainty in climate change prediction—the role of clouds and their interactions with solar radiation. ARM seeks to develop a better quantitative understanding of how atmospheric properties, including the extent and type of cloud cover and changes in aerosols and greenhouse gas concentrations, affect the solar and infrared radiation balance that drives the climate system. It also includes support to archive and analyze climate change data, including data from the ARM sites, and data on greenhouse gas emissions and concentrations and to make such data available for use by the broader climate change research community.

ARM's goal is addressed through a combination of continuous ground-based observations, data analysis, modeling of local and regional physics, and development of parameterizations for global models. Through these activities, the ARM Program seeks the answers to two principal questions:

- How accurate are both longwave and shortwave radiative transfer calculations for any given column of the atmosphere?

- How well can cloud properties in a column of the atmosphere be predicted from knowledge of larger-scale atmospheric properties?

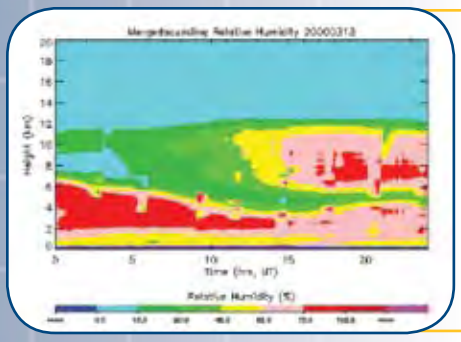
Because of the complexity and global scope of the research involved in answering these questions, the ARM Program collaborates extensively with other laboratories, agencies, universities, and private firms in gathering and sharing data. This collaborative approach allows ARM to leverage its investment in **research sites, instruments, data, and science** to gain the knowledge necessary to improve the accuracy of the computer models used to simulate global and regional climate changes.

Publications Feature ARM Research: *In addition to papers appearing in peer-reviewed journals, several areas of ARM research were featured in high-profile publications within the atmospheric science community in 2006. Examples include:*

- *The Bulletin of the American Meteorology Society included short feature articles about the 2006 deployment of the ARM Mobile Facility in Niger, Africa, and sky imaging techniques developed by ARM researchers to assist with analyses of cloud macrophysical properties. The articles were published in the April and June 2006 issues, respectively.*
- *The ARM Mobile Facility deployment in Africa was also featured in a longer article published in the Global Energy and Water Cycle Experiment (GEWEX) newsletter in February (Vol.16, No.1). In addition, the opening commentary of the August GEWEX newsletter (Vol.16, No.3) cited the use of data acquired from the ARM Climate Research Facility Southern Great Plains site, describing the detailed datasets as a "benchmark against which [global climate model] GCM developers can compare their model codes for cloud-free, liquid cloud, and ice cloud conditions."*

ARM Climate Research Facility: Successful Science Program Leads to User Facility Designation

Through the ARM Program, the DOE funded the development of several highly instrumented ground stations for studying cloud formation processes and their influence on radiative transfer, and for measuring other parameters that determine the radiative properties of the atmosphere. This scientific infrastructure, and resultant Data Archive, is a valuable national and international asset for advancing scientific knowledge of earth systems. In fiscal year (FY) 2003, the DOE designated the ARM infrastructure as a national scientific user facility: the **ARM Climate Research Facility (ACRF)**. The ACRF has enormous potential to contribute to a wide range of interdisciplinary science in areas such as meteorology, atmospheric



Principal Investigator Datasets Now Available: *Principal Investigator (PI) data products are datasets generated by PI algorithms, which complement existing data holdings at the ARM Data Archive. To increase the visibility and availability of these data for use by the global scientific community, ACRF initiated a campaign to collect and archive them. Ten PI datasets were added to the ARM Data Archive in 2006, including preliminary data for the Broadband Heating Rate Profile Project, and continuous water vapor profiles and cloud microbase profiles for each of the ACRF sites. For a complete list of PI data products, see* ***http://www.arm.gov/data/pi_products.stm.***

Continuous high-resolution time series datasets of water vapor vertical profiles for selected 30-day periods at each of the fixed ACRF sites are now part of the PI holdings in the ARM Data Archive.

aerosols, hydrology, biogeochemical cycling, and satellite validation, to name only a few.

Three primary locations—the Southern Great Plains (SGP), Tropical Western Pacific (TWP), and North Slope of Alaska (NSA)—and the portable ARM Mobile Facility (AMF) are heavily instrumented to collect massive amounts of atmospheric measurements needed to create data files. Using these data, ARM scientists are studying the effects and interactions of sunlight, radiant energy, and clouds to understand their impact on temperatures, weather, and climate. As part of this effort, ARM scientists and ACRF infrastructure staff analyze and test the data files to create enhanced data products. Software tools are provided to help open and analyze these products, which are made available for the science community via the ARM website to aid in further research.

The SGP site in Oklahoma provides a wide variability of climate cloud types and surface flux properties, and large seasonal variation in temperature and specific humidity.

Sites Around the World Enable Real Observations

A central feature of the ACRF is a set of instrumented field research locales for measuring atmospheric radiation and the properties controlling this radiation, such as the distribution of clouds and water vapor. To obtain the most useful climate data, three locales were chosen that represent a broad range of weather conditions.

Southern Great Plains

The SGP site was the first field measurement site established by ARM. The SGP experiences a wide variety of cloud types and surface flux properties, as well as large seasonal variations in temperature and specific humidity. The site consists of a highly instrumented Central Facility near Lamont, Oklahoma, and smaller "satellite" facilities scattered over approximately 142,450 square kilometers in north-central Oklahoma and south-central Kansas.

Cooperative partnerships have evolved with a variety of government laboratories and agencies, and with universities, permitting collaborative use of several state-of-the-science radar and climate-observing systems and networks. Collection of continuous measurements at this location began in 1994, with a complete suite of instruments operating since 1996. This site is now the largest and most extensive climate research field site in the world.

Deep atmospheric convection is one of many characteristics in the TWP locale that combine to drive global climate.

Tropical Western Pacific

The TWP locale spans an area roughly between 10°N to 10°S of the equator from Indonesia to the dateline. This area—referred to as the Pacific "warm pool"—is

characterized by warm sea temperatures, deep and frequent atmospheric convection, high rain rates, strong coupling between the atmosphere and ocean, and substantial variability associated with El Niño.

Three instrumented sites operate in the TWP locale. The first of these sites was established in 1996 on Manus Island, Papua New Guinea. Site operations on Manus are conducted in collaboration with the Papua New Guinea National Weather Service. The second TWP site was established on Nauru Island in 1998. Nauru operations are performed with the cooperation of the Nauru Department of Island Development and Industry. A third TWP facility began operating in April 2002 at Darwin, Australia, in partnership with the Australian Bureau of Meteorology. This facility collects data typical of tropical land convection and monsoon circulations.

North Slope of Alaska

The NSA locale is situated on the edge of the Arctic Ocean. This area provides important information for ARM research because fundamentally different climate processes—such as planetary heat loss from the poles and extensive sheets of ice that affect solar absorption and sea level—occur at high latitudes. Due to generally cold temperatures, atmospheric water vapor concentrations in the Arctic are quite low, allowing heat energy from the surface to escape through the atmosphere more easily than in other regions.

The NSA's principal instrumented facility was installed near Barrow in 1997, followed by a smaller remote site at Atqasuk in 1999. Routine operations at these sites are conducted in partnership with employees of Ukpeagvik Iñupiat Corporation/ Science Division.

ARM Mobile Facility

The AMF was developed to address science questions beyond those addressed by the "fixed" measurement sites. The AMF is similar to the permanent ACRF sites in that it contains many of the same instruments and data systems, but is designed to be deployed around the world for campaigns lasting 6–12 months.

The AMF consists of several portable shelters, a baseline suite of instruments, data communications, and data systems. Designed to collaborate with other agency experiments (particularly those with aircraft), it also has the ability to host instruments other than the baseline collection. Datastreams produced by the AMF are available to the atmospheric community for use in testing and improving parameterizations in global climate models.

Unmanned Aerospace Vehicle Program

The ARM Unmanned Aerospace Vehicle (ARM-UAV) Program complements ARM's long-term ground-based measurements of cloud and atmospheric properties by emphasizing instrumented airborne measurement campaigns. UAVs and piloted aircraft may be used to obtain key climate measurements that cannot be made by other means. In situ data obtained from instrumented aircraft at various altitudes provide critical data for studying how clouds interact with solar and thermal radiation. In 2007, the UAV Program will be restructured as the ARM Aerial Vehicles Program.

The NSA locale provides data about cloud and radiative processes in the Arctic, which has been identified as one of the most sensitive regions to climate change.

In 2006, the AMF was stationed in Niger, Africa, to collect data on desert dust and summer monsoons. The AMF moves to Germany in 2007 as part of a precipitation study in the Black Forest region.

The high-altitude Proteus aircraft flew eight missions during the Tropical Warm Pool-International Cloud Experiment, held in Darwin, Australia, in January and February 2006.

Where in the World is ACRF? *The online ACRF site map was integrated with Google™ Maps API technology in 2006 to enhance ARM website users' experience. Web visitors and data subscribers can now easily see where ACRF sites are located around the world, and use the Google map feature to zoom in—sometimes close enough to actually see the site facilities in the satellite images! Google map technology also makes it easy to add site markers as the AMF continues its worldwide travels.*

State-of-the-Art Instrumentation Yields Comprehensive Datasets

ARM's approach to instrument development and procurement began with a fundamentally new idea in mind: carry out continuous and simultaneous ground-based observations of the atmospheric column using a suite of passive and active sensors. Previously, most sensors used to investigate atmospheric properties and compositions were strictly research instruments and, in many cases, inadequately understood and calibrated. The goal of ARM's instrument development initiative was to bring existing research instrumentation to the advanced state of development required to allow routine, highly accurate operation in remote areas of the world, and to develop new instrumentation as required.

Because side-by-side comparisons and calibration techniques are critical to instrument understanding, the ACRF routinely sponsors and hosts field campaigns focused on this subject. As a result, the new generation of ground-based, remote sensing instruments include millimeter-wave cloud radar, Raman lidar, infrared interferometers using electronic coolers (instead of cryogens), and updated sky imagers, among others. These instrument arrays represent some of the most sophisticated tools available for conducting atmospheric research.

In addition to the instruments, data on surface and atmospheric properties are also gathered through aircraft, forecast models, satellites, field campaigns, and value-added processing. Once collected, the information is sent to site data systems and reviewed for quality. Approved data are then stored in the ARM Data Archive for use by the atmospheric science community.

Science Team Approach Encourages Collaboration

ARM's Science Team is a unique collaboration of laboratory, university, agency, and private partners from around the globe. From the United States and abroad, cloud and radiation scientists ranging from senior scientists to post-docs and students make up the team. Though diverse in geographic location, these science representatives provide the most direct channel through which ARM research results can affect development and evaluation of global climate models. Key support is provided by software and hardware engineers who maintain the infrastructure necessary for advancing ARM Science Team research.

New Leader for ARM Science Team: *The ARM Science Team is led by a Chief Scientist, who is selected by DOE for a 3-year term. In 2006, Dr. Warren Wiscombe took the helm as ARM's new Chief Scientist. As one of the founding members of the ARM Program, Dr. Wiscombe helped develop the original ARM Science Plan and has conducted collaborative ARM research since 1990. His research has centered on remote sensing and radiative transfer of clouds, single-scattering theory, and the development of new satellite system concepts.*

Working Groups Provide Leadership, Focus on Specific Problems

To enable focused research on the various pieces of the cloud physics puzzle, the ARM Program divides its research into key areas, or Working Groups. These groups are the principal organizational structure within the ARM Science Team. Each Working Group concentrates on a specific set of issues related to climate modeling. The Working Groups include:

- **Aerosols** – relate observations of radiative fluxes and radiances to atmospheric composition, and use these relationships to develop and test parameterizations to accurately predict atmospheric radiative properties
- **Cloud Parameterizations and Modeling** – relate observations and data analysis to climate model development and evaluation to improve cloud parameterizations in global climate models
- **Cloud Properties** – develop and implement algorithms that characterize the physical state of the cloudy atmosphere, including cloud occurrence, cloud condensed water amount, and cloud optical properties
- **Clouds with Low Optical [Water] Depth** – determine the best strategy for measuring clouds with low optical depths and low liquid water paths at ACRF locales
- **Instantaneous Radiative Flux** – test radiation parameterizations, particularly for shortwave radiation and cloudy-sky conditions, at the accuracy required for climate studies.

Well Deserved Recognition: *In September, Dr. Robert Ellingson, a member of the ARM Science Team since 1990 and leader of the Instantaneous Radiative Flux Working Group since 1992, received the prestigious DOE Distinguished Associate Award. This is the DOE's highest award and is given only to those who have made significant accomplishments in their fields. Dr. Ellingson was recognized for his role as one of the leading architects in the creation of the ARM Program. The award cited his tenure as Chair of the ARM Science Team Executive Committee, as well as his unselfish service and strong scientific leadership in charting the path forward in achieving ARM Program goals.*

Oversight Ensures Relevant Science, Promotes Facility Use

Oversight of the ACRF is provided by the ACRF Program Director. The ACRF Program Director routinely conducts programmatic reviews using subcommittees of the Biological and Environmental Research Advisory Committee. In addition, all proposals for facility use undergo a rigorous review process. The review process has two primary dimensions—a science peer review and a review of costs, logistics, and schedule, performed by the ACRF Infrastructure Management Board (IMB). Proposals that are projected to incur costs between $101K to $300K are forwarded to the ACRF Science Board for review.

The IMB assesses the availability and resource requirements of the proposed facility usage. The objective of the IMB is to provide fair and equitable distribution of available funds between the fixed-site facility infrastructure costs, field campaigns (also known as intensive operational periods, or IOPs), and special projects. A primary objective of ACRF is to increase external (non-ARM) use of the facility without inhibiting the achievement of ARM scientific progress.

Based on input by the science community, recommendations for future development of the ACRF are developed annually. These recommendations are presented to the ACRF Program Director for consideration and potential inclusion in budget and spending plans.

ACRF Science Board Welcomes New Chair: *In January, Dr. Sally Benson was appointed to a 2-year term as the new chair of the 11-member ACRF Science Board. As the chair, Dr. Benson will lead the Board—composed of highly respected ARM-supported scientists and representatives from the external climate research community—in reviewing scientific proposals for use of the ACRF.*

New Director for ARM Science Program: *In June, Dr. Kiran Alapaty joined the Climate Change Research Division within DOE's Office of Biological and Environmental Research to manage the ARM Science Program. Prior to Dr. Alapaty's appointment, both the ARM Science Program and ACRF infrastructure were directed by Dr. Wanda Ferrell. Dr. Alapaty will direct and oversee the research and planning of the ARM Science Team, and will work closely with Dr. Ferrell, Program Director for the ACRF.*

Global Program Managed by Many

Eight national laboratories and numerous government agencies, universities, private companies, and foreign organizations are involved in the ARM Program and ACRF. Each entity serves a vital role in managing and conducting the research, operations, and administration of the science program and user facility. Representatives of the ARM Program make up the majority of ACRF users.

For ARM Program science activities, direction and oversight is the responsibility of **DOE Headquarters**. A **Science Team Executive Committee** reviews scientific progress and provides recommendations for future research. **Working Group**

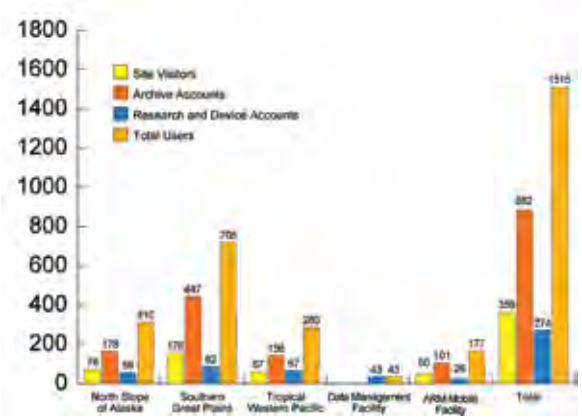
representatives coordinate the ARM research agenda as appropriate. The site infrastructure that enables ARM science is managed through the ACRF.

The ACRF is also directed by **DOE Headquarters**. An **Infrastructure Management Board** coordinates the scientific, operational, data, financial, and administrative function of the ACRF. An 11-member **Facility Science Board**, selected by the ACRF Program Director, serves as an independent review body to ensure appropriate scientific use of the ACRF.

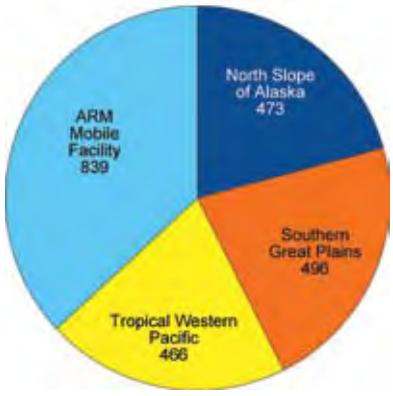
Fiscal Year 2006 Budget Summary and User Statistics

Atmospheric Radiation Measurement Program FY 2006 Budget ($K)	
Total ARM Program	**46,274**
Infrastructure	31,443
Science	14,831

User Statistics for the Period of October 1, 2005 - September 30, 2006



User Summary



Visitor Days by Site

Operational Statistics for the Period October 1, 2005 - September 30, 2006		
	Data Availability	
SITE	**GOAL**	**ACTUAL**
NSA	0.90	0.94
SGP	0.95	0.97
TWP	0.85	0.95
Site Average	**0.90**	**0.95**
AMF*	0.95	0.98

**Because the AMF is a temporary site, its data availability is based on operational days during field deployment, not 24 hours a day/365 days a year like the fixed sites.*

Key Accomplishments

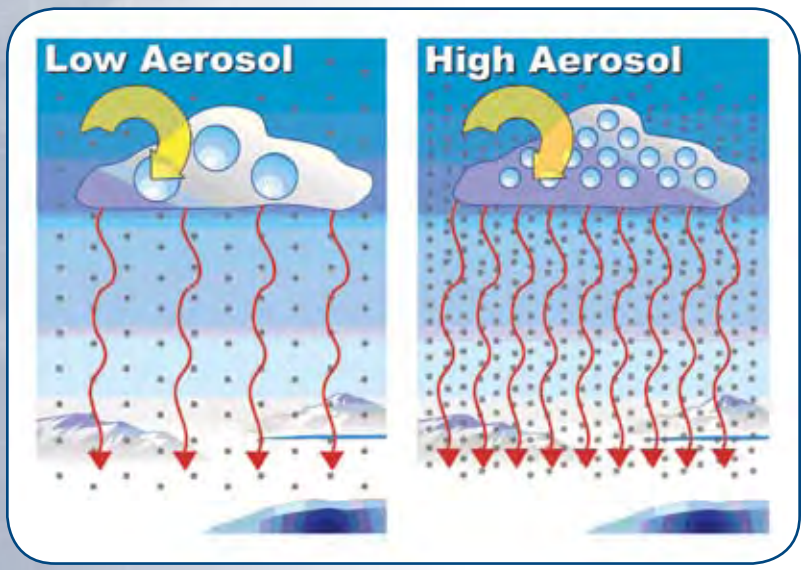
The following pages highlight a selection of research results, field campaigns, and infrastructure achievements from FY 2006 (October 2005 through September 2006). A complete list of FY 2006 field campaigns and publications is provided in the back of this report. More detailed information can be found on the following web pages:

- *http://www.arm.gov/publications/pub_database.stm* for Publications
- *http://www.arm.gov/science/fc.stm* for Field Campaigns
- *http://www.arm.gov/acrf/updates.stm* for Operations Updates.

Research Highlights

Members of ARM's Science Team publish an average of 150 refereed journal articles per year, and ARM data are used in many studies published by other scientific organizations. In addition, ARM investigators present their research at key conferences each year. These documented research efforts represent tangible evidence of ARM's contribution to advances in almost all areas of atmospheric radiation and cloud research, and their relevance to climate change modeling efforts.

Aerosols Help Clouds Warm Up Arctic



In a process known as the first aerosol indirect effect, enhanced aerosol concentrations cause the droplets in a cloud to be smaller and more numerous within a cloud of fixed water amount. This study found that this process can make many clouds more opaque and emit more thermal energy to the surface.

In a process known as the first aerosol indirect effect, an increase in aerosol amount causes an increase in cloud droplet concentration and a decrease in droplet size within a cloud of fixed water amount. Until now, scientists knew little about how this process would affect the cloud's emission of thermal energy to the surface. In January 2006, scientists supported by the ARM Program reported in *Nature* magazine that enhanced aerosol concentrations increase the amount of thermal energy emitted by many Arctic clouds to the surface, augmenting the increase caused by greenhouse gas warming. The increase is comparable to the surface-warming effect from established greenhouse gases, suggesting it plays a significant role in the Arctic energy balance.

The key to understanding this process lay in the long-term measurements obtained from the ACRF site in Barrow, Alaska. In concert with aerosol measurements made by the adjacent National Oceanic and Atmospheric Administration (NOAA) Climate Modeling and Diagnostics Laboratory, 6 years of data from the Barrow site were analyzed to determine the impact of aerosol on Arctic clouds and the surface thermal energy budget. The study focused on thin, single-layer clouds close to the surface, with temperatures that would favor them containing liquid water (as opposed to ice). Liquid water was recently discovered to largely govern Arctic cloud radiative properties during spring and summer, with liquid water found in clouds at temperatures as low as –34°C.

The analysis showed that the first aerosol indirect effect operates in these clouds that frequently occur in the Arctic, causing cloud droplets to be smaller when the aerosol concentrations are high. At the same time, there is a significant increase measured in the clouds' downwelling thermal energy. The portion of the energy that can be attributed solely to the systematic changes in the cloud droplet size is an average of 3.4 W/m^2, comparable to the surface warming effect from established greenhouse gas enhancements. Because the cloud amount during the Arctic spring generally exceeds 80 percent, this implies that the observed enhancement is significant to the Arctic energy balance.

(Reference: Lubin, D, and AM Vogelmann, 2006: "A climatologically significant aerosol longwave indirect effect in the Arctic," *Nature*, 439, 26 January, 453-456, doi:10.1038/nature04449.)

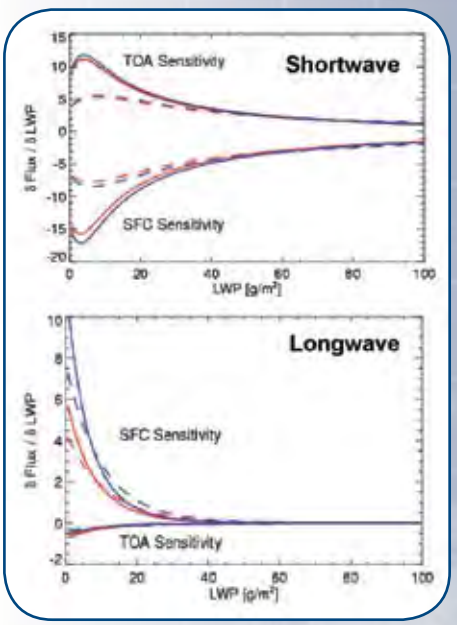
"Thin" Liquid Water Clouds are Heavy in Radiative Importance

Liquid water path, or LWP, is a term used to quantify the total amount of liquid water in column through a cloud. If the LWP is less than about 100 gm^2, the cloud becomes tenuous and can be referred to as "thin." In a paper accepted by the *Bulletin of the American Meteorological Society*, ARM scientists show that shortwave and longwave radiative fluxes are very sensitive to small changes in the LWP for "thin" clouds. Further, their research shows that methods currently used to observe cloud LWP for climate studies are challenged to achieve the accuracy needed to accommodate this large sensitivity.

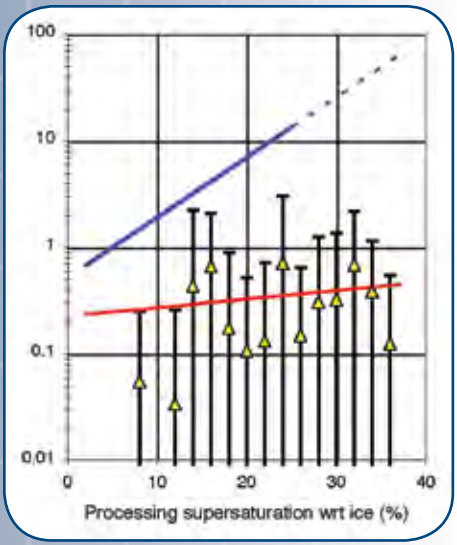
Over the climate regimes encompassed by all the ACRF sites—the Arctic, mid-latitudes, and tropics—approximately 50 percent of the clouds containing liquid water are "thin." Because thin clouds occur so frequently in the world's main climate regimes, their influence on the Earth's radiative energy balance must be accurately quantified in order to understand our climate. Observations from radiometers at the surface or on satellites, via sophisticated methods, are used to determine cloud LWP. These observations are essential for obtaining the type of long-term observations needed for cloud and climate studies. ARM scientists used data from the SGP site to ascertain the accuracy of these measurements by evaluating the results from 18 state-of-the-art methods, which span the spectrum of techniques currently used.

ARM researchers used model calculations to illustrate the large sensitivity of broadband fluxes to small changes in cloud LWP, as would be seen at the surface and at the top of atmosphere. Data plots from the model calculations showed that the change in flux per unit LWP change were greatest for small LWPs, and decreased as LWP increased. In addition, shortwave fluxes were shown to be more sensitive than longwave fluxes. The surprising result is that, even for the simplest cloud, very large discrepancies were found among the different determinations of cloud LWP. The differences carry significant implications for the broad climate community's ability to observe and subsequently represent these clouds in climate models.

(Reference: Turner, DD, AM Vogelmann, R Austin, JC Barnard, K Cady-Pereira, C Chiu, SA Clough, CJ Flynn, MM Khaiyer, JC Liljegren, K Johnson, B Lin, CN Long, A Marshak, SY Matrosov, SA McFarlane, MA Miller, Q Min, P Minnis, W O'Hirok, Z Wang, and W Wiscombe, 2006: "Thin liquid water clouds: Their importance and our challenge." *Bull. Amer. Meteor. Soc.*, accepted.)



Model calculations show changes to the daily averaged broadband flux (W/m^2) per unit LWP change at the surface (SFC) and top of atmosphere (TOA). The simulated sky is overcast, and the cloud is placed in the lower 1 kilometer of atmospheres typical of mid-latitude summer (red) and mid-latitude winter (blue). The cloud uses common average, effective drop sizes of 6 microns (solid) and 12 microns (dashed).



Project-average IN concentration data from M-PACE are shown, processed in finite bin intervals as a function of ice supersaturation. A best fit for the current binned and weighted data is shown as a solid red line; for comparison, the blue line shows a standard ice nucleation parameterization used in many models for the same supersaturation range.

Low Ice Nuclei Concentrations Contribute to Cold Liquid Clouds

Clouds play a particularly important role for the surface energy balance in the Arctic, but are difficult to model. One possible reason for this is the difference in the aerosol properties of the Arctic atmosphere compared to lower latitudes. Global climate models used to assess climate change use the same cloud and aerosol descriptions in the Arctic as anywhere else on Earth, and are calibrated to provide a reasonable global climate. However, applying formulations optimized for mid-latitude and tropical conditions to the Arctic—where conditions are clearly different—results in a poor representation of this region.

To better understand cloud processes in this region, the Mixed-Phase Arctic Cloud Experiment (M-PACE), conducted from late September 2004 through October 2004 in the vicinity of the NSA locale, successfully documented the microphysical structure of Arctic mixed-phase clouds. Liquid was found in clouds with cloud-top temperatures as cold as -30°C, the coldest cloud-top temperature warmer than -40°C sampled by the aircraft. Observations in widely different forcing conditions indicated that the cause of the persistent liquid in these cold, ice-precipitating clouds was not in their dynamical characteristics, but rather was microphysical in origin. The prevalence of liquid down to these low temperatures could be explained by the relatively low ice nuclei (IN) concentrations measured.

Concentration measurements of IN (shown in the figure) included a substantial contribution (~87 percent) from measurements for which no IN were detected, and average concentrations were much lower than are measured at lower latitudes. These data were compared to a parameterization commonly used in many models, often without regard to the location, season, or altitude being modeled. The parameterization was clearly not representative of average IN behavior as assessed during M-PACE flights in the vicinity of lower level Arctic stratiform clouds. These results indicate that continued use of this parameterization will impair scientists' ability to predict cloudiness and related radiative forcing in this region, and emphasize the need to include realistic treatments of aerosols and aerosol/cloud interactions in future climate simulations. These results also suggest that global models which under-predict liquid-water clouds may feature a larger shift from ice to liquid clouds as the model climate warms. This constitutes an enhanced, unrealistic, positive feedback on climate change and may partly explain the large model sensitivity to such features as projected ice cover.

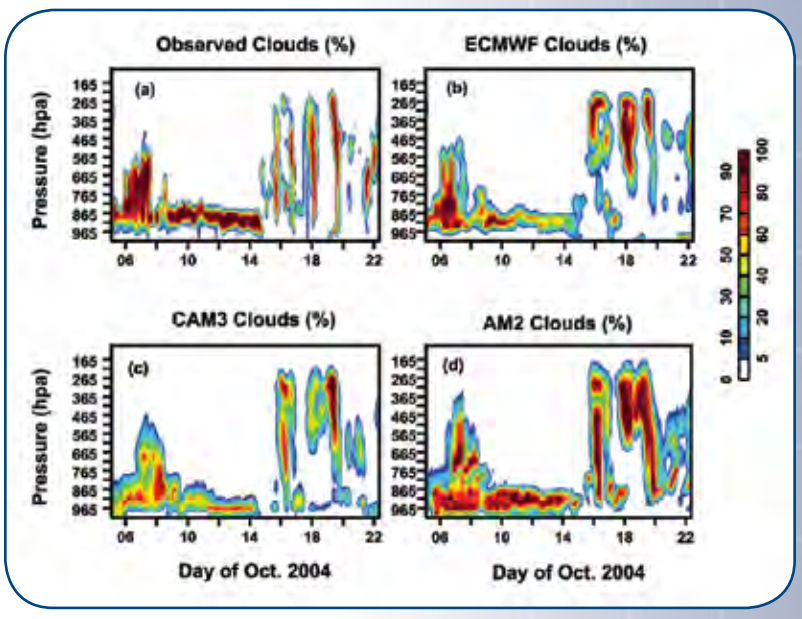
(References: (1) Prenni, A, JY Harrington, M Tjernström, PJ DeMott, A Avramov, CN Long, SM Kreidenweis, PQ Olsson, J Verlinde, 2006: "Can ice-nucleating aerosols affect Arctic seasonal climate?" *Bull. Amer. Meteor. Soc.*, accepted. (2) J Verlinde, JY Harrington, GM McFarquhar, VT Yannuzzi, A Avramov, S Greenberg, N Johnson, G Zhang, MR Poellot, JH Mather, DD Turner, EW Eloranta, BD Zak, AJ Prenni, JS Daniel, GL Kok, DC Tobin, R Holz, K Sassen, D Spangenberg, P Minnis, TP Tooman, MD Ivey, SJ Richardson, CP Bahrmann, M Shupe, PJ DeMott, AJ Heymsfield, R Schofield 2006: "The Mixed-Phase Arctic Cloud Experiment (M-PACE)." *Bull. Amer. Meteor. Soc.*, in press.)

Special Issue of JGR Features Aerosol Field Campaign

The ARM Aerosol Intensive Operational Period in 2003 yielded an unprecedented 18 peer-reviewed papers published in a special issue of the Journal of Geophysical Research. These papers capture the state of the science in terms of measurement of the optical properties of ambient-state aerosols. This special issue includes results from successful "first-ever" instrument deployments and provides measurement comparisons involving both redundant and independent determinations of key aerosol optical properties that govern the direct and indirect effects of aerosols on climate.

Models Evaluated for Consistency, Accuracy in Simulating Arctic Cloud Systems

The effects of climate change have been shown to first appear in the sensitive Arctic environment. However, accurately representing Arctic clouds and interactions between clouds and radiation in global weather forecast and climate models has been a challenging task in the modeling community. This is mainly due to a lack of sufficient observations and basic cloud studies in the Arctic.



Temporal and vertical distributions of observed and simulated clouds from ECMWF, CAM3, and AM2 at Barrow, Alaska, during M-PACE, show good consistency in cloud occurrence, but wide variability in cloud microphysical properties.

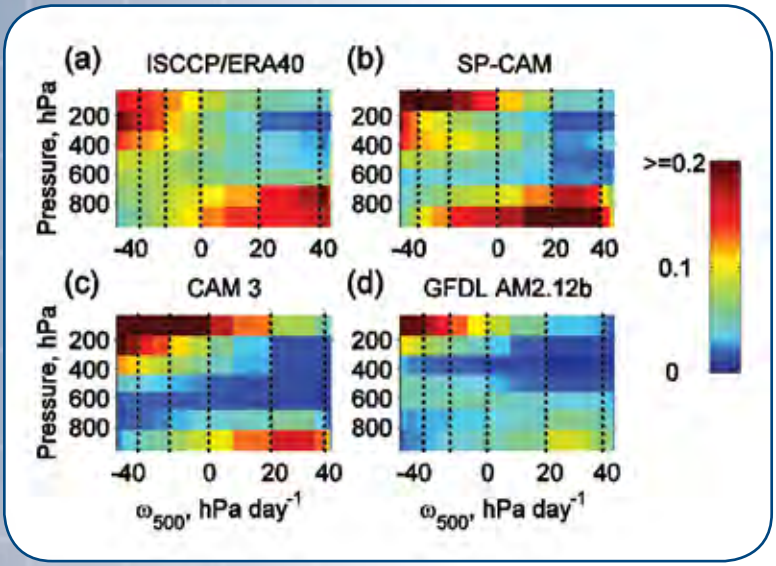
With the data collected from M-PACE (see previous highlight), ARM scientists evaluated the performance of three major models in simulating the Arctic cloud systems observed during the experiment. Two major U.S. climate models were evaluated: the Community Atmosphere Model (CAM3) of the National Center for Atmospheric Research, and the Atmosphere Model (AM2) of the NOAA Geophysical Fluid Dynamics Laboratory. These climate models were evaluated using a framework developed through a joint effort between the DOE's Climate Change Prediction Program and ARM Program, called the CCPP-ARM Parameterization Testbed (CAPT). This testbed is a diagnostic tool that allows running climate models in weather forecast mode so that climate models can be directly assessed using ARM data. The third major model—the weather forecast model of the European Center for Medium-Range Weather Forecasts (ECMWF)—was directly assessed using the M-PACE data.

As described in the *Journal of Geophysical Research*, their study revealed that though the models simulated the overall occurrence of clouds fairly consistently, the microphysical properties of the clouds were widely varied and were in substantial error. In particular, the two climate models simulated cloud bases that were too low, and significantly underestimated the observed cloud liquid and ice water contents in the mixed-phase boundary-layer clouds. These problems are closely related to potential deficiencies with the parameterizations of clouds and cloud microphysical processes in these models. The errors with the simulated cloud fields directly affect the simulation of radiative fluxes.

All three models overestimated the outgoing longwave radiation at the top of the atmosphere, and the ECMWF and CAM3 models substantially underestimated the incoming longwave radiation when boundary-layer clouds were present. Such biases in simulated radiation impact the simulated surface energy budget. The fine resolution of the ECMWF model allowed a further comparison with ARM observations, and showed that the ECMWF model had a much larger energy loss than observed at the surface during the M-PACE period. ARM data from MPACE will be used to suggest improvements for these models.

(Reference: Xie, S, SA Klein, JJ Yio, ACM Beljaars, CN Long, and M Zhang, 2006: "An assessment of ECMWF analyses and model forecasts over the North Slope of Alaska using observations from the ARM Mixed-Phase Arctic Cloud Experiment," *J. Geophys. Res.*, 111, D05107, doi:10.1029/2005JD006509.)

Superparameterization Shows Promise for Cloud and Climate Modeling



Comparison of (a) ISCCP cloud fraction for 30S-30N sorted by ECMWF ERA40 with ISCCP-simulator cloud fraction of (b) SP-CAM model climatology, (c) CAM 3 (Eulerian core) Atmospheric Model Intercomparison Project (AMIP), and (d) GFDL AM2.12b AMIP simulations. The cloud fraction is summed over all optical thickness categories.

Based on a combination of theory and observation, scientists use approximations of various cloud properties as input, or parameters, to global climate models (GCMs). These approximations, called parameterizations, are what drive the results simulated by the models. The better the parameterization, the better the model can simulate reality. Taking this a step further, the use of a cloud-resolving model (CRM) to replace traditional cloud parameterizations represents a potential breakthrough to more realistically simulate subgrid-scale motions and thus more accurately simulate cloud fraction. This new approach is called superparameterization.

In *Geophysical Research Letters*, ARM researchers present the first calculations of the climate sensitivity of an atmospheric GCM that uses a CRM as a convective superparameterization. The climate sensitivity was analyzed by comparing the top-of-atmosphere radiation budgets of 3.5-year simulations with specified climatological sea surface temperature (SST) and with the SST increased by 2K. Their analysis showed weak climate sensitivity primarily due to an increase in low cloud fraction and liquid water in tropical regions of moderate subsidence, as well as substantial increases in high-latitude cloud fraction. These increases were primarily associated with boundary-layer clouds, which are not well resolved by the horizontal and vertical grid of a superparameterization or a GCM. At the same time, the model showed comparable climate sensitivity to recent aqua-planet simulations of a global CRM. This somewhat surprising conclusion encourages further study, especially using a more diverse range of high-resolution global modeling frameworks.

In addition, the researchers compared global features of the low-latitude (30N-30S) cloud climatology of the superparameterized model (SP-CAM) against satellite observations from NASA's International Satellite Cloud Climatology Project (ISCCP). The two major U.S. climate models—NCAR's Community Atmospheric Model (CAM) with the traditional parameterization and NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) climate model (AM2.12b)—were also included in the comparison. The observations included top-of-atmosphere cloud radiative forcing, cloud LWP from passive microwave radiometry, and the joint distribution of cloud-top temperature and cloud optical depth. GCM grid columns and observations were binned based on their monthly-mean 500 hPa vertical velocity. This sorts the model output into dynamical regimes with different characteristic cloud types that range from strong deep convection in regions of mean ascent to boundary-layer clouds in regions of persistent mean subsidence. The goal was to see whether the clouds were more realistically represented in the superparameterized GCM than in the leading conventional GCMs from the United States.

The superparameterized GCM simulated the cloud radiative forcing and LWP with fidelity comparable to current GCMs. This is an encouraging result because little tuning has been done to constrain poorly-known parameters in the

superparameterized GCM as compared to current GCMs, which do so using cloud radiative forcing observations. Even more encouraging is that the superparameterized GCM simulated the ISCCP-derived distribution of cloud heights and thicknesses better than current GCMs, even in boundary-layer cloud regimes, where superparameterization might be expected to perform less favorably. The ARM datasets will provide future opportunities to evaluate and improve this exciting new approach for parameterizing cloud processes in GCMs.

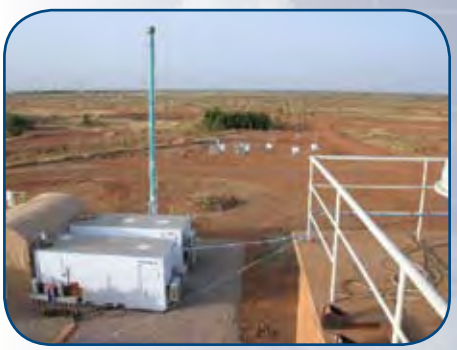
(Reference: Wyant, MC, M Khairoutdinov, and CS Bretherton, 2006: "Climate sensitivity and cloud response of a GCM with a superparameterization," *Geophys. Res. Lett.*, 33, L06714, doi:10.1029/2005GL025464.)

Featured Field Campaigns

ACRF users—whether sponsored by ARM or other scientific organizations—regularly conduct field campaigns to augment routine data acquisitions and to test and validate new instruments. A field campaign that is proposed, planned, and implemented at one or more research sites is also referred to as an intensive operational period, also known as an IOP, as during this time, increased activities to support additional data acquisition occur. These concentrated efforts direct focused resources on a specific research area, resulting in valuable data to further scientific understanding of cloud and radiative processes.

Influence of West African Monsoon on Global Climate

Dust from Africa's Sahara desert—the largest source of dust on the planet—reaches halfway around the globe. During its travels through Western Africa, Europe, and across the Atlantic Ocean to Central and North America, the dust particles absorb sunlight, warming the atmosphere and providing condensation nuclei for raindrops. Unfortunately, Africa is one of the most under-sampled climate regimes in the world, leaving scientists to wonder about the dust's contribution to global climate.

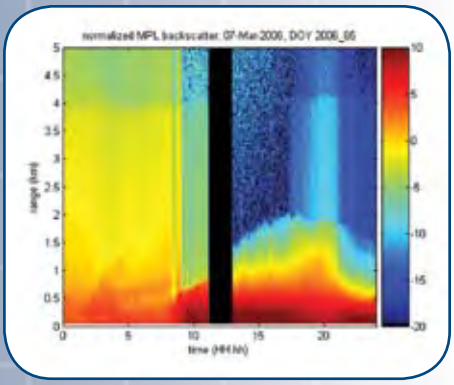


Located at the airport in Niamey, the capitol of Niger, Africa, the AMF collected atmospheric data from January through December 2006.

In January, the AMF began collecting atmospheric data on absorbing aerosols from desert dust in the dry season, and moisture loadings from deep convective cloud systems during the summer monsoon. Deployed in Niamey, Niger, and within view of an overhead geostationary satellite, measurements obtained by the AMF will provide information about radiative feedback of the Earth's atmosphere in the region, the interaction of clouds with dust and aerosols, and West African monsoons.

A valuable part of the dataset will be complementary measurements obtained from an ancillary site located approximately 60 km away from the airport. Reflecting the natural environment of the Sahel region, the site was chosen as the most representative of the countryside, and the location was deemed suitable for making radiometric and meteorological observations. "Sahel" is an Arabic word for "border" or "margin" and accurately describes the transition zone between the arid Sahara to the north, and the wetter, more tropical area to the south.

Combined with associated satellite data, measurements from the 1-year AMF deployment in Niamey will allow scientists to study how dust storms start, how far they spread, and what impact they have on incoming solar energy and the generation of monsoons. Also, in providing the first well-sampled direct estimates of the

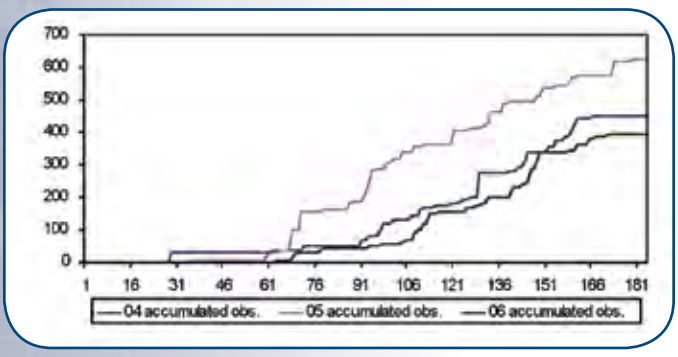


In this lidar (pulsed laser) image of the dust storm, the red color indicates significant scattering of the laser light. Note the very dark red color appearing at about 0930 as the dust storm arrives. The layer grows in height with time. Because the dust attenuates the laser light, the actual height of the layer cannot be accurately determined at times, but it extended to about 2 km.

energy balance across the atmosphere, it will lead to a greater understanding of the atmosphere than could be gained from either dataset alone. Ultimately, this information will help to improve model simulations of global climate, as well as increase scientific understanding of the influence of the West African Monsoon on the physical, chemical, and biological environment, both regionally and globally.

Results: On March 7, the AMF recorded the onset of the largest Saharan dust storm recorded in the Niamey area in the past 2 years. The dust storm approached the site at about 0930 UTC and rapidly reduced visibility. A thicker dust cloud, several kilometers in height, rolled in about 1230 UTC, reducing visibility even further. The dust storm continued unabated for 2 more days and then gradually dissipated over the next several days. Measurements of optical depth—which indicates how much a specific layer in the atmosphere attenuates solar radiation—during the first 2 months of 2006 were around 0.3 to 0.5 in Niamey. During the March dust storm, optical depths were in excess of 3, which decreased the solar radiation reaching the surface by about 150 W/m^2, or 15 percent of its usual value. Optical depth was approximately constant with visible wavelength, indicating the dust particles were relatively large in size. Average dust particle size decreased with time, suggesting the larger particles fell to the surface, leaving a smaller size distribution.

In June, the monsoon season began. After below-average rainfall in June and July, August rainfall was slightly above the 1941–2000 mean. Thus, the various AMF measurements made in August should be fully representative for the peak month of the monsoon season. However, by the end of August, the accumulated rainfall was even less than in 2004, after which famine conditions occurred in southern Niger east of Niamey and received considerable international publicity. September received barely half of the 1941–2000 average rainfall, and cumulative rainfall for the monsoon season was the second lowest in the last 20 years. Preliminary results indicate that the 2006 monsoon season at Niamey will fall into the "very bad" category on an overall basis.



Accumulations of daily rainfall in Niamey, Niger, for the months of April through September for the last 3 years indicate a dry monsoon season for 2006.

These are just a few examples of the data collected by the AMF in Niamey. Development of a comprehensive seasonal cycle background for the entire 2006 AMF deployment is planned, including meteorological parameters such as daily maximum and minimum temperature, dew point, vapor pressure, and visibility.

Tropical Clouds Probed for Climate Clues

For almost 4 weeks in January and February, simultaneous air, sea, and ground measurements were obtained during the Tropical Warm Pool-International Cloud Experiment (TWP-ICE) in Darwin, Australia. In a collaborative effort led by the ARM Program and the Australian Bureau of Meteorology, more than 200 researchers, graduate students, and infrastructure staff from the Unites States, Canada, the United Kingdom, Japan, and Australia took part in the complex experiment. Timed to coincide with maximum rainfall and convective activity during the summer monsoon season across northern Australia, the experiment focused on cirrus clouds associated with tropical convection, and their impact on the environment.

Cirrus clouds are ubiquitous in the tropics but the properties of these clouds are poorly understood. Therefore, a crucial product from the experiment was the collection of a dataset to produce the necessary link between tropical cirrus cloud properties and computer models used to simulate them. To collect these data, a fleet of aircraft, a research ship, and a network of strategically located surface sites were operated to supplement the continuous data collected at the ACRF site in Darwin.

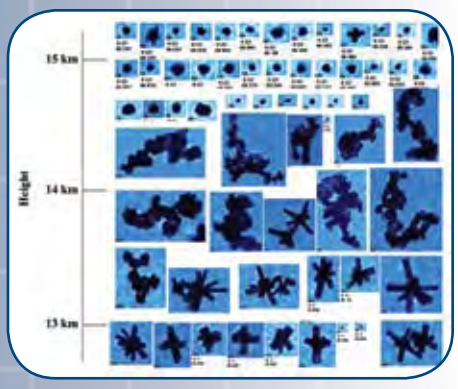
The aircraft flew below, in, and above the clouds in various patterns to collect cloud property data. Weather balloons were launched every 3 hours from outlying surface sites to collect measurements of wind speed, wind direction, pressure, temperature, and humidity. These measurements provided a detailed record of meteorological conditions within the experiment domain throughout the course of the experiment. Additional surface sites were equipped with passive instrumentation and lightening detection systems to measure turbulent and radiant energy exchange between land and the atmosphere. Radars at the surface sites were used to obtain profiles of cloud properties and wind speed, and to provide 3-dimensional distributions of precipitation for daily mission planning and analysis. Finally, the Southern Surveyor research vessel, located about 97 kilometers offshore in the Timor Sea, was equipped with a full complement of surface-based instrumentation for measuring atmospheric properties. The ship also served as one of the sites for launching weather balloons and measuring energy fluxes at the surface.

While on the ground, the Twin Otter (left) and Proteus (right) shared hangar space at the Royal Australian Air Force base for the duration of TWP-ICE field operations.

Daily activities and logistics for this complex experiment were conducted out of operations headquarters, located at Charles Darwin University. In addition to ensuring the overall safety of the participants, each day involved monitoring the data and operational status of the outlying ground sites and aircraft, conducting a series of briefings to review current weather forecasts and the desired science goals, and making a decision as to the suitability of weather conditions for successful science flights. On flight days, science team members guided the aircraft missions from the Bureau of Meteorology's Forecast Center in Darwin.

Results: During TWP-ICE, a progression of weather systems provided researchers with a broad range of conditions for studying cloud properties. The experiment began with an active monsoon period with widespread convection, cloud cover, and precipitation. During this period, a large storm system passed directly through the experiment array, providing a unique look at a tropical storm. After the system passed, the region settled into a less active period. However, the storm continued to produce cirrus over the area for several days, providing an excellent opportunity to study the evolution of tropical cirrus layers. This period was followed by several days of clear skies. The experiment ended with a week of so-called "break" conditions when convection tended to be localized in coastal regions and exhibited a strong diurnal cycle.

Twenty missions with multiple aircraft flying at altitudes ranging from 60 feet to 55,000 feet were completed throughout the course of the experiment, providing critical in situ cloud observations combined with observations of the atmospheric environment. Because high-altitude tropical clouds impact the energy exchange between earth and space, they have a large impact on climate and global weather patterns. In addition to showing researchers the composition of high-altitude



Approximately midway through the experiment, images from instrumentation on the high-altitude Proteus aircraft showed distinct differences in ice particle shape and size as a function of temperature and altitude. These factors influence the longevity of the cloud, and therefore the amount of radiative energy both reaching and escaping the earth.

clouds, the in-cloud observations will be used to refine cloud properties derived from long-term data obtained at the permanent site in Darwin.

While the aircraft provided detailed measurements of cloud properties, weather balloons and surface flux measurements provided critical data for constraining computer simulations of the convection during the TWP-ICE period. With these observations used as inputs, cloud model simulations will be performed to generate cloud fields, which will then be compared with the cloud observations. In this way, the experiment dataset can be used to evaluate cloud models in a tropical environment. The dataset obtained in Darwin will be used for years to come as scientists seek to refine computer models for forecasting regional weather and simulating climate change.

To facilitate ongoing data analysis and collaboration between the various groups associated with the experiment, a pair of workshops was held in November. The first workshop was hosted by the ACTIVE/SCOUT teams—the European component of the Darwin experiment—and was held in Cambridge, United Kingdom. ARM representatives attended this workshop to present results from the TWP-ICE and obtain detailed information about the status of the ACTIVE/SCOUT measurements. The following week, a TWP-ICE workshop was held in New York City. This workshop also included an ACTIVE/SCOUT component, but focused on TWP-ICE. At both meetings, details of measurements were presented and roundtable discussions provided a forum to develop focused plans for the next stage of analysis.

As part of the Aircraft Carbon field campaign, a set of carbon-cycle instruments and sample collection systems were added to the aircraft that routinely collect aerosol measurements at the ACRF SGP site. The airplane at upper left was collecting flasks at the same time as they were being collected at the 60-meter tower.

Aircraft Carbon Field Campaign Measures Carbon Dioxide Concentration Profiles

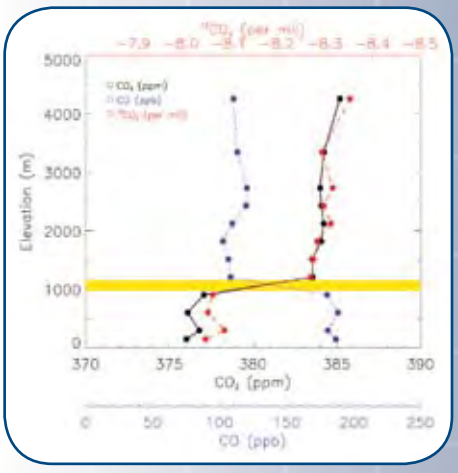
July 2006 marked the beginning of a 2.5-year field campaign at the SGP site to obtain airborne trace-gas measurements. Trace gases include harmless inert gases, such as helium and neon, but also radiatively active gases, like methane and carbon dioxide. These latter gases, especially carbon dioxide, have been shown to enhance earth's natural greenhouse effect. As such, their contribution to global climate change is the focus of much research.

During the first year of the Aircraft Carbon field campaign, ARM researchers will focus on developing the capability to measure continuous carbon dioxide concentration profiles from the surface to mid-troposphere (i.e., 5–7 kilometers). Such measurements will facilitate calibration of the Orbiting Carbon Observatory—a satellite mission sponsored by the National Aeronautics and Space Administration (NASA)—and improve computer models that simulate Earth's carbon budget. They will also augment existing flask-based collection of trace gases (carbon monixide, methane, and stable isotopes of carbon dioxide, or $^{13}CO_2$) by sampling at more heights and adding a sampler for radiocarbon ($^{14}CO_2$). This suite of trace gases, enhanced by the continuous carbon dioxide profiles, will provide comprehensive data for inverse methods that infer ecosystem carbon exchange and quantify anthropogenic (manmade) combustion emissions.

After the first year, researchers plan to add two other temporary measurement systems: (1) a collection system for large air volumes (to capture ^{222}Radon, a tracer for atmospheric transport), and (2) equipment for trapping water vapor for isotopic

analysis. Additional collaborators will support developing the instrument systems and analyzing the data. Trace gas measurement obtained at the SGP site during this campaign will provide valuable data for addressing carbon-cycle questions stressed by the U.S. Climate Change Science Program and the North American Carbon Program.

Results: The suite of carbon cycle gases being measured at the SGP site reflect the regional sources and sinks—natural or manmade contributors or removers—of atmospheric CO_2. In particular, they provide a powerful constraint on estimates of the size of emissions and uptake of CO_2. As an example, atmospheric profiles of CO_2, $^{13}CO_2$, and CO from flasks collected by aircraft from 10 a.m. to noon local time, June 15, 2006, showed the free troposphere to be well mixed (no vertical structure in concentration) with concentrations matching the regional background values. In contrast, the boundary layer has a sharp reduction in CO_2 concentration, due to net ecosystem uptake (i.e., net photosynthesis) of CO_2.



Data collected by aircraft for 2 hours on June 15, 2006, at the SGP site show atmospheric profiles of various carbon species. The yellow shading shows the approximate height of the boundary layer at the time.

The large increase in ^{13}C values between the free troposphere and mixed layer corroborates that the decrease in CO_2 concentration was due to photosynthetic uptake. This is because the process of photosynthesis favors ^{12}C and discriminates against the heavier (i.e., ^{13}C) isotope—thus leaving the atmosphere with more of the heavier isotope. Different types of plants and groundcover have varying levels of efficiency with respect to photosynthetic pathways, so isotopic measurements can help estimate when certain crops are taking up carbon.

Another gas species, carbon monoxide, was shown to be elevated in the boundary layer relative to the free troposphere, indicating an anthropogenic (manmade) combustion source of CO and CO_2. Thus, the magnitude of the drawdown of CO_2 near the surface is the net effect of ecosystem sinks and combustion emissions.

The Aircraft Carbon field campaign continues through 2008, with the previously noted enhancements to the carbon collection instrumentation in 2007. These enhancements will also contribute to another ACRF field campaign at the SGP site called the Combined Land Surface Interaction Campaign, or CLASIC. This field campaign will focus on the impact of landscape changes affecting energy balance/flux partitioning and their impact on cloud/atmospheric dynamics. Using several aircraft and surface sites to collect data, CLASIC begins in May 2007 and will last for 3 months.

HydroKansas Follows Water Flowing Through Space and Time

In May 2006, a 3-year field campaign called "HydroKansas" began in the Whitewater River basin in south-central Kansas. HydroKansas is an interdisciplinary effort to predict atmospheric, hydrologic, landscape, and ecological responses to natural hydro-climate fluctuations and human-induced changes. A primary goal of HydroKansas is to develop a predictive understanding of runoff and floods on multiple spatial and temporal scales, using high-resolution rainfall and streamflow data collected throughout the 1100 square-kilometer basin.

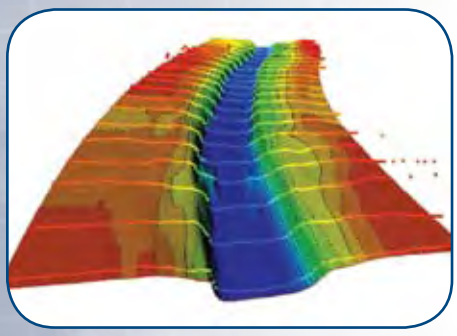
The study considers the role topography, land use, and vegetation play in controlling statistics of floods. With respect to topography, the Whitewater River basin is

Sets of rain and stream gauges like this one are providing information about water level and flow rates from sites throughout the Whitewater River watershed during the HydroKansas field campaign.

located in a transition zone between dry and wet climates, and its soils are characterized by low infiltration; thus, the basin responds quickly to rainfall. Land use in the basin is mainly agricultural, with minimal urban development. However, numerous atmospheric experiments have been conducted in the area, resulting in a well developed observational infrastructure.

With hydrological instrumentation strategically distributed throughout the basin, HydroKansas will focus on the primary variables relevant to studies of flooding and runoff generation. These variables include rainfall, stream discharge, infiltration, soil moisture, and evaporation and transpiration—called evapotranspiration—from hillslopes and riparian vegetation along the rivers. Evapotranspiration from riparian zones (the wetlands adjacent to a stream or river) is an important component of land-atmosphere interaction, and HydroKansas will be one of the first experiments to directly account for moisture loss from riparian zones in the context of other hydrological and ecological measurements.

Scientists involved with the HydroKansas project developed and implemented a new fluid mechanics-based stream gauging method, which determines channel roughness from field measurements of the channel geometry, the physical roughness of the bed and banks, and the vegetation density on the floodplain. In support of the field campaign, 28 rain gauges at 14 sites, and 12 stream gauges at 12 sites were deployed within the basin.



Digital elevation models are being developed for each site in the Whitewater River basin. This example, from a channel in the basin's East Branch, was generated from survey data mapped to a curvilinear grid.

Results: In 2006, surveying was completed for all of the sites, including a detailed characterization of the channel and floodplain topography and the bed, bank, and floodplain roughness elements. For the real-time streamflow network, 20 submergible pressure transducers were installed at sites throughout the basin, ranging from small headwater channels to the basin outlet. These transducers were coupled with barometric sensors to capture atmospheric pressure fluctuations. In spring 2007, these pressure transducers will be connected to a real-time network, after which estimates of discharge from the 12 Whitewater sites will be available remotely from the internet.

Numerical modeling of discharge for each stream reach is currently underway, and rating curves have been developed for 6 of the initial 12 sites. Each site uses the flow depths from the transducers with the calculated rating curves to convert the flow depth information to stream discharge. The discharge is determined for each water stage using the process-based, fully predictive model. This new method drastically reduces the amount of time required to produce discharge rating curves compared to the many years often required by standard empirical approaches.

Infrastructure Achievements

Infrastructure activities include management of site operations at the research facilities, instrumentation and engineering support, data quality and storage, and communication and education/outreach. All of these areas are key components of enabling ARM science and promoting the capabilities of the ACRF for new users.

Site Operations

Increased Weather Balloon Soundings Begin at Barrow

In April 2006, operations staff began launching balloon-borne sounding systems—better known as weather balloons—two times per day at the NSA site in Barrow, Alaska. Based on the recommendation of both the ARM Cloud Properties and Instantaneous Radiative Flux Working Groups, and approval by the IMB, the frequency of balloon soundings at Barrow increased from once to twice each day. The additional wind data from the soundings will provide climate scientists with more information about atmospheric conditions in the sensitive Arctic environment.

Each weather balloon is equipped with a radiosonde package for measuring air pressure, temperature, and humidity, as well as a global positioning system to provide profiles of wind speed and direction. The balloons are launched at 6 a.m. and 6 p.m. GMT, offsetting launches from the National Weather Service research station in Barrow by 6 hours.

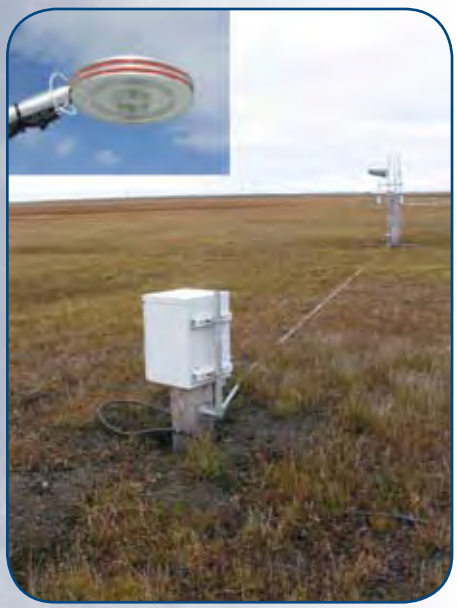
The balloon-borne sounding system consists of a small sensor package—called a radiosonde—attached by a long string to a large balloon. As the balloon rises, atmospheric measurements recorded by the radiosonde are picked up via an antenna on the ground.

New Operations Status System Improves Tracking, Reporting

Though some ACRF operations activities are site-specific, many—such as routine maintenance, corrective maintenance, shipping and receiving, inventory, spares, and calibrations—are common elements found at all the ACRF sites. Because these tasks have a large impact on budget planning and operational efficiency, the need was identified to standardize the cross-site elements into a common database. In 2006, a comprehensive Operations Status System (OSS) was developed to better track and report the status of operations capabilities at the widely disbursed ACRF sites. By serving as a central collection point for all ACRF site status information, the OSS enables timely and cost-effective decisions about site operations, particularly with respect to instrument performance issues.

The OSS was designed for tracking the states of various instrument and computer systems and components at each ACRF site. It was also designed to have the capability as an inventory tracking system. Now, site operators enter notable operational events into the OSS. These statistics are then used to develop diagnostic metrics, such as "accumulated time in service" and "mean-time to repair." This information allows site managers to objectively and promptly identify any necessary actions and consider future budget expenditures.

The CCN Counter consists of a vertical column with wetted walls, which provides the water vapor necessary to produce supersaturations. Particles activate into droplets when exposed to the supersaturated conditions, and the droplets are then counted by an optical particle counter.



The precipitation sensor at Barrow was installed about 2 meters above the surface on the piling in the foreground, with power connected through a nearby Climate Reference Network box (background).

Instrument Enhancements

New Instrument "Counts" Cloud Particles

Microscopic airborne particles are commonly referred to as "aerosols." Every one of the trillions of droplets in a cloud originates on one of these tiny "cloud condensation nuclei" (CCN). Through their role as CCN, aerosols affect cloud properties by altering the concentration of cloud droplets, and the brightness (reflectivity) and lifetime of clouds. To characterize how changes in CCN concentrations may be changing the properties of clouds observed at the SGP site, a CCN Counter was added to the suite of instruments that compose the site's Aerosol Observing System (AOS). This instrument measures CCN number concentration at supersaturations between 0.1–2 percent. Its optical particle counter measures the size distribution of the droplets that grow from CCN, collecting data every second in 20 particle-size bins from 0.75 to 10 microns.

Datasets from the CCN Counter at the SGP site will be available on a quarterly basis, following data quality review by the AOS instrument mentor team. Ultimately, the goal is for AOS systems at each ACRF site to use identical components, including the CCN Counter. An identical CCN instrument was deployed as part of the AOS during the AMF field campaign at Point Reyes, California, in 2005, and in Niamey, Niger, Africa in 2006.

Precipitation Sensor on Duty at North Slope of Alaska

Because the impacts of climate change are shown to occur most rapidly in the sensitive Arctic environment, accurate precipitation measurements are needed for characterizing boundary layer (surface to 1000-meter altitude) conditions and simulating cloud formation as input to climate models. To obtain these measurements, a new precipitation sensor was installed at the NSA site in Barrow. This instrument provides measurements of snow-fall amounts, snow depth (and density), and snow temperature. The sensor's electrical components are designed to operate in temperatures spanning ±50°C.

Manufactured by Yankee Environmental Systems, the "hot plate" precipitation sensor head consists of two isolated plates positioned one on top of the other. It measures the rate of rain or snow based on how much power is needed to evaporate precipitation on the upper plate to keep its surface temperature constant. The second plate is positioned directly under the evaporating plate; it is heated to the same temperature to factor out cooling from the wind. Data collected by the sensor—situated approximately 0.4 kilometers south and east of the site's primary instrument facility—is transferred via fiber optic cable. The sensor's proximity to a nearby rain gauge allows hour-by-hour comparisons of measured snow rate.

Out with the Old, In with New: Micropulse Lidars Replaced

In 2006, all the ACRF sites were outfitted with upgraded micropulse lidars (MPLs) equipped with new polarization capability. Each MPL provides critical backscatter measurements used to derive cloud-base heights, including high cirrus clouds (~18–20 kilometers). The backscatter measurements are also used in several value-added products to provide additional cloud and aerosol properties.

Representatives from Sigma Space Corporation—the MPL manufacturer—accompanied the initial MPL deliveries and provided extensive training sessions to technicians for each ACRF site. The training covered installation, initial set up, operation, problem diagnosis, and field repairs. Because the lidar is a sophisticated laser instrument, it requires laser safety training, special laser goggles, and a baseline eye examination for all technicians authorized to replace the laser diode module. The comprehensive training permits the technicians to assume responsibility for tasks that previously required either the instrument to be shipped offsite or the instrument mentor to travel to the site. The training is expected to dramatically reduce the time and expense required to repair the systems and return them to operation.

A representative from Sigma Space Corporation trains ACRF operations staff in Darwin, Australia, on various components of the new MPL. The lidar, shown at left, will be placed in one of the outdoor instrument shelters, below a hole in the roof for the laser to pulse through.

New Shortwave Spectroradiometer Deployed at SGP

Based on a successful test period in 2004, a new shortwave spectroradiometer (SWS) began operating at the SGP site in late April as part of the permanent instrument suite. The instrument measures the zenith (1.4° field of view) solar spectral radiance between 300–2200 nanometers. Two Zeiss miniature monolithic spectrometers, with a spectral resolution of 8 nanometers in the range 300–975 nanometers, and 12 nanometers in the range 975–2200 nanometers, are part of the SWS. These measurements of visible and near infrared radiation will be used for testing shortwave radiation transfer models, as well as input to retrievals of cloud and aerosol properties.

Technicians at the SGP site will calibrate the instrument biweekly, using a dedicated 31-centimeter diameter LabSphere integrating sphere. This task involves removing the optic element from the roof port and placing it in a fixture designed to align it with the integrating sphere. To perform these routine calibrations without moving the sensitive spectrometer, SGP site operations staff created a "darkroom" by partitioning the east end of the SGP Optical Trailer (where the spectrometer is located) and painting it black.

A ceiling port in the SGP Optical Trailer houses the optic element of the SWS, which connects to the spectrometer inside the trailer via fiber optic cable.

Upgrades to Darwin Radar Double Data Delivery

The millimeter wavelength cloud radar (MMCR) is the only source for obtaining detailed information about cloud location and internal structure in the atmospheric columns above the ACRF sites, and can be operated in almost any atmospheric condition. In November, a major upgrade to the 35-GHz MMCR at the TWP site in Darwin, Australia, increased the time resolution and associated data rates by an order of magnitude (i.e., x 10) over the previously installed radar. This upgrade also involved replacing obsolete computers and removing components that caused maintenance problems over the years, greatly increasing the reliability of the radar. This improvement came just in time to support TWP-ICE (see the Featured Field Campaigns section of this report).

During the past few years, MMCRs at the SGP and NSA sites were upgraded with C40 Digital Signal Processors. However, for the TWP, the science team opted to deploy a PIRAQ-III processor design for several reasons, including minimal hardware modifications, compatibility with other meteorological radars, availability of parts and technical support, enhanced performance, increased reliability, and minimal risk and costs. In just a few days of operation, data comparisons between

The new processor for the MMCR (antenna shown in upper right of photo) at Darwin collects spectral data in four different modes, resulting in approximately 3.4 gigabytes of signal output per day.

the SGP and NSA MMCR processors (C40 upgrade) and the Darwin MMCR processor (PIRAQ) showed a nearly two-fold increase in data rates for both raw moment files and spectra files. As an essential contributor to cloud and radiation research, the upgraded MMCR will help the ARM Program remain a leader in remote sensing of the atmosphere.

Data Delivery

Increased Server Power Pumps Up Data Management Performance

In 2006, a collection of new computer servers joined the production system at the ACRF Data Management Facility (DMF). The new Sun servers use the most current operating system available, Solaris 10, which ensures maximum reliability and security. These servers provide much needed processor power to handle the ever-increasing processing load.

The DMF is responsible for collecting and processing hourly data from all the ACRF sites each day. Processing involves the application of algorithms for performing simple averaging routines, qualitative comparisons, or more complicated experimental calculations. The previous systems experienced overloading problems on backlogged data. With the new servers online, primary data ingesting and value-added product processing services were transferred over with very noticeable, positive performance results. All the old server systems were retired, and processing software for the data systems were recompiled and optimized for Solaris 10 and the new hardware.

One-Stop Data Shopping Expanded to Include Field Campaigns

In 2005, the ARM website was integrated with the ARM Data Archive to allow users to browse and order data using a data shopping cart feature. This ability, however, only applied to "routine" data—data that are collected continuously from the ACRF sites—leaving a large holding of special field campaign data at the Archive inaccessible via the shopping cart. Working with data managers at the Archive, ARM website developers added the ability to order field campaign data through the instruments and measurements webpages via the shopping cart.

Users can now browse for field campaign data after selecting an instrument or measurement and entering the shopping cart. Once in the cart, users will see a list of field campaigns that used the specified instrument or collected the specific measurement. This information appears alongside the routine ARM data. Field campaign data of interest can then be downloaded directly from the cart just as easily as routine ARM data.

Navigating the Landscape of Field Campaign Pages

Continuing on the website design work accomplished in 2005, the ARM field campaign web pages underwent additional renovation in 2006 to further improve navigation and accessibility. While the pages remain consistent with the overall design of the ARM website, the right-hand navigation was redesigned to aid users

in finding current, upcoming, and past field campaigns quickly and easily. As part of this usability improvement, a filter was added that allows users to "hide" field campaign web pages that do not include data. Once users select a category of field campaigns, the newly designed interface allows users to quickly scan the summary table and select the column of interest. This generates a sorted table that makes it easy to locate the desired data. Information in all the data status columns was color coded to aid in scanning for data availability, with a direct link to the ARM Data Archive for downloading. A new guided search form and interactive timeline were also added to provide users with additional ways to search for a field campaign.

In a related activity, the preproposal form for submitting a field campaign request was redesigned. To assist lead scientists in preparing their request, all the questions are now provided on one page for review, rather than a progression of questions. Questions were reworded to clarify intent, and instructions and guidance were provided for all questions.

Field campaign information was previously presented in a fixed hierarchy that was tedious to search. This information is now presented in a tabular display that is easily scanned and sorted.

Communication, Education, and Outreach

Hands-On Activities Help Interest Kids in Science

Education and outreach activities sponsored by the ACRF are geared toward K–12 students and teachers, as well as the communities that host ACRF sites. In January, education and outreach staff participated in WeatherFest, a public science fair that kicks off the annual meeting of the American Meteorological Society. During the 4-hour event, visitors to the ACRF education and outreach booth inquired about the online ACRF Education Center, checked out the NSA interactive DVD, and picked up lesson plans. In addition, education and outreach staff handed out more than 400 climate change activity and coloring books to teachers and students.

Kids attending the Chickasaw Nation Aviation and Space Camp learned to decode station model plots, contour temperature maps, create tornadoes in a bottle (shown here), and build wind-resistant houses.

June was also a busy month for ACRF education and outreach staff. During a day camp held outdoors at Reeves Park in Norman, Oklahoma, they helped nearly 100 local Girl Scouts earn their weather badges. Seven "learning stations" were staffed by female volunteers ranging from professional meteorologists to graduate and undergraduate students. Station topics included pressure and temperature, weather maps, fronts, tornadoes, lightning, heat, and seeing the instruments of a weather station. Later in June, additional education and outreach staff presented half-day weather sessions at two Chickasaw Nation Aviation and Space Camps. Students were given weather maps to chart the formation of a small tornado, and watched video of the tornado as it tore through an abandoned airplane hangar at the El Reno, Oklahoma, airport. Students were also supplied with Styrofoam meat trays, straws, popsicle sticks, tape, cardboard, and construction paper to build a wind-resistant structure. A total of 75 students attended the space camps, held at the Ada Municipal Airport in Ada, Oklahoma.

Interactive Kiosk and School Visits Promote Climate Education in the Tropics

Several ARM scientists involved in the TWP-ICE field campaign took time out from their research for a very important purpose—to talk to students about climate

Titled Climate Change: Science and Traditional Knowledge, *ACRF's latest education kiosk is now on permanent display at the Museum and Art Gallery of the Northern Territory in Darwin, Australia.*

change. As a preview to the new interactive climate education kiosk at the Museum and Art Gallery of the Northern Territory in Darwin, they made visits to Darwin area schools, plus a remote school for Aboriginal children. To kick off each visit, ACRF education and outreach staff gave an introduction about the ARM Program and provided information about climate education resources in their area. This was followed with a presentation by ARM scientists and graduate students about clouds, solar radiation, instrumentation, data, and the ongoing field campaign. All teachers were given packets with ARM lesson plans, newsletters, and a copy of the kiosk program on DVD, and the young students received stickers and ARM activity books with puzzles, coloring pages, and mazes.

At the end of the field campaign, a dedication ceremony was held at the museum to present the new educational kiosk display to community leaders. Titled *Climate Change: Science and Traditional Knowledge*, this hands-on learning tool provides information about climate change in the global "warm pool"—the equatorial western Pacific region which features the warmest sea surface temperatures on earth. The kiosk components include footage of interviews with atmospheric scientists, local fishermen, traditional land owners, and members of Australia's Aboriginal community. The interviews focus on the science and impacts of climate change in Darwin, as well as general information about climate change research. Copies of the kiosk DVD are available free of charge to educators around the world for classroom use.

Exhibit staff provided background information about the ARM Science Program and the ACRF to visitors at the 86th Annual Meeting of the American Meteorological Society.

Exhibit Draws Interest from Scientific Community and Youth

More than 2,200 academics, government officials, private researchers, and leading atmospheric scientists gathered in January at the American Meteorological Society's 86th Annual Meeting in Atlanta, Georgia. Between sessions, they perused the adjoining exhibit hall, where ACRF staff shared information about ARM science with interested attendees and answered questions about using the ACRF. Visitors to the ACRF display booth were most interested in learning about the latest AMF deployment, the ongoing field campaign in Australia, ordering ARM data, how to submit a proposal to conduct their own field campaign, and the 2005 Annual Report.

ACRF also staffed its exhibit at the 2005 American Geophysical Union (AGU) Fall Meeting held in San Francisco in December. As a record-setting 11,904 scientists gathered to discuss the latest issues affecting all areas of earth and space sciences, ACRF staff shared information about the program's mission and goals with attendees. Many conference attendees inquired about data availability and accessibility, and some participants requested more information about using the AMF. On the last day of the meeting, ACRF exhibit staff participated in the first-ever Student Exploration of Research in the Earth and Space Sciences program. Local middle school students were invited to visit the AGU exhibit hall to learn about research and careers in earth and space sciences, meet scientists, view demonstrations, and gather take-home activities. The ACRF Education and Outreach climate change coloring and activity book was received with enthusiasm by interested teachers and students.

Media Day and Open House Provide a Public Peek at Experiment

Members of the TWP-ICE science team and Australian officials hosted a media day to provide an opportunity for reporters to learn about the experiment, touted as one of the largest scientific experiments ever conducted in Australia. In addition to briefings, they provided tours of the aircraft on base and the ship at Darwin Harbor. Attended by more than a dozen reporters, photographers, and film crews, plus a handful of documentary teams, the media day resulted in numerous news articles by Australian and European media. Several of the documentary teams remained on location to provide more extended coverage of the complex field campaign, and Australian radio programs aired brief updates throughout the 21-day experiment. A comprehensive list of media coverage resulting from the experiment is available at http://science.arm.gov/twpice/media.stm.

A film crew for the Discovery Channel-United Kingdom interviews ARM scientist Jim Mather, co-lead for the TWP-ICE field campaign.

The TWP-ICE science team also took part in an "Open Day" at Charles Darwin University, where experiment headquarters was located. The Open Day, similar to an "open house" in the United States, was coordinated with university staff to thank them for providing technical support and free use of the university facilities and infrastructure during the experiment. Geared toward the general public and prospective students, the 2-hour morning and afternoon sessions consisted of a series of presentations and question-and-answer sessions. Turnout for the event was excellent, with each session ending in standing-room-only space in the lecture theater (capacity of about 125). In addition, the visitors browsed with interest through various informational displays and materials situated in the hall leading to the lecture theater. ARM science team members were on hand at the TWP-ICE and ARM display throughout the day, answering questions from visitors both young and old.

2006 Field Campaigns

Dates	Name	Status	Description
North Slope of Alaska			
January 2004 – June 2006	Extended Range Atmospheric Emitted Radiance Interferometer (AERI-ER) Intercomparison IOP	Completed	This intercomparison was conducted to verify the reproducibility of calibration on the AERI-ER and to identify the source of a small bias identified in AERI-ER data in clear-sky, low precipitable water vapor situations. To meet these objectives, two AERI-ER systems (one provided by the University of Wisconsin) were operated side-by-side at the NSA site in Barrow for a 6-week period during the cold, dry season. Preliminary results indicate the AERI-ER calibration can be reproduced using an out-of-band correction procedure, however the bias in clear, dry conditions remains unresolved.
April 2005 – April 2006	Atmospheric Infrared Sounder (AIRS) Validation Soundings, Phase IV and V (Also at TWP and SGP)	Completed; awaiting data	A special series of radiosonde launches were conducted at all the ACRF sites in support of validation studies for the AIRS instrument aboard NASA's Aqua satellite. The AIRS instrument is intended to make highly accurate measurements of air temperature, humidity, clouds, and surface temperature. The data collected by AIRS during the past several years will be used by scientists around the world to better understand weather and climate.
January 2005 – January 2006	High-Latitude Optical Turbulence Characterization	Completed	The University of Alaska-Fairbanks and U.S. Army Research Laboratory (ARL) implemented this joint proposal at the NSA site in Barrow. The scientific objective of this 9-month campaign was to characterize the near-surface atmospheric optical turbulence over a flat, relatively low-humidity, high-latitude location. Results from the data collection effort will be compared to those from an equivalent flat, relatively low humidity, mid-latitude desert site. Ultimately, these comparisons will be used to improve the ARL Surface Layer Stability Transition Forecast Model, which was shown to display a strong seasonal contribution in diurnal atmospheric stability transition patterns.
June 2006 – Ongoing	National Science Foundation (NSF) Ultraviolet (UV) Monitoring Support	In Progress	In this ongoing field campaign, ACRF is providing onsite support to the NSF UV monitoring network, which measures solar UV radiation at six high-latitude sites and at San Diego, California. This network was founded in 1987 in response to severe ozone depletion reported in Antarctica and is operated by Biospherical Instruments, Inc. Instrumentation installed at network sites includes high-resolution, ultraviolet-visible spectroradiometers (measuring spectral irradiance between 280 and 600 nanometer) as well as multi-channel filter radiometers. The network site at Barrow, Alaska, was established in 1991, with instrumentation located in the Ukpeagvik Iñupiat Corporation building. In 2005, ACRF took over site operations support previously provided by by NOAA's Climate Monitoring and Diagnostics Laboratory. Preliminary data from the network are available within 1 week after collection and can be accessed via the project's website at http://www.biospherical.com/NSF. The project's website also provides additional information on the network, its data, and applications.
June 2006 – Ongoing	Global Positioning System (GPS) Base Station – Atqasuk	In Progress	A GPS base station in Atqasuk provides a local source of geodetic quality differential corrections for GPS data post-processing by scientists and others operating in the Atqasuk area of the North Slope. The station, located at the ACRF's Atqasuk site, provides security, power, and ethernet communications. The station runs continuously, and 15-second sample rate data are archived at UNAVCO (http://facility.unavco.org) and available to the public. Higher sample rate data are also recorded on the receiver in hourly files, and will be made available to users as needed. Because all data are available via the Internet users do not need to have physical access to the receiver.
August 2006 – July 2007	Pyranometer Infrared (IR) Loss Study	In Progress	This field campaign will provide a long-term (1-year) set of measurements needed to investigate and refine the IR loss correction methodology for data obtained at the NSA sites. An extensive effort will be directed toward gaining an understanding of what effects the current ventilator heaters might be having on the basic measurements. The IOP will also involve investigating the various permutations of the amount of ventilation and heating to perhaps optimize ARM's broadband measurement strategy for NSA. These latter studies may evolve as early results are obtained. Overall, the IOP is targeted at improving both the understanding, and the quality and accuracy, of NSA measurements.

Southern Great Plains			
February 2005 – Ongoing	Near Real-Time GPS Water Vapor Data Availability	In Progress	The SGP site hosts the worlds' largest concentrations of GPS receivers dedicated to atmospheric research. Since 1993, the facilities and resources of the SGP site have been used by NOAA's Forecast Systems Laboratory (FSL), other government agencies, and universities to develop ground-based GPS water vapor observing systems and perform data intercomparisons to assess their characteristics and evaluate their suitability for climate research and observing system (primarily radiosonde and satellite) calibration and validation. In addition to their use in research and climate studies, GPS water vapor measurements have proven to be extremely useful in improving short-range weather forecasts accuracy over the contiguous United States, providing situational awareness under rapidly changing conditions, verifying other moisture observations, and validating weather model predictions. Another promising GPS application developed by FSL displays 1-hour, 2-hour, and 3-hour changes in IPW at each site. This provides forecasters with current information about moisture convergence zones and where thunderstorms are most likely to first break out. At the request of FSL, the ACRF evaluated and upgraded the communications at these sites to provide data in near real-time for operational forecasting.
March 2005 – February 2006	Precision Gas Sampling (PGS) Validation	Completed; awaiting data	Accurate prediction of the regional responses of CO_2 flux to changing climate, land use, and management requires models that are parameterized and tested against measurements made in multiple land cover types and over seasonal to inter-annual time scales. In an extension of earlier work on crop systems, this 12-month campaign investigated the effects of burning on the cycles of carbon, water, and energy in an example of grazed land in the SGP region.
March 2006 – February 2007	PGS Validation Field Campaign	In Progress	This collaboration with the U.S. Department of Agriculture Grazing Lands Research Laboratory (GRL), involves a treatment-control experiment comparing fluxes and other ecosystem properties in adjacent burned and unburned fields containing native prairie at GRL near El Reno, Oklahoma. Our hypotheses, specific to the burning experiment, are that burning will (1) affect the timing and amount of above-ground production, but (2) not affect the total carbon exchange when the carbon lost during the burn is accounted for.
January – March 2006	Aura/Thermal Emission Sounder (TES) Validation	Completed	This field campaign involved validation of the TES on the Aura satellite to provide improved global measurements of ozone and temperature. Ozone is a radiatively active gas with upper-atmospheric concentrations expected to decline in the next decade. Climate investigation and validation of satellite data are important for the measurement of this ozone decline and to ascertain satellite accuracy. The validation consisted of balloon-borne ozonesondes released from the SGP site on a schedule compatible with the ephemerides of Aura/TES. Six segments were scheduled with a 5-day period of no ozonesondes between each segment. NASA Accurate Temperature Measuring (ATM) radiosondes were released with ARM RS92 radiosondes for temperature comparisons.
February 2006	RS92 – NASA ATM Radiosonde Temperature Intercomparison	Completed	Bias in upper-air temperature and relative humidity measurements affect estimates of the radiative properties of the atmosphere. Improving the accuracy of these measurements is a goal of the ARM Program. Analysis of data collected during earlier ARM radiosonde IOPs suggested a possible day-night temperature bias in the RS92 sensor. This IOP piggybacked a series of dual-radiosonde flights with ATM radiosondes during the Aura validation IOP to check temperature errors in RS92 radiosondes. The goal was to compare the temperature measurements of the RS92 with the well-characterized NASA ATM sensor.
March 2006 – June 2011	Magnetic Field Observations at Purcell, Oklahoma	In Progress	Collaborators from the University of California installed a magnetometer at the SGP boundary facility at Purcell, Oklahoma, and for the next 5 years will collect continuous measurements of the magnetic field. These data can be used to study a wide range of physical processes of the sun-Earth system, including magnetic storms, ionospheric currents, and other phenomena whose source energy originates from enhanced solar activity.
April 2006	Sun and Aureole Measurement (SAMNET) Validation	Completed	Reliable ground-based measurements of cloud optical depth and particle-size distribution provide important truth data for the post-launch calibration and validation of environmental satellite cloud algorithms, as well as consistent datasets for long-term climate change research. To obtain these measurements, a new instrument named SAM, for Sun and Aureole Measurement, makes precise measurements of the radiance profile of the solar disk and aureole. The radiance of the solar disk affords a definitive measure of the column optical depth when corrected for forward scattering. The aureole profile is a measure of the forward scattering properties of the particles in the column. It can be used to correct the optical depth, as well as to derive the size distribution of particles in the column. Validation of the SAM instrument and processing algorithms will make use of coincident datasets from a number of other instruments at the SGP site, as well as retrievals from sensors aboard NSA satellites.

April 2006	CO_2flx-Ameriflux-Intercomparison	Completed	Sites conducting CO_2 flux measurements in North America can participate in the DOE Ameriflux network, thereby increasing the use of site data by the carbon cycle community, and the value of the site to the North American Carbon Program. Participating sites are ranked in the Ameriflux program according to (1) the breadth and intensity of supporting data collected, and (2) the quality of the flux data, as judged by periodic intercomparisons with the Ameriflux Roving Instrument System. The SGP Central Facility qualifies as a Tier 1 site in all respects except for the lack of an intercomparison with the Roving Instrument. In this IOP, the Ameriflux team visited the SGP Central Facility for a 1-week flux measurement intercomparison during the wheat-growing season.
May 2006 – October 2009	HydroKansas	In Progress	For 3.5 years, the Whitewater River (Kansas) watershed will serve as the focus of a NSF long-term study intended to develop and field-test new innovative theoretical approaches for better understanding the non-linear coupling among atmospheric processes, the landscape, vegetation and important elements of the hydrological cycle, especially as they relate to changes in climate and in the occurrence of extreme events such as floods.
May 2006 – July 2007	Combined Wind Profiler and Polarimetric Radar Study of Precipitation	In Progress	In this campaign, a 915-MHz boundary-layer radar (BLR) at the SGP boundary facility (BF-6) located in Purcell, Oklahoma, is being used to study the vertical structure of rain under various meteorological conditions. Unlike many remote sensing instruments, a vertically pointing BLR can directly measure the size distribution of rainfall particles. The so-called drop size distribution (DSD) is a crucial parameter used in radar rainfall retrieval techniques; however, the DSD typically must be assumed to follow a prescribed analytic form. If the actual precipitation does not match the assumed form of the DSD then the rainfall estimates provided are biased. Precipitation data obtained using the 915-MHz BLR will be compared against measurements made using a ground-based disdrometer and from the National Severe Storms Laboratory polarimetric WSR-88D radar. Additionally, data from the NOAA Profiler Network 404-MHz radar will be used in the study.
May 2006 – August 2006	Disdrometer and Polarimetric Radar Measurements of Precipitation Microphysics	Completed	Accurate quantitative precipitation estimation and forecast require characterization of rain microphysics, which in turn requires information regarding DSD. During this 3-month campaign at the SGP site, rain DSD was measured by disdrometers and retrieved from polarimetric radar observations, fielded by researchers from Oklahoma University.
June 2006 – August 2009	Observation-based Precipitation Microphysics Study	In Progress	Understanding precipitation microphysics is important in accurate quantitative precipitation estimation and forecast. A two-dimensional video disdrometer (2DVD) measures size, shape, orientation and falling speed of each precipitating particle. A polarimetric radar provides information about cloud/precipitation physics with a large spatial coverage. The University of Oklahoma purchased and deployed a 2DVD at the SGP BF-6 to measure hydrometeor DSD. An 2DVD from the National Center for Atmospheric Research will also be placed side-by-side with the university's 2DVD, providing data to improve the understanding of precipitation microphysics for the SGP region of the United States, to develop radar retrieval algorithms/forward operators, and to verify polarimetric radar measurements.
July 2006 – December 2008	Aircraft Carbon	In Progress	The goals of this IOP are to acquire the ability to measure carbon dioxide concentrations and sample for a suite of trace gases from the surface to mid-troposphere. Airborne measurements of trace gases will (a) provide valuable data for addressing carbon cycle questions that have been identified by the U.S. Climate Change Research Program and the North American Carbon Program, (b) facilitate the calibration of the NASA Orbiting Carbon Observatory, and (c) provide a basis from which to develop inverse methods to infer ecosystem carbon exchange and quantify anthropogenic combustion emissions.
September 2006	Summer 2006 Aerosol/CCN Study	Completed	This field campaign was conducted to evaluate the relative abilities of different classes of aerosols to act as cloud condensation nuclei (CCN). To do so, the science team used a new CCN probe that couples a supersaturating column with a phase dopler interferometer. The supersaturating column exposes ambient particles to a specified supersaturation for a known duration, and the phase dopler interferometer measures droplet diameter at a resolution of <1 micron. The precision of these measurements allows mass accommodation coefficient to be estimated. In addition, the science team collected filter samples of fine aerosols for future chemical analysis, and to measure their adsorption and scattering coefficients. This will enable them to relate the kinetics of the measured aerosols to their composition.

Tropical Western Pacific			
December 2004 – January 2006	Darwin Lightning Detection	Completed	The objective of this IOP is to characterize convection produced from lightning by using a VHF broadband digital interferometer (VHF BDITF) at the TWP Darwin site. Because electrical storms are common in the Darwin area and lightning is a useful indicator of convective strength, the instrument would (a) monitor the evolution and activity of a thunderstorm system; (b) add to the convective characterization component of lightning; and (c) complement the existing scanning centimeter radars. The VHF BDITF will enable the characterization of the lightning at a high resolution (1 microsecond) and will provide a new convective characteristic component that will complement existing measurements.
September 2005 – November 2010	Orbiting Carbon Observatory (OCO) – Fourier Transform Spectrometer (FTS) Validation	In Progress	The NASA OCO Science Team will deploy, operate, and maintain ground-based solar-viewing FTS mobile laboratories at the TWP site in Darwin, Australia, to validate space-based CO_2 retrievals. Long-term operation of both FTSs will continue through the end of the OCO mission (2010).
January – February 2006	Tropical Warm Pool – International Cloud Experiment (TWP-ICE)	Completed; awaiting data	This intense month-long field campaign took place between January and February, centered on the ACRF site in Darwin, Australia. TWP-ICE was aimed at describing the properties of tropical cirrus and the convection that leads to their formation. A crucial product from this experiment will be a dataset suitable to provide the forcing and testing required by CRMs and parameterizations in global climate models. This dataset will provide the necessary link between cloud properties and the models that are attempting to simulate them. The campaign was a collaborative effort between the ARM Program, the Australian Bureau of Meteorology, NASA, the European Commission DG RTD-1.2 and several United States, Australian, Canadian, and European universities.
June 2006 – June 2011	Geoscience Australia Continuous Global Positioning System (GPS) station	In Progress	The TWP site in Darwin is hosting a new GPS station that will form part of the Australian Regional GPS Network and South Pacific GPS Network. These networks consist of more than 30 continuous GPS stations operating within Australia and its territories (including Antarctica) and the Southwest Pacific. They support a number of different science applications, including but not limited to, the maintenance of the Geospatial Reference Frame (both national and international), continental and tectonic plate motions, sea-level rise, and global warming.
ARM Mobile Facility			
January – December 2006	RAdiative Divergence using AMF, GERB and AMMA STations (RADAGAST)	In Progress	The primary purpose of this 1-year deployment in Niamey, Niger, Africa, was to combine an extended series of measurements from the ARM Mobile Facility (AMF) with those from satellite instrumentation to provide the first well-sampled, direct estimates of the divergence of solar and thermal radiation across the atmosphere. The deployment is timed to coincide with the field phases and special observing periods of the African Monsoon Multidisciplinary Analyses and related experiments in 2006.
Special Data Set Requests			
June 2004 – June 2009	Cooperative Atmosphere Surface Exchange Study (CASES) Data Analysis	In Progress	Two field programs—CASES-97 (morning and evening) and CASES-99 (evening, night, morning)—from the National Center for Atmospheric Research provide a robust dataset for looking at the diurnal changes of the wind, temperature, humidity, and their vertical transports near the ground and through the lowest few kilometers where surface effects are directly felt—the atmospheric boundary layer. Combined with data from the International H_20 Project, CASES-97 will provide a description accurate and comprehensive enough to isolate and mitigate problems in land-surface models (the "piece" of weather and climate models that describes heat and moisture transports) and to test and improve the inner workings of the interacting land-surface and boundary-layer models in a fully operating numerical weather forecast model.
Fall 2005 – Ongoing	Study of Environmental Arctic Change (SEARCH) Data Archival	In Progress	NOAA is deploying a climate-monitoring site in Eureka, Canada, as part of the SEARCH Program in an effort to duplicate the ACRF site in Barrow, Alaska, in terms of instruments, datastreams, and data formats. Because datasets would be similar to those in the ARM and SEARCH datasets, a combined archive will be used to create a comparison to facilitate Arctic research.

FY 2006 Publications

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