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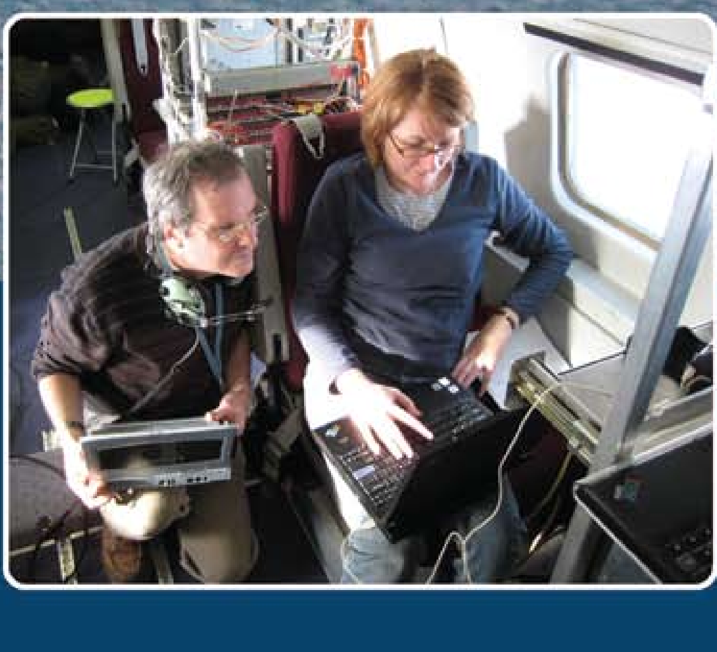
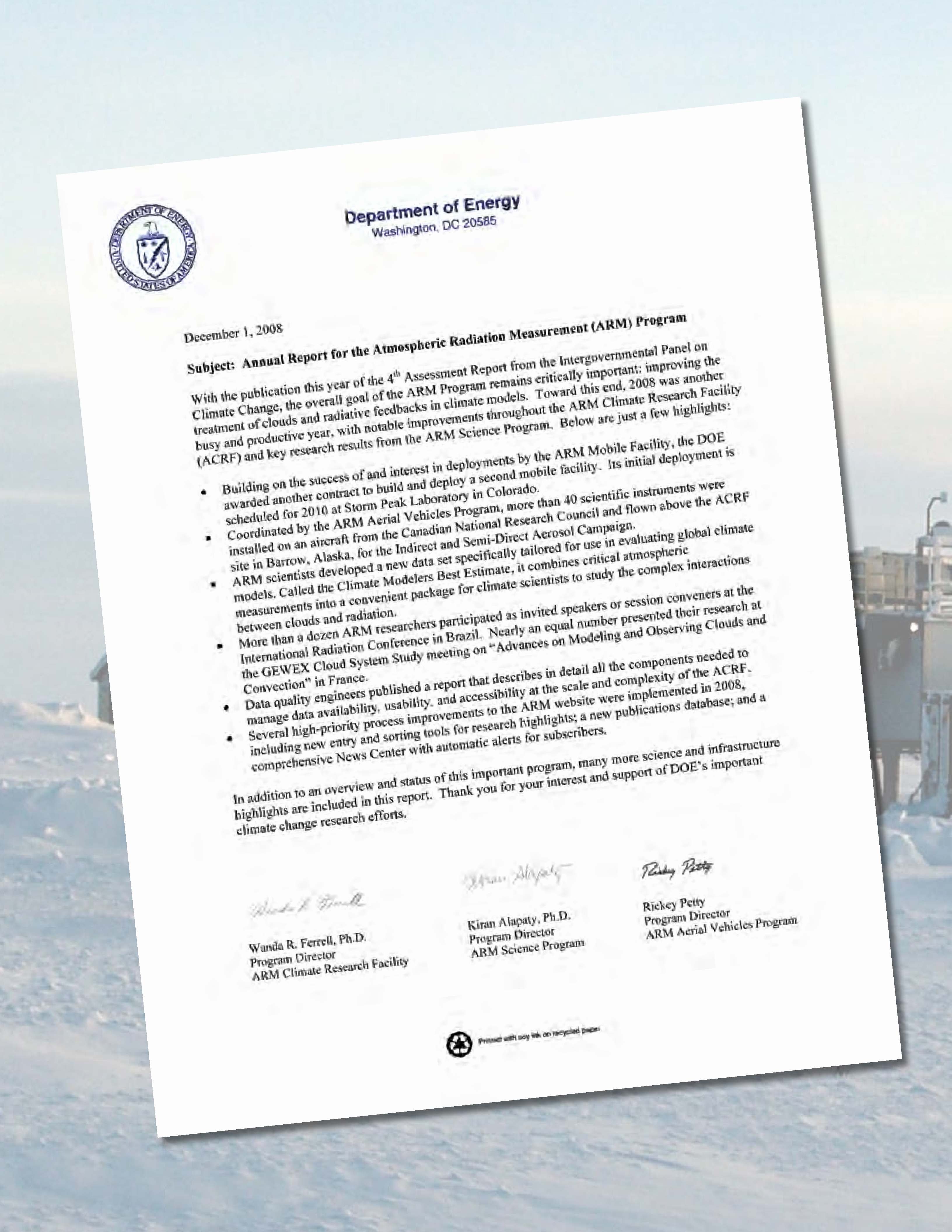
Atmospheric Radiation Measurement
CLIMATE RESEARCH FACILITY
U.S. Department of Energy

Annual Report 2008





Department of Energy
Washington, DC 20585

December 1, 2008

Subject: Annual Report for the Atmospheric Radiation Measurement (ARM) Program

With the publication this year of the 4th Assessment Report from the Intergovernmental Panel on Climate Change, the overall goal of the ARM Program remains critically important: improving the treatment of clouds and radiative feedbacks in climate models. Toward this end, 2008 was another busy and productive year, with notable improvements throughout the ARM Climate Research Facility (ACRF) and key research results from the ARM Science Program. Below are just a few highlights:

- Building on the success of and interest in deployments by the ARM Mobile Facility, the DOE awarded another contract to build and deploy a second mobile facility. Its initial deployment is scheduled for 2010 at Storm Peak Laboratory in Colorado.
- Coordinated by the ARM Aerial Vehicles Program, more than 40 scientific instruments were installed on an aircraft from the Canadian National Research Council and flown above the ACRF site in Barrow, Alaska, for the Indirect and Semi-Direct Aerosol Campaign.
- ARM scientists developed a new data set specifically tailored for use in evaluating global climate models. Called the Climate Modelers Best Estimate, it combines critical atmospheric measurements into a convenient package for climate scientists to study the complex interactions between clouds and radiation.
- More than a dozen ARM researchers participated as invited speakers or session conveners at the International Radiation Conference in Brazil. Nearly an equal number presented their research at the GEWEX Cloud System Study meeting on "Advances on Modeling and Observing Clouds and Convection" in France.
- Data quality engineers published a report that describes in detail all the components needed to manage data availability, usability, and accessibility at the scale and complexity of the ACRF.
- Several high-priority process improvements to the ARM website were implemented in 2008, including new entry and sorting tools for research highlights; a new publications database; and a comprehensive News Center with automatic alerts for subscribers.

In addition to an overview and status of this important program, many more science and infrastructure highlights are included in this report. Thank you for your interest and support of DOE's important climate change research efforts.

Wanda R. Ferrell, Ph.D.
Program Director
ARM Climate Research Facility

Kiran Alapaty, Ph.D.
Program Director
ARM Science Program

Rickey Petty
Program Director
ARM Aerial Vehicles Program

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Table of Contents

On the cover: Since 1997, the ARM Climate Research Facility site in Barrow, Alaska, has provided continuous measurements for Arctic climate research. In 2008, scientists used a heavily instrumented Convair aircraft to obtain measurements of cloud and aerosol properties above, within, and below clouds near the Barrow site for the Indirect and Semi-Direct Aerosol Campaign. For more information, see the *Featured Field Campaigns* section of this report.

Program Overview

The Importance of Clouds and Radiation for Climate Change

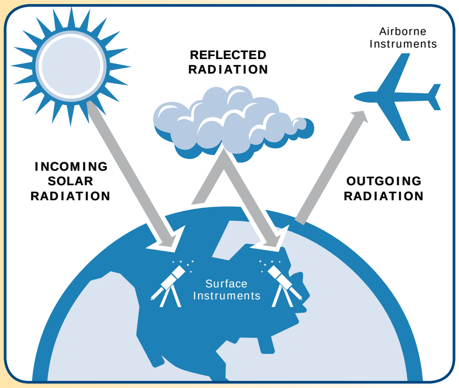
The Earth's surface temperature is determined by the balance between incoming solar radiation and thermal (or infrared) radiation emitted by the Earth back to space. Changes in atmospheric composition, including greenhouse gases, clouds, and aerosols, can alter this balance and produce significant climate change. Global climate models (GCMs) are the primary tool for quantifying future climate change; however, there remain significant uncertainties in the GCM treatment of clouds, aerosol, and their effects on the Earth's energy balance.

The 2007 assessment by the Intergovernmental Panel on Climate Change reported a substantial range among GCMs in climate sensitivity to greenhouse gas emissions. The largest contributor to this range is the way cloud processes are handled by different models.

In 1989, the U.S. Department of Energy (DOE) Office of Science created the Atmospheric Radiation Measurement (ARM) Program to address scientific uncertainties related to global climate change, with a specific focus on the crucial role of clouds and their influence on the transfer of radiation in the atmosphere. To reduce these scientific uncertainties, the ARM Program uses a unique two-pronged approach:

- The ARM Climate Research Facility, a scientific user facility for obtaining long-term measurements of radiative fluxes, cloud and aerosol properties, and related atmospheric characteristics in diverse climate regimes; and
- The ARM Science Program, focused on the analysis of ACRF and other data to address climate science issues associated with clouds, aerosols, and radiation, and to improve GCMs.

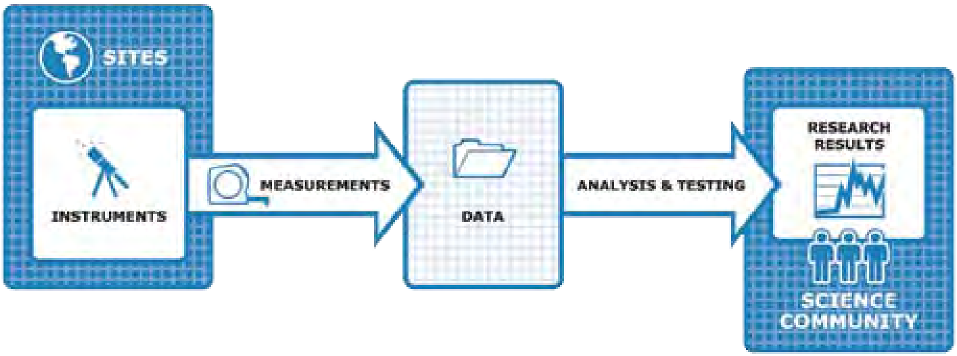
This report provides an overview of each of these components and a sample of achievements for each in fiscal year (FY) 2008.



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.

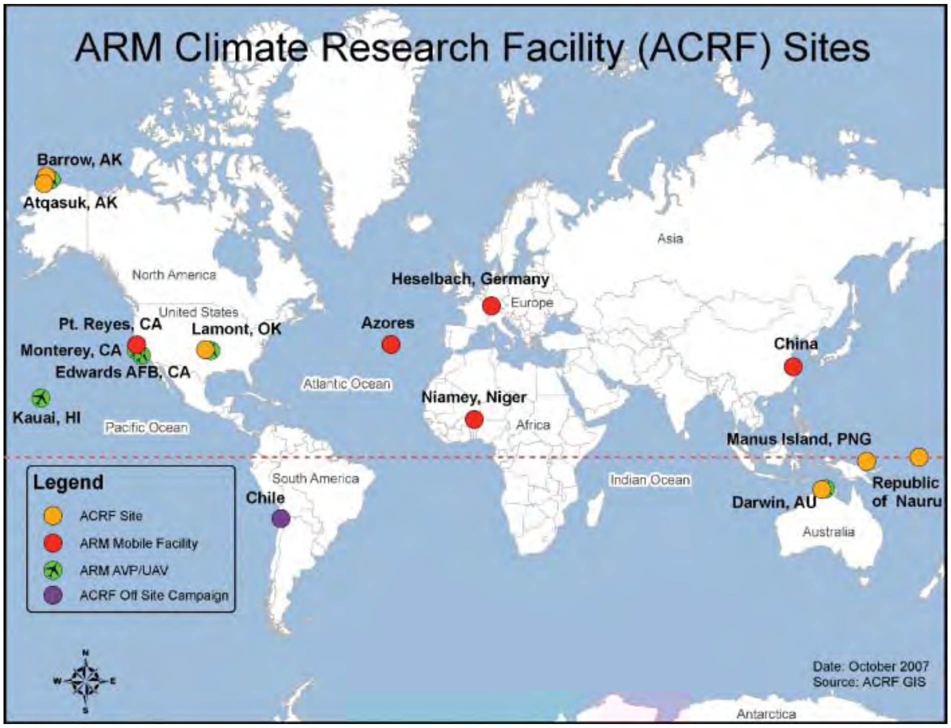
ARM Climate Research Facility

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 are known as the ARM Climate Research Facility, or ACRF.



Three primary locations—the Southern Great Plains (SGP), Tropical Western Pacific (TWP), and North Slope of Alaska (NSA)—plus aircraft and a mobile facility—are heavily instrumented to collect massive amounts of atmospheric measurements needed to create data files. Using these data, 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 ACRF Data Archive (***www.archive.arm.gov***) to aid in further research.

The ACRF has enormous potential to contribute to a wide range of interdisciplinary science in areas such as meteorology, atmospheric aerosols, hydrology, biogeochemical cycling, and satellite validation, to name only a few.



Sites Around the World Enable Real Observations

A central feature of the ACRF is a set of permanent, highly instrumented field sites for continuously 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. Measurements obtained at the permanent sites are supplemented with data obtained from intensive field campaigns using the ARM Mobile Facility (AMF) or ARM Aerial Vehicles Program (AVP).

ACRF Promotes Capabilities to International Science Community. *In FY 2008, ACRF representatives were invited to participate in two prestigious international forums: the Global Energy and Water Cycle Experiment (GEWEX) Radiation Panel Meeting held in Brazil and the Global Climate Observing System Upper Air Reference Network (GRUAN) meeting in Germany. Participation in the GEWEX Radiation Panel ensures ongoing dialogue with international leaders in the latest theoretical and experimental approaches regarding radiative interactions and climate feedbacks associated with cloud processes. Partnerships among the GRUAN organizations allow ACRF to contribute its expertise to GRUAN's goals related to long-term, high-quality, upper-air climate records and fully characterizing the properties of the atmospheric column.*

Southern Great Plains

Southern Great Plains

The SGP site consists of a highly instrumented Central Facility near Lamont, Oklahoma, and smaller "satellite" facilities scattered over approximately 143,000 square kilometers in north-central Oklahoma and south-central Kansas. This area experiences a wide variety of cloud types and surface flux properties, as well as large seasonal variations in temperature and humidity. 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.

Tropical Western Pacific

Tropical Western Pacific

The TWP locale spans the equatorial region 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 at the following locations: Manus Island, Papua New Guinea, since 1996; Nauru Island, since 1998; and Darwin, Australia, since 2002.

North Slope of Alaska

North Slope of Alaska

Situated on the edge of the Arctic Ocean, this region experiences fundamentally different climate processes than other latitudes, such as planetary heat loss from the poles and extensive ice sheets that affect solar absorption and sea level. As such, this area is known to be especially sensitive to climate change. The NSA's principal instrumented facility was installed near Barrow in 1997, followed by a smaller remote site at Atqasuk in 1999.

ARM Mobile Facility

ARM Mobile Facility

The AMF was developed to investigate science questions beyond those addressed by the permanent sites. It can be deployed around the world for campaigns lasting 6–12 months, and consists of a baseline suite of instruments similar to the fixed sites, operations and instrument shelters, and data and communications systems. Because deployments may often be associated with experiments from other agencies, it was designed to host guest instruments in addition to the baseline collection. A second mobile facility is under development.

ARM Aerial Vehicles Program

ARM Aerial Vehicles Program

Complementing the ACRF's long-term, ground-based measurements of cloud and atmospheric properties, the AVP emphasizes instrumented airborne measurement campaigns. In situ and remote sensing data acquired from instrumented aircraft at various altitudes provide critical information for studying how clouds and aerosols interact with solar and thermal radiation. Aircraft may be used for short, intensive field campaigns, or for longer-term, regularly scheduled flights.

Setting the Standard for Ground-Based Climate Observations

The goal of ACRF's instrument development initiative is to deploy advanced measurement systems around the world and operate them on a continuous basis to provide high-quality research data sets. This approach relies mainly upon the evolution of existing commercial research instrumentation to operate routinely at remote sites and occasionally the specification and development of new instrumentation. As a result, the current generation of ground-based, remote sensing instruments includes two frequencies of millimeter-wave cloud radar, Raman lidar, infrared interferometers, aerosol observing systems, and several frequencies of microwave radiometers, among others. These instrument arrays represent some of the most sophisticated tools available for conducting atmospheric research.

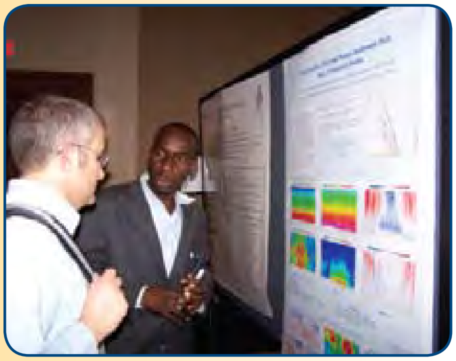
Total Precipitation Sensor Tested for Arctic Snowfall. *Estimating the amount of snowfall on the North Slope is important for a basic understanding of the water cycle and climate variability affecting Arctic regions. However, sparse observations, cold temperatures, and high winds present a particular challenge for obtaining these measurements. At the ACRF site in Barrow, scientists are testing a new precipitation sensor called the Total Precipitation Sensor. Designed to overcome biases in the measurements from standard gauges, the sensor measures the rate of rain or snow by the amount of power needed to evaporate precipitation from its upper plate and keep its surface temperature constant. The sensor's performance is being compared to additional state-of-the-art gauges and sensors installed at the Barrow Environmental Observatory.*

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 carefully reviewed for quality. Approved data are then stored in the Data Archive for use by the atmospheric science community.

Through the scale and quality of this approach to climate research, the ACRF sets the standard for ground-based climate research observations, while ARM scientists lead the world in discoveries related to the interactions of clouds and radiation.

ARM Website Relays Research Accomplishments. *As the online voice of the ARM Science Team, many website improvements were made in 2008 to help ARM scientists share their accomplishments. The research highlights submission form was refined to include the ability to look up and add multiple collaborators from the ARM people database. The research highlights web page now includes the option to download a nicely formatted, two-page PDF version of each highlight, and new highlights are automatically announced through the ARM news center. In addition, a link from the research highlights to the ARM publications database now aids submitters in retrieving their journal reference directly from the publications database, eliminating the need for separate database entries.*

In a related effort, the ARM publications database underwent a significant conversion that allows publications to be better categorized and indexed with common ARM terms, such as research areas, sites, working groups, instrument classes, measurements types, and field campaigns. A new submission form for this database standardizes bibliographic references and key words that will link publications to other key website areas in the future.



Researchers from around the world gather annually at the ARM Science Team meeting to discuss progress and results with their colleagues. Here, scientists discuss results from the AMF deployment in Niger, Africa.

ARM Science Goals

Research in the ARM Program seeks to develop a better quantitative understanding of how atmospheric properties affect the solar and infrared radiation balance that drives the climate system. This includes the extent and type of cloud cover and changes in aerosols and greenhouse gas concentrations. Much of the research is focused on improving the quantitative models necessary to predict possible climate change at global and regional scales. It also includes support to archive and analyze climate change data, including data from fixed research sites and data on greenhouse gas emissions and concentrations, and to make such data available for use by the broader climate change research community. Through these activities, ARM scientists seek the answers to two principal questions:

- How accurate are both solar and infrared radiative transfer calculations for a cloudy 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, ARM scientists collaborate extensively with other laboratories, agencies, universities, and private firms in gathering and sharing data.

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.

Working Groups Provide Leadership, Focus on Specific Problems

To focus their efforts on a specific set of issues related to climate modeling, the ARM Science Team divides its research into key areas, or Working Groups. These groups are the principal organizational structure within the ARM Science Team. The Working Groups include:

Aerosol – quantify the impact of aerosols on the radiative balance of Earth's climate system, both directly and indirectly through their influence on clouds.

Cloud Modeling – relate observations and data analyses 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.

Radiative Processes – test radiation parameterizations, particularly for shortwave radiation and cloudy-sky conditions, at the accuracy required for climate studies.

New Data Product for Climate Modelers. *In 2008, diligent efforts by the Cloud Modeling Working Group culminated in the development of a new data set specifically tailored for use in evaluating global climate models. The Climate Modeling Best Estimate, or CMBE, includes long-term best estimates from 10 selected measurements at all the ACRF sites. After its initial release in February, improvements were subsequently made to the cloud fraction, cloud liquid water path, precipitable water vapor, and surface radiative fluxes. The new CMBE, released in July, is available as a showcase data set at the ACRF Data Archive.*

Cooperation and Oversight Enable Success

Nine DOE national laboratories and numerous government agencies, universities, private companies, and foreign organizations contribute to ARM Science and the ACRF. Each entity serves a vital role in managing and conducting the research, operations, and administration of the science program and user facility.

For ARM Science activities, direction and oversight is the responsibility of **DOE Headquarters**. A **Science and Infrastructure Steering Committee** assists DOE Headquarters in developing the overall science vision and implementation plan. This includes strategies for developing data products and measurement systems, and identifying needed model improvements. **Working Group** members play a large role in the detailed implementation of the ARM research agenda, for example, in prioritizing new instrument purchases and in forming focus groups to pursue specific topics.

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.

New Members Join Science Board. *In January, the ACRF Science Board welcomed two new members to its ranks—Dr. Judy Curry from Georgia Tech in Atlanta, and Dr. Susanne Crewell from the University of Cologne, Germany. Dr. Curry is the chair of the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology. Her expertise includes polar meteorology and climatology, atmospheric physics, remote sensing, and air/sea/ice interactions. Dr. Crewell is the chair of the Goescience Department at the University of Cologne. Her expertise encompasses development of millimeter and submillimeter radiometers, remote sensing, stratospheric trace gases, cloud physics, and model evaluation. Both members will serve on the board for a term of at least two years.*

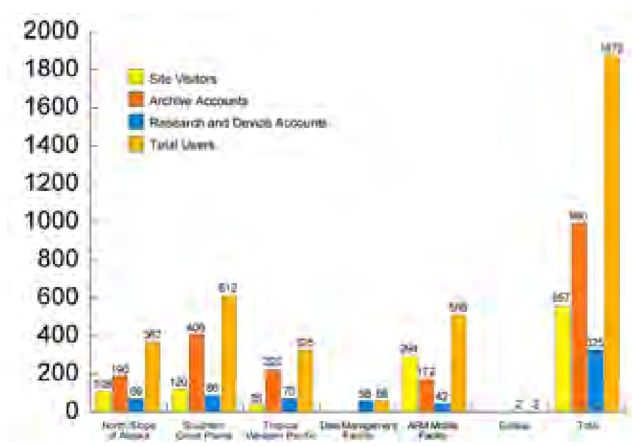
Dr. Judy Curry (left) and Dr. Susanne Crewell joined the ACRF Science Board in 2008.

Fiscal Year 2008 Budget Summary and User Statistics

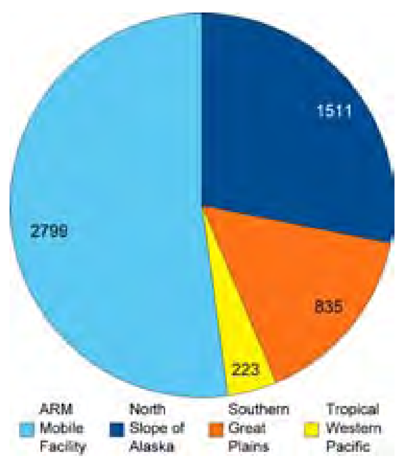
Atmospheric Radiation Measurement Program FY 2008 Budget ($K)	
Total ARM Program	**50,016**
Infrastructure	35,251
Science	14,765

Operational Statistics for the Period October 1, 2007 – September 30, 2008		
	Data Availability	
SITE	**GOAL**	**ACTUAL**
NSA	0.90	0.94
SGP	0.95	0.95
TWP	0.85	0.95
Site Average	**0.90**	**0.95**

User Statistics for the Period of October 1, 2007 – September 30, 2008



User Summary



Visitor Days by Site

Key Accomplishments

The following pages highlight a selection of field campaigns, research results, and infrastructure achievements from FY 2008 (October 2007 through September 2008). A complete list of FY 2008 field campaigns and publications is provided at the end of this report. More detailed information can be found on the following web pages:

- ***www.arm.gov/acrf/fc.stm*** for Field Campaigns
- ***www.arm.gov/publications/publist*** for Publications
- ***www.arm.gov/news/fac.php*** for Facility Updates.

Featured Field Campaigns

Indirect and Semi-Direct Aerosol Campaign

The Convair takes off on one of its 16 flight days from Fairbanks to Barrow, Alaska, during the month-long ISDAC field campaign. Both wings were heavily instrumented with cloud and aerosol probes.

To improve scientific understanding of cloud-aerosol interactions, particularly in the Arctic where observational data are sparse, the ACRF conducted the Indirect and Semi-Direct Aerosol Campaign (ISDAC). In April 2008, scientists involved in ISDAC used 42 instruments—including two that had never flown in an official airborne research mission before—mounted on the National Research Council of Canada (NRC) Convair research aircraft to obtain in situ cloud and aerosol measurements from the region above the NSA site in Barrow.

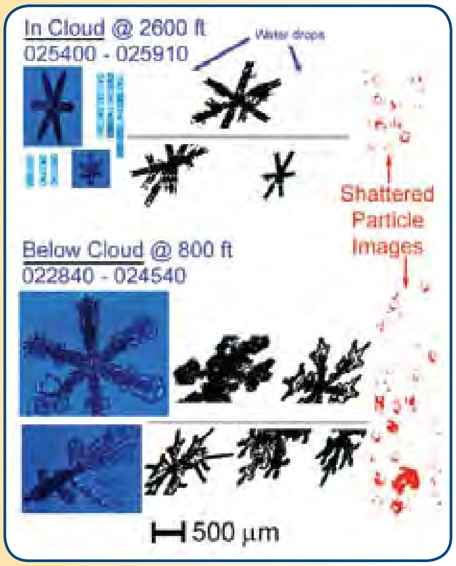
Based out of Fairbanks, Alaska, more than 80 scientists and logistics personnel participated in the campaign, which resulted in 27 science flights and a total of 103 research hours. These flights included golden cases on April 8 and 26, where both cloud and aerosol measurements were obtained above, within, and below single-layer stratocumulus clouds. Heavy pollution detected on April 19 is another case that will receive critical analysis.

Dr. Greg McFarquhar (second from left) emphasizes the goals of the ISDAC campaign during an all-hands kickoff meeting at the aircraft hangar in Fairbanks. He was co-lead for the study along with Dr. Steve Ghan, on his right.

In preparation for the campaign, the AVP team worked closely with collaborators at Environment Canada and NRC to establish the precise weight of the Convair payload and adjust the final instrument package to stay within the combined fuel/payload weights limits. All of the campaign's primary objectives were met, plus some secondary objectives, to help answer the team's science questions related to Arctic cloud-aerosol interactions. The data set obtained during ISDAC will improve scientific understanding of the relationship between properties of aerosol particles and their activity as cloud condensation and ice nuclei, which play a major role in the amount of precipitation and heat that reach the Earth's surface.

> *"The success of ISDAC far exceeded what we anticipated when we originally proposed the experiment," said Dr. Greg McFarquhar from the University of Illinois at Urbana-Champaign and co-lead scientist for the campaign. "Our comprehensive instrument suite worked exceptionally well in the harsh conditions, collecting a wide range of cloud and aerosol data that will prove very useful for process model studies. The complete data set will greatly enhance our understanding of aerosol-cloud interactions in the Arctic and improve representations of these processes in models with a wide range of spatial scales."*

Results: Using state-of-the-art instruments, the ISDAC campaign generated a wealth of new data to link cloud microphysics, aerosol chemistry, and optical properties, particularly for ice and mixed-phase clouds, which are key regulators of Arctic climate. Taking place during the International Polar Year, many ancillary observing systems collected data to allow synergistic interpretation of ISDAC data. The April 2008 ISDAC campaign also provided an important contrast with the Mixed-Phase Arctic Cloud Experiment (M-PACE), which took place in the NSA region in October 2004. This contrast will allow scientists to investigate seasonal differences in arctic aerosol properties.



These examples of ice particle images were measured in cloud and in precipitation below cloud by a cloud particle imager and a two-dimensional stereo probe, both from SPEC Inc., on April 26, 2008–one of the campaign's golden days. In conjunction with other observations, these data will help to characterize properties of mixed-phase clouds where water and ice co-exist and to quantify the contributions of particle artifacts produced by shattering on probe inlets.

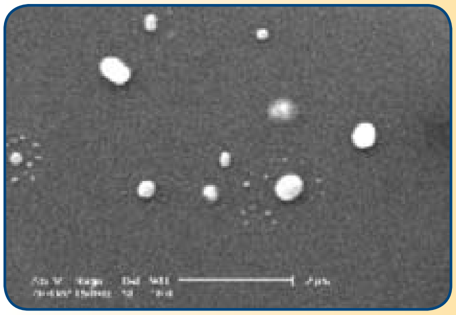
Using models initialized with surface data from both M-PACE and ISDAC, scientists can determine the extent to which the differences between spring and fall Arctic aerosols produce differences in the observed cloud microphysical and macrophysical properties and surface energy balance. The cloud data will also be useful for evaluating the performance of cloud models, climate model parameterizations, and long-term retrievals of aerosols, clouds, precipitation, and radiative heating from surface-based measurements.

The unprecedented array of cloud microphysical probes used during ISDAC provided measurements of the different particle sizes and shapes, as well as the integrated mass and extinction cross-sections of the particles. These data will allow scientists to assess, for the first time, the consistency and performance of multiple cloud probes through closure tests of mass and extinction. In particular, scientists will be able to assess whether the shattering of large crystals on the probe inlets artificially amplify the concentrations of small ice crystals—a conundrum that has mystified scientists for the past 20 years. Newer probes that will be particularly useful in these investigations include:

- the two-dimensional stereo probe, developed by the Stratton Park Engineering Research Company (SPEC Inc.)
- two-dimensional cloud probes with specially designed tips to minimize shattering, designed at Environment Canada
- a cloud droplet probe, which minimizes shattering due to the absence of a shroud and inlet, developed at Droplet Measurement Technologies
- a forward-scattering probe measuring the inter-arrival time of particles developed at SPEC Inc.
- a probe for measuring bulk cloud extinction, developed at Environment Canada.

Measurements from this combination of cloud probes, together with data obtained from the aerosol probes, are allowing scientists to examine issues such as identifying the conditions necessary for maintaining mixed-phase clouds where ice and water co-exist; examining the spatial scales over which water and ice can co-exist in cloud; and statistically characterizing the properties of Arctic mixed-phase clouds for modeling and remote sensing evaluations.

The campaign also successfully demonstrated first-time airborne deployments of key instruments for measuring aerosol properties. The Single Particle Laser Ablation Time-of-Flight mass spectrometer, or SPLAT, was originally developed at Pacific Northwest National Laboratory to obtain size-resolved aerosol composition data. The DOE Atmospheric Science Program funded conversion of the instrument for airborne deployment. Throughout the campaign, SPLAT-II provided real-time measurements of the size, density, shape, fractal dimension, and composition of individual particles down to 50 nanometers in diameter. With the capacity to detect and measure up to 100 particles per second, more than 1 million particles were sampled during the month-long mission.



Preliminary screening and analysis of images from the time-resolved aerosol collector indicate particles laden with carbon and sulfur. These data were obtained on April 8, 2008.

Another instrument—the continuous flow diffusion counter from Texas A&M University—provided a data set of ice nuclei concentrations as a function of operational temperature and supersaturation with respect to ice. During ISDAC, aerosol populations from different source locations were sampled. Fluctuations in ice nuclei from less than 0.1 to more than 10 per liter reflect changes in the composition in distinct layers of Arctic haze and can influence aerosol-cloud interactions.

The campaign also featured the deployment of the world's first 3-laser photoacoustic nephelometer instrument. Developed by scientists at Los Alamos National Laboratory, this instrument measured aerosol absorption, scattering, and single-scattering albedo at 405, 532, and 781 nanometers. On numerous flights, the instrument recorded pervasive pollution layers above Alaska. Real-time satellite data assimilated transport models indicate that this pollution was imported from Chinese dust storms and Siberian fires, as well as Eurasian sulfate sources. Wavelength-dependent optical properties were used to diagnose the soot, dust, sulfate, and organic components of this pollutant layer.

Orbiting Carbon Observatory – Fourier Transform Spectrometer Validation

The Orbiting Carbon Observatory, or OCO, is a NASA Earth System Science Pathfinder mission designed to make precise, time-dependent global measurements of atmospheric carbon dioxide from an Earth-orbiting satellite. The primary validation data for the space-based retrievals will come from a network of laboratories outfitted with ground-based Fourier transform spectrometers (FTS). These FTS instruments measure the near-infrared region of the solar spectrum at very high resolution, allowing scientists to calculate the concentration of greenhouse gases in the atmosphere. The SGP and TWP sites are each hosting an FTS mobile laboratory.

A camera, weather station, and sun tracker with a protective dome are located on the roof of the fully automated FTS mobile laboratory. Inside the shelter, the spectrometer receives the reflected solar beam from the sun tracker (inset), while the main computer system operates all the instruments and acquires the data.

Light from the sun is absorbed by different gases as it passes through the Earth's atmosphere. Measurements of the solar spectrum at high resolution allow scientists to calculate the concentration of these gases in the atmosphere. In the FTS mobile laboratory configuration, a sun tracker sends a solar beam downward through a hole in the roof. This beam hits a mirror positioned at 45 degrees below the hole and is directed into the spectrometer.

Traditionally, aircraft equipped with infrared gas analyzers have provided world standard measurements of in situ carbon dioxide. However, their ability to obtain long time-series measurements is limited by the cost of conducting airborne campaigns. The continuously operating ground-based FTS not only solves this problem, it also measures a broader range of the infrared spectrum and, therefore, can measure additional atmospheric gases. Ground-based measurements from nearly two dozen FTS stations will be used to validate the OCO satellite data obtained from around the globe.

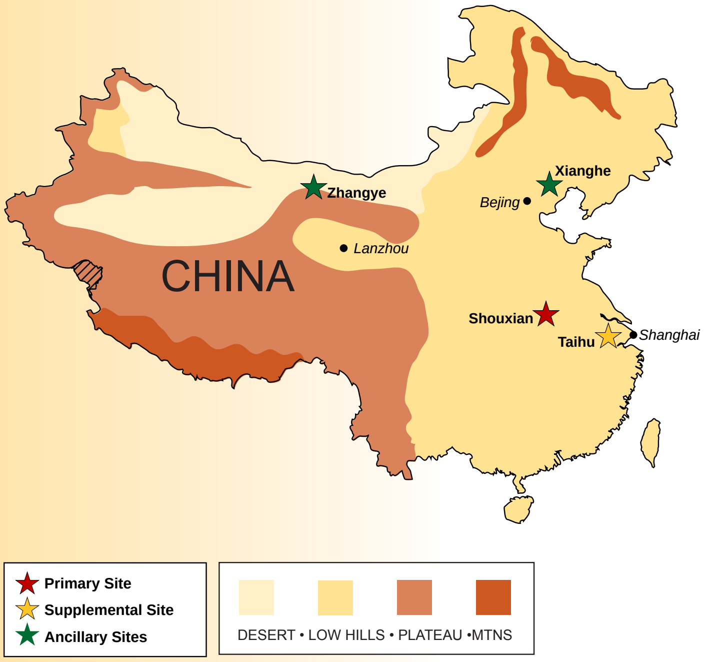
"One of the most interesting parts of the OCO validation effort is that we can turn the satellite and point it at a target of interest on the ground. This is what we call 'target mode'," said Dr. Debra Wunch, a postdoctoral researcher at the California Institute of Technology and validation team member. "Both the SGP and Darwin sites are important target sites during the OCO mission and will provide coincident measurements needed to validate OCO."

Results: The OCO field campaign began with the installation of the FTS in Darwin in late 2005. Soon after, overflights of the FTS laboratory by the European Union's Geophysica aircraft, equipped with an infrared gas analyzer, obtained highly accurate measurements of in situ carbon dioxide, which were used to calibrate the ground-based data. Additional "flights of opportunity" by ARM's Proteus aircraft during the Tropical Warm Pool-International Cloud Experiment obtained additional comparative data in January and February 2006.

In July 2008, another FTS mobile laboratory was installed at the SGP site after completing a 1-year side-by-side test with the OCO flight instrument at NASA's Jet Propulsion Laboratory. Aircraft overflights of the SGP site are planned for 2009, again providing important calibration information for the ground-based instrument.

Throughout the OCO campaign, the science team is measuring carbon dioxide and related gases, including methane and carbon monoxide. After the OCO satellite launch in January 2009, scientists will analyze measurements from the spectrometers onboard the OCO satellite against the FTS data to improve our understanding of the natural processes and human activities that regulate the abundance and distribution of this important greenhouse gas. This improved understanding will enable more reliable forecasts of future changes in the abundance and distribution of carbon dioxide in the atmosphere and the effect that these changes may have on the Earth's climate.

The OCO science team is leveraging the ACRF's expertise and infrastructure in ground-based and in situ sampling of atmospheric aerosol properties and carbon cycle trace gases to aid in this high-profile mission. This collaboration between DOE and NASA represents a significant contribution to the interagency Carbon Cycle Science Initiative of the U.S. Global Change Research Program.



Anchored by the AMF in Shouxian, additional instrumented sites to the east and north provided a comprehensive atmospheric data set for studying aerosol effects in the region.

Study of Aerosol Indirect Effects in China

In its most complex deployment to date, the AMF participated in a four-site observational effort to acquire essential cloud, aerosol, radiative, and meteorological measurements for the Study of Aerosol Indirect Effects in China. Anchored by the AMF in Shouxian, the campaign also included a supplemental facility at Lake Taihu and an ancillary facility that operated in series at two sites to the north. Extensive measurements of clouds, aerosols, radiation, and precipitation at the sites between May and December 2008 will provide comparative measurements to study regional aerosol effects.

Aerosols in China are very dense and have diverse properties which have been observed in the atmosphere across the Pacific Rim. This atmosphere provides a natural testbed for studying the climatic effects of aerosols, which the Intergovernmental Panel on Climate Change identified as a high priority. Although progress is being made, continuing uncertainty is due chiefly to a lack of adequate observations.

While China has a very extensive meteorological observation network, development of climate research oriented facilities did not start until recently; the climate observatory in Shouxian is among the first under development in China. In partnership with the Institute of Atmospheric Physics, Chinese Academy of Science, the study was conducted under the "climate science" agreement established in 1987 between the DOE and China Ministry of Science and Technology.

The AMF operated at the Shouxian National Climate Observatory, approximately 500 kilometers west of Shanghai. A supplemental facility with a reduced complement of AMF instruments obtained measurements at an observatory on the shores of Lake Taihu, just 96 kilometers west of Shanghai. This facility is located at the permanent observatory maintained by the Chinese Academy of Sciences; it was enhanced with additional instruments and staff from the Nanjing University of Information Science and Technology and the University of Maryland. Both the AMF and supplementary facility operated from May through December 2008.

In addition, an ancillary facility with a subset of AMF instruments was established to the north and was operated by collaborators from Lanzhou University. Between May and October 2008, this facility obtained comparative measurements in locations with different environmental conditions: semi-desert conditions at Zhangye in north-central China, followed by a primarily agricultural environment at Xianghe on the northeast coast.

Measurements obtained from all the study sites during the 8-month deployment in China will help scientists to validate satellite-based data, understand the mechanisms of the aerosol indirect effects in the region, and examine the roles of aerosols in affecting regional climate and atmospheric circulation, with a special focus on the impact of the East Asian monsoon system.

Nearly 50 Chinese officials, researchers, and media attended an opening ceremony at the Shouxian National Climate Observatory on May 16, 2008.

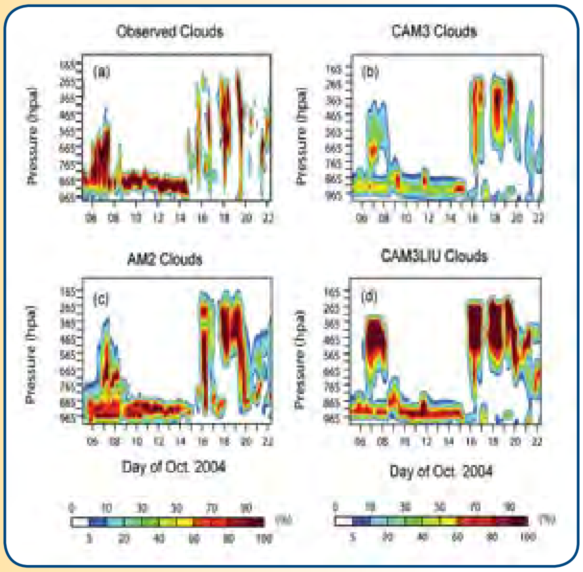
Several AMF instruments were located on the roof of the Shouxian National Climate Observatory, while the primary AMF operations area (shown here) and instrument field were located just outside the building.

"While complex, the collaboration received from Chinese agencies made the deployment to China a success," said Kim Nitschke, AMF site manager. "In particular, the assistance received from the Institute of Atmospheric Physics has made this project a leading example for future U.S.-China scientific collaborations."

Research Highlights

Mixed-Phase Cloud Data Used to Improve Arctic Climate Simulations

(Xie, S, J Boyle, SA Klein, X Liu, and S Ghan. 2008. "Simulations of Arctic mixed-phase clouds in forecasts with CAM3 and AM2 for M-PACE." *J. Geophys. Res.*, 113: Art. No. D04211, doi:10.1029/2007JD009225.)



Time versus height cross sections comparing M-PACE observations of cloud frequency (top left) against modeled cloud fraction for several climate models show discrepancies in boundary layer cloud fraction and condensate.

Detailed in situ observations of Arctic mixed-phase clouds and their microphysical properties were obtained using various ground-based remote sensors and aircraft during M-PACE in October 2004 at the NSA site. Using this data set, ARM scientists tested two major U.S. climate models: the National Center for Atmospheric Research (NCAR) Community Atmospheric Model version 3 (CAM3) and the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) climate model (AM2). The focus of the model evaluation was to reveal potential deficiencies related to the cloud and cloud microphysical schemes used in these two climate models through direct comparisons with the data from M-PACE. They also tested a new physically based cloud microphysical scheme in CAM3 to help understand how cloud microphysical processes affect the evolution and phase partitioning of the mixed-phase clouds. The models were tested using a framework developed through a joint effort between DOE's Climate Change Prediction Program (CCPP) and the ARM Program, called the CCPP-ARM Parameterization Testbed (CAPT), which allows running climate models in weather forecast mode so that climate models can be directly assessed using ARM data.

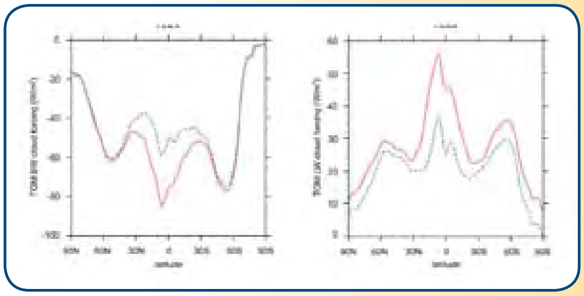
Their results show that CAM3 significantly underestimated the observed boundary-layer mixed-phase cloud fraction and, due to its oversimplified cloud microphysical scheme, it cannot realistically simulate the variations of liquid water fraction with temperature and cloud height. In contrast, AM2 reasonably reproduced the observed boundary-layer cloud fraction while its clouds contained much less cloud condensate than CAM3 and the observations. Simulation of the boundary-layer mixed-phase clouds and their microphysical properties improved considerably in CAM3 when the new physically based cloud microphysical scheme, CAM3LIU, was used. The new scheme also improved simulations of the surface and top-of-atmosphere longwave radiative fluxes.

Simulations Bring Ice Crystal Assumptions Down to Earth

(Mitchell, DL, P Rasch, D Ivanova, G McFarquhar, and T Nousiainen. 2008. "Impact of small ice crystal assumptions on ice sedimentation rates in cirrus clouds and GCM simulations." *Geophys. Res. Lett.*, 35: Art. No. L09806, doi:10.1029/2008GL033552.)

Surface temperatures predicted by GCMs depend primarily on two physical parameters; the efficiency by which clear air is mixed into thunderstorms, called "entrainment," and the fall speed of ice particles in cirrus clouds. Ice particles are difficult to measure and their concentrations are highly uncertain. With new parameterizations for ice cloud size distributions, sedimentation rates and optical properties—all developed through the ARM Program—researchers performed two 1-year CAM3 simulations to examine the model's sensitivity to two different temperature-dependent small ice crystal assumptions.

The researchers found that higher assumed small ice crystal concentrations resulted in lower fall speeds, more cirrus cloud ice content with a 5.5 percent global increase in coverage, and more than a 3 degrees C increase in temperature in the upper tropical troposphere. The figure summarizes cloud forcing for the two simulations. Cloud forcing refers to the upwelling solar (shortwave) or terrestrial (longwave) radiation flux at the top of the atmosphere with a cloudless atmosphere minus that with clouds included. These changes, due to higher concentrations of small ice crystals, had an overall cooling effect in the tropics, but a warming effect elsewhere. The difference between simulations in small ice crystal concentrations reflect less uncertainty than that associated with in situ measurements. Because the GCM simulations were only 1-year long, the longer-term effect is unknown and longer simulations are recommended.



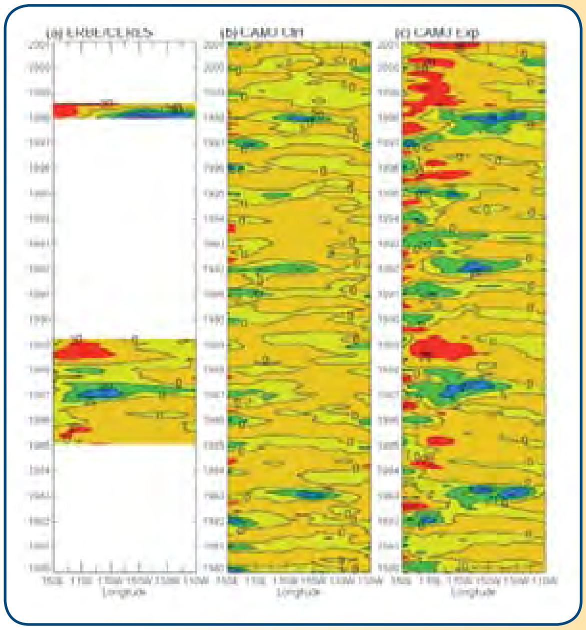
Differences in shortwave (left) and longwave (right) cloud forcing are shown for the two simulations, with the red line indicating the simulation with higher concentrations of small ice crystals.

This research demonstrates the dependence of the representative ice fall speed on the concentration of relatively small ice crystals and relates the difference in small ice crystal concentration directly to GCM predictions of climate. It suggests that the direct effect of ice particle size on cirrus radiative properties may be secondary to its effect on ice fall speed and subsequent impacts on the global radiation budget. This study underscores the need to reduce measurement uncertainties regarding the concentration of small ice crystals in cirrus clouds.

Revised Convection Scheme Captures El Niño Anomalies

(Li, G, and GJ Zhang. 2008. "Understanding biases in shortwave cloud radiative forcing in the National Center for Atmospheric Research Community Atmosphere Model (CAM3) during El Niño." *J. Geophys. Res.*, 113: Art. No. D02103, doi:10.1029/2007JD008963.)

Cloud radiative forcing is an important component of the Earth's radiation budget, and El Niño represents the most prominent mode of interannual climate variability. Thus, it is imperative that GCMs simulate the radiative response to El Niño well in order for them to be useful for climate variability studies and future climate prediction. To investigate known shortcomings in the current NCAR CAM3 simulations for El Niño response, ARM researchers used a revised convection parameterization scheme developed by Zhang and McFarlane to compare the standard NCAR CAM3 simulation with sea surface temperature (SST) observations obtained by satellites. The goal was to improve simulations of shortwave cloud forcing (SWCF) response to El Niño in CAM3 and examine the physical mechanisms responsible for such improvements. Because SWCF depends on cloud optical and physical properties, the researchers systematically examined the simulation of cloud amount, liquid water path (LWP), and ice water path (IWP) in response to El Niño.



Observed SWCF anomalies (left) during 1986/1987 and 1997/1998 El Niños were largely missed by the standard CAM3 simulation (middle), but were reproduced well with the revised convection scheme (right).

Examination of the relationships among simulated cloud IWP, LWP, cloud amount, and SST anomalies showed that differences in cloud LWP anomalies between the simulations were responsible for the differences in SWCF response. Further analysis of cloud amount and in-cloud LWP indicated that excessive decreases of cloud amount and cloud LWP for low-level clouds—both of which contribute to the negative LWP anomalies—led to weak SWCF anomalies during

El Niño in the CAM3 control simulation. Results also showed that reduced shallow convection may have contributed to the negative cloud amount LWP anomalies in the control run. Using the modified Zhang-McFarlane convection scheme, shallow convection was more active compared to the control, and liquid water content anomalies were higher due to enhanced transport of water vapor by shallow convection to the lower-middle troposphere. Comparison with a higher-resolution simulation confirmed the importance of LWP anomalies in improving the SWCF simulation.

Simulating Mixed-Phase Clouds: Sensitivity to Ice Initiation

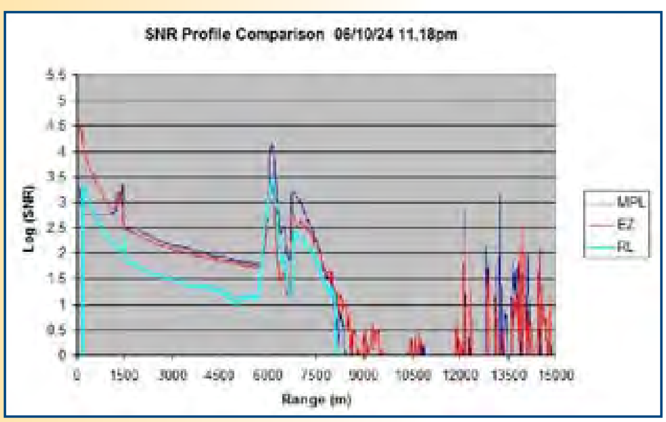
(Sednev, I, S Menon, and G McFarquhar. 2008. "Simulating mixed-phase Arctic stratus clouds: Sensitivity to ice initiation mechanisms." *Atmos. Chem. Phys. Discuss.*, 8:11755-11819.)

The vertical structure and radiative properties of persistent low-level Arctic clouds depend on their microphysics. Therefore, the relative significance of the microphysical processes that occur in these mixed-phase clouds is important. For the longevity of mixed-phase clouds, the ice initiation process (IIP) is crucially important, and the Bergeron-Findeisen process is commonly used to represent this evolution. To examine IIP with and without the liquid phase, as well as the WBF process, ARM researchers used a bin-resolved model (BRM) coupled to NASA's GISS line-by-line, single-column model and applied it to observations of single-layer stratiform mixed-phase clouds obtained during M-PACE in October 2004 at the NSA.

Observed and simulated microphysical characteristics (concentration of liquid and solid particles, liquid water content, cloud droplet effective radius for liquid, and ice water content) were quite similar. However, the simulated and observed ice crystal effective radius (Rei) differed considerably. The researchers determined that Rei definition based on melted radius is more useful for evaluation of the relative importance of different microphysical processes, such as different IIPs. Their sensitivity runs also showed that originated ice crystals continue to grow in simulated clouds mainly due to the rate of glaciation of single-layer, mixed-phase

New Lidar Shows Promise for Cloud and Aerosol Measurements*. Atmospheric scientists routinely use light detection and ranging (lidar) systems to obtain data about cloud and aerosol layering and optical properties. A new lidar instrument from Leosphere, called the EZLIDAR™, is a compact, robust, turn-key and eye-safe lidar system which can be easily integrated on an all-weather remote sensing platform. The EZLIDAR was operated next to the established ACRF Micropulse lidar at the SGP site in 2006 to evaluate its performance and potential, and analyzed against a variety of measurements from additional instruments at the SGP site.*

Results from this validation effort show the EZLIDAR data quality are comparable with the SGP Micropulse lidar data during the daytime under multilayered cloud conditions and has similar maximum range under clear-sky conditions. Combined with its outdoor and unattended use capabilities, these results indicate the instrument is suitable for obtaining automated aerosol and cloud measurements.



Signal-to-noise ratio measurements from the Micropulse lidar (dark blue), EZLIDAR (red), and Raman lidar (light blue) at the SGP site in October 2006.

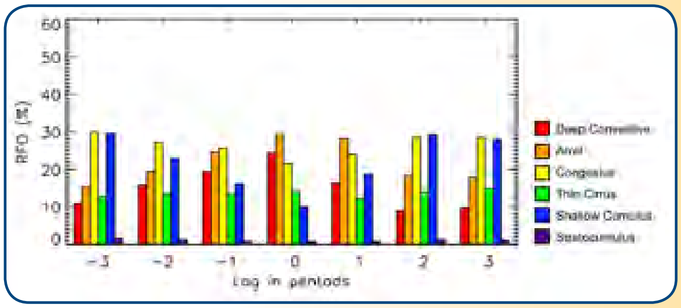
M-PACE clouds. In bulk schemes, the droplet activation process does not account for the broad spectrum of newly nucleated cloud droplets, so the researchers suggested the creation of a unified modeling framework that includes a computationally expensive BRM-type scheme and a computationally efficient, but less sophisticated, microphysics scheme. Development of such a scheme should be based on observations and numerical simulations obtained using the benchmark BRM scheme.

Questioning Cloud Clusters to Model Tropical Climate

(Chen, Y, and AD Del Genio. 2008. "Evaluation of tropical cloud regimes in observations and a general circulation model." *Clim. Dyn.*, doi:10.1007/s00382-008-0386-6.)

Scientists sometimes apply a clustering algorithm to satellite data and model output to create objective "cloud regimes" for evaluating GCMs. As an example, joint histograms of cloud top pressure and optical thickness in the International Satellite Cloud Climatology Project (ISCCP) data set produce six cloud regimes in the tropics, crudely related to times and places dominated by deep convective, anvil, midlevel congestus, thin cirrus, shallow cumulus, and stratocumulus clouds. To assess the validity of the ISCCP clusters before evaluating GCMs against ISCCP, ARM scientists used optimized data from the ACRF Manus and Nauru sites and aggregated the highest cloud top distributions by coincident ISCCP cluster occurrence. Taking this a step further, they focused on the Madden-Julian Oscillation (MJO)—the major mode of sub-seasonal variability in the Tropical Western Pacific—to determine whether clusters vary systematically with the large-scale dynamic state.

Their study showed that the ISCCP overestimated midlevel and low-level clouds in the anvil and congestus clusters. When the ISCCP cloud top heights were adjusted to match the ACRF data, the independence of several clusters disappears. Direct clustering of the ACRF cloud profiles produced only four independent regimes at Manus and three at Nauru. An MJO analysis of cloud cluster relative to the MJO phase (see figure) showed that ISCCP congestus and shallow cumulus clusters dominated during the suppressed phase, giving way near the peak to the deep convective and anvil clusters. This progression was consistent with the recharge-discharge view of MJO evolution due to moisture preconditioning of the troposphere by shallow and midlevel clouds. Analysis of cloud profiles at the ACRF Manus site aggregated by MJO phase supported this view of the progression of cloud types. The thin cirrus regime was insensitive to MJO phase, suggesting a non-convective origin. The researchers concluded that the six ISCCP clusters probably do contain independent information, but represent neither a true distribution of all clouds nor a true distribution of highest cloud top heights.



Relative frequency of occurrence (RFO) of each cloud regime as a function of lag in 5-day increments (pentads) relative to the MJO peak for eight MJO events covering November-April of 1999-2003.

Another analysis using NASA's Goddard Institute for Space Studies (GISS) "Model E" GCM produced only four clusters, most closely resemble the deep convective, cogestus, shallow cumulus, and stratocumulus regimes. However, closer inspection revealed that the model in fact rarely produced midlevel congestus, and shallow convection occurred almost equally often in the two suppressed regimes. This indicates that clustering on cloud properties does not accurately reflect the parameterized physical processes operating in the model.

Infrastructure Achievements

Site Operations

Interagency Land-Use Agreement Signed for North Slope of Alaska

As scientific neighbors on Alaska's North Slope, the ACRF site at Barrow operates between the USGS (left) and the NOAA (right) research facilities. Less than 1 kilometer to the northwest, the shore of Elson Lagoon leads to the Arctic Ocean.

After more than a year of discussions and negotiations, the ACRF renewed its land-use agreement with interagency partners to continue operations at the NSA Barrow site. Signed by the U.S. Bureau of Land Management (BLM), NOAA, and the U.S. Geological Survey (USGS), the new agreement extends for 10 more years, with a provision for operations up to 40 years, contingent on an extension of the NOAA/USGS land-use withdrawal agreement. As ACRF's site operations team at the NSA, Argonne National Laboratory, and Sandia National Laboratory are also signers to the agreement.

When the original ACRF research site in Barrow was established in 1997, the agencies signed a "right of way" agreement for operation of the Great White instrument shelter for 10 years. As originally intended, this time period would be sufficient to establish the minimum climate record for use by the atmospheric research community. With the success of the ARM infrastructure and its designation as a national user facility in 2003, it became clear that ACRF would continue operations in the area into the foreseeable future, and the agreement would need to be renegotiated and extended. A series of meetings between the agencies began in earnest in 2007, with each party negotiating in good faith to ensure the success of each organization's scientific efforts. The commitment of all parties to this agreement strengthens each organization's position in the Arctic research community.

Staying in Sync

GPS receivers are installed at all the extended facilities throughout the SGP domain.

Accurate time stamps on data collected at the ACRF sites are very important for confidence in using the measurements for research. At the dispersed facilities across the SGP site, making sure all the instruments and their associated data logging systems are on the same clock is no easy task. Due to their remote locations, many of these field facilities still rely on dial-up Internet connections and are susceptible to frequent power outages. After uncovering a minor but pervasive offset in time records, SGP site operations staff quickly diagnosed the problem and set about implementing a solution. New synchronization software installed throughout the site will ensure that future automatic clock resets account for any "drift" between the instrument hardware and data collection systems, keeping SGP site data in sync.

In February, SGP site operations staff discovered the flaw in the time-sync process used at the extended and intermediate facilities. During system startups or reboots, the method used for data transport—an Ethernet-based serial port—was causing clock instability. In addition, the start-up process did not include access to the highly precise global positioning system (GPS) time signal available from the GPS receivers at each facility. The new time synchronization software runs independently of offsite network connections, minimizing the risk of incorrect time settings, particularly where offsite communications are less reliable.

Wildlife Challenges Lead to Wireless Solutions

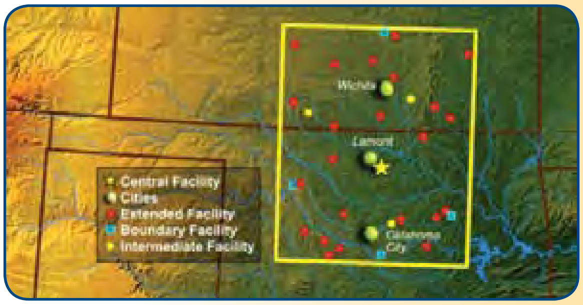
The total precipitation sensor at the ACRF Barrow site provides measurements of snow and rate (see sidebar in Program Overview). Though covered by snow during the winter, exposure of the 1-kilometer length of fiber optic cable that transfers data from the sensor to the Great White instrument shelter clearly presented a temptation to the local animal population during the summer months. After falling victim to curious and possibly hungry lemmings and other wildlife in the area, the fiber optic cable was replaced in 2008 with a wireless data acquisition system and virtual access port. This not only negates the possibility of further cable damage from furry friends, but reduces the potential for water-related damage during peak melting seasons and allows remote access for monitoring the data.

ACRF operations staff Walter Brower (standing) and Jimmy Ivanoff (kneeling) reinstall the total precipitation sensor near the Great White instrument shelter in Barrow.

"Lemmings apparently don't respect the fact that this is mil-spec armored cable," said Mark Ivey, ACRF site manager for the NSA locale. Enclosing the cable within buried conduit was considered, but operations and engineering staff proposed another solution: a point-to-multipoint weblink to enhance the existing wireless system for the Great White tower cam. An Ethernet control device now provides a virtual port from which the software acquires data from the sensor. Not only was this solution more cost effective and less disruptive to the environment than the buried conduit option, it allows for easier relocation or addition of other sensors.

High-Speed Internet Deflects Information Overload

A little more room in the Internet link at the SGP site is providing needed relief to the crowded lines that keep data flowing from the site. In July 2008, the Internet service from the SGP Central Facility was switched to a much faster 6-megabits link, increasing the bandwidth by almost four times and providing a significant cost savings. In addition, a number of SGP extended facilities, boundary facilities, and intermediate facilities have been converted from dial-up connections to digital subscriber lines to improve both bandwidth and reliability.

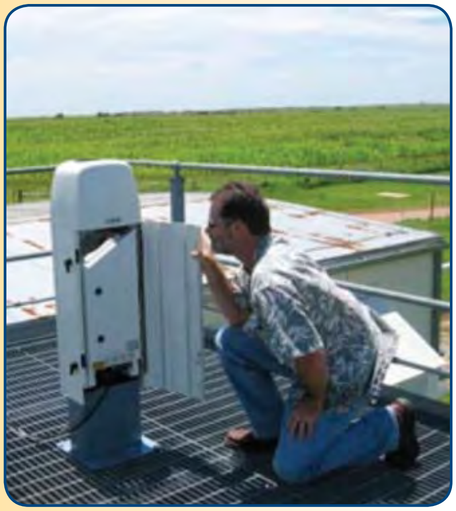


Covering approximately 143,000 square kilometers in Oklahoma and Kansas, instruments at the various facilities throughout the SGP site generate approximately 27 gigabytes of data every day.

Established in 1992, the SGP remains the flagship ACRF site, with the most instruments and the longest data record. Continued increases in data flowing through the SGP Central Facility began approaching the critical limits of the original bandwidth. Recognizing the need for faster data transfer to keep the lines from bogging down, ACRF operations staff pursued new Internet services for this critical component of the site data system. Cost savings were achieved by moving from an offsite T1 connection to a local Internet provider. The physical length of the original T1 service line contributed significantly to its higher cost. Infrastructure at the SGP Central Facility will now support a 20-megabits link, if needed, for future instrument enhancements.

Instrument Enhancements

New Ceilometer Evaluated at Southern Great Plains Site

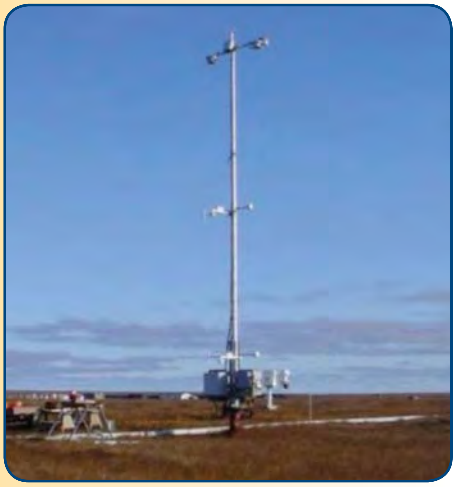


Dan Nelson, SGP facilities manager, inspects the new ceilometer during its evaluation period on the platform of the SGP Guest Instrument Facility between June and July 2008.

Improved techniques for measuring cloud properties and the ability to support these observation systems beyond 2010 are critically important to understand and improve the performance of global climate models. To analyze cloud properties, ARM scientists use data from an instrument called a ceilometer. In preparation for a pending upgrade to the instrument, operations staff completed a field campaign at the SGP site to evaluate the new CL31 ceilometer against the current model, as well as against other instruments that measure similar properties. For 3 days in June, the new model was deployed alongside the current ceilometer and Micropulse lidar at the SGP site. In addition to comparing and contrasting measurements against the lidar, measurements of mixing-layer height from the CL31 will be compared to measurements obtained by the SGP's balloon-borne sounding system during the same time period.

The ACRF uses ceilometer model CT25K at all its sites, but they are approaching the end of their supportable lifetime, with repairs getting more and more expensive. The ceilometer manufacturer, Vaisala, recently released the CL31 model, which includes additional capabilities, such as a newly developed algorithm for mixed-layer cloud detection. The CL31 demonstration will help the ACRF to develop instrument requirements and specifications for replacement of the CT25Ks. Data from the instrument comparison are being analyzed by Vaisala and researchers at the University of Iowa, who are interested in the instrument for application to carbon cycle research.

Sensor Upgrades Improve Meteorological Systems at North Slope of Alaska Sites



Met towers at the ACRF Barrow and Atqasuk (shown here) sites are sporting new instrumentation that improves data delivery and requires less maintenance.

At the NSA sites, standard meteorological measurements such as wind speed, wind direction, air temperature, dew point, and humidity are obtained using conventional sensors mounted on 10- and 40-meter towers. Unfortunately, in freezing weather, ice develops on the wind vanes, cup anemometers, and aspirator inlets for the temperature and humidity sensors. To alleviate data quality issues associated with these conditions and to upgrade aging and failing parts, new ultrasonic sensors and heated probes were installed on the "met" towers at both the Atqasuk and Barrow sites in 2008.

Ultrasonic sensors measure the transmit time between three equally spaced "heads" to determine wind speed and direction. With no moving parts, the ultrasonic sensors do not require costly calibration and, unlike the older wind sensors, spares can be kept to a minimum. To validate sensor accuracy, local operators can make simple checks that verify the geometry of the heads and ensure that the sensors measure 0 meters per second when there are no winds. For the temperature and relative humidity (RH) probes, a new HMT-337 sensor with heated RH probe is designed to operate in cold and high humidity environments. A separate temperature probe is combined with the HMT-337s so the data that have been collected in the past continue. Both of these "smart" sensors include an onboard monitoring system and no longer require the iterative calibration that previous sensors required. When needed, calibration can be carried out at the SGP site, reducing costs by leveraging the current capabilities within the ACRF.

New Radiometer Tested for Measuring Thin Clouds

A thin-cloud rotating shadowband radiometer (TCRSR) completed a month of testing at the SGP site to assess its ability to simultaneously retrieve measurements of cloud optical depth, drop size, and cloud liquid water depth in "thin" clouds, i.e., clouds with water content less than 100 grams per square meter. All of these properties are essential to understanding cloud-climate interaction, but current measurement techniques are not as accurate as desired.

The TCRSR measures the angular distribution, or spread, of light from the sun scattered toward the instrument in six narrow spectral bands. Each of these bands is approximately 10 nanometers wide and centered at 415, 500, 610, 660, 870, and 940 nanometers. The prototype instrument was designed and tested in the summer and fall of 2007. Based on promising results, it was deployed at SGP in early January 2008. Results from the TCRSR observations will be compared to those made by other ACRF instruments. If the technique is successful, the TCRSR may be considered for routine deployment at all the ACRF sites.

Two shadowbands rotate around the TCRSR sensor, located just inside the smaller shadowband. As they sequentially rotate about their axis, the downwelling irradiance is partially blocked, allowing irradiation variations across the solar aureole to be observed.

Radar Antenna Replacement Effort Begins in Barrow

For estimates of cloud boundaries, there is no better capability than the millimeter wave cloud radar (MMCR). The MMCR antenna transmits pulses of millimeter-wave energy into the atmosphere and receives the return signals that bounce back from cloud particles, bugs, or other objects in the atmosphere. These "retrievals" are used to determine cloud tops, bottoms, reflectivity, and vertical velocities. This sophisticated radar is part of the standard instrument suite at all the permanent ACRF sites except for Atqasuk, Alaska. With the 3-meter antenna at the SGP site more than 11 years old, and the 2-meter antennas in the Arctic and tropics ranging from 8 to 10 years old, wear and tear were beginning to take their toll. In late November 2007, ACRF engineering staff replaced the MMCR antenna at the NSA site in Barrow, beginning an effort to replace the aging radar antennas throughout the user facility.

On November 28, 2007, ACRF operations and engineering staff braved -15 degrees F weather to install the new radar antenna at Barrow. Here, ACRF lead engineer Kevin Widener goes gloveless to securely fasten all the tiny connecting screws and bolts—brrrrr!

In the past few years, the antenna's reflector surface started showing signs of wear, and corrosion began to appear on the antenna's support struts. In addition, the water-repellent coatings for the radomes were losing their effectiveness. Because refitting, recalibrating, and shipping the old antennas would cost almost as much as installing new equipment, the ACRF sites are receiving new antennas in the coming years. The new antennas include improved technology for radar echo measurements that help to remove return signals from insects and are useful for precipitation studies. The replacement effort also includes upgrading the radar's data acquisition systems at SGP and Barrow from analog to digital processors for increased sensitivity and efficiency.

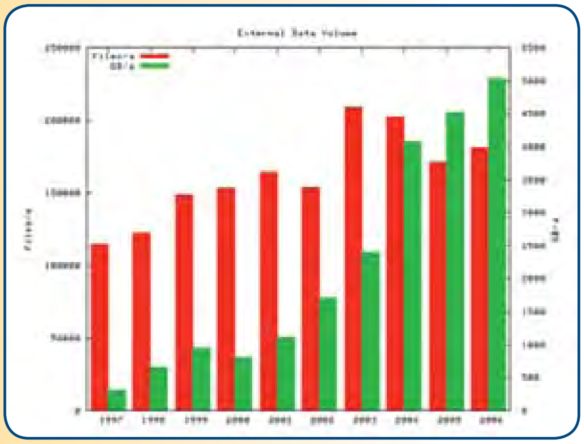
Data Delivery

Enhanced Visualization Tool Eases Data Identification, Extraction

Like many scientific organizations, the ACRF Data Archive stores and distributes atmospheric data from the ACRF sites in Network common data form, or NetCDF. This file format applies names or attributes to the various layers of data for efficient identification and processing. Then, using an interactive web-based tool called NCVweb, users can plot the data sets for easy viewing. In June, the Data Archive rolled out an enhancement to the NCVweb tool that allows users to extract a subset of fields from a datastream to create custom NetCDF files. The new data extraction capability also performs a number of visualization functions that would be time-consuming or difficult for users to do themselves, especially users new to ARM-formatted files.

Unlike generic NetCDF data viewers, NCVweb "understands" ARM data file conventions, which results in improved plot displays. It has many powerful features, such as producing detailed tables of NetCDF file contents, data extraction, generating statistics, and plotting one variable against another. Using NCVweb, users can plot their data orders from the Archive or plot regular standing data orders. The enhanced tool helps to eliminate the need for and problems associated with downloading large volumes of data, installing and configuring visualization software, or writing custom data exploration software.

External Data Center Completes Storage Expansion



When the XDC began operation in October 1996, it processed 26 datastreams based on 11 external data product collections and transferred an average of 12 gigabytes/month to the Data Archive. Today, the XDC handles 250 datastreams based on 31 external data product collections with an average volume of 473 gigabytes/month, and daily operations continue to require more storage.

The ARM External Data Center, or XDC, routinely acquires, processes, and transmits data sets that are scientifically relevant and complementary to ARM data, but originate from external agencies. External data often include large data sets, such as model and satellite data, which consume tremendous amounts of storage space. In November, the XDC completed a storage system upgrade to support ever-growing file storage needs and increase the speed of large batch processing. The new system consists of the newest mainstream disk technology, called SATA disk arrays. This disk system provides fault tolerance (data will not be affected in case of a disk failure) and 9 terabytes of backup storage capacity.

The new system was put into place in phases, beginning with replacing old Sun systems with new rack-mounted servers that provide database, data transfer, and backup functions. Then the backup system was upgraded to provide both disk-to-disk and disk-to-tape backups. The disk-to-tape backup capacity is now 25 terabytes, and can be expanded to 33 terabytes. Four servers were added to the rack to handle increased web services and satellite data processing. And finally, the old disk storage arrays were replaced with new SATA arrays.

Report Details One-of-a-Kind Data Quality Assurance Approach

Very few long-running (10+ years) field-based measurement programs have the diversity of instruments and data types that the ACRF does. In July, the ACRF data team published a report that goes beyond the narrow definition of data quality assurance by describing its end-to-end approach to data quality, which has evolved since 1992. Titled *Quality Assurance of ARM Program Climate Research Facility Data*, the document includes a comprehensive overview of the scope and complexity of the ACRF infrastructure and describes in detail all the components needed to manage data *availability*, *usability*, and *accessibility* at this scale—key components on which ACRF performance is measured. In sharing this information with the climate research community, ACRF is providing the report as a sort of "conceptual model" for those who may want to attempt a similar feat in other locations or with other observational themes.

With about 315 instruments systems operating 24/7 at locations around the world, dedication to data quality is a hallmark of the ACRF. Most research programs strive for useable, large-scale data collections, but few have succeeded on such a grand scale. The ACRF has implemented the systems needed to accomplish this capability—very important for maintaining a climate-scale (decades) collection of field observations. Organizations planning on fielding automated environmental and climate data collection sites could find information in the report valuable. The technical report is available on the ARM website under Technical Reports.

"The uniqueness of the ACRF is its diversity of measurements and sites combined with longevity," said Randy Peppler, ACRF data quality assurance manager and one of the lead authors of the report. "While some organizations have one or the other, no other program can take credit for both attributes at a similar scale."

Global Earth Observations Portal Provides Gateway to ACRF Data

Data obtained at the ACRF sites are freely available to users worldwide through the ACRF Data Archive. In August, the ACRF added another entry point to its data collection by registering the ARM Program and Data Archive as components within the Global Earth Observation System of Systems (GEOSS). This web-based decision-support tool links together existing and planned observing systems around the world and supports the development of new systems where gaps currently exist. As components of GEOSS, the Data Archive and ARM Program website can be found and explored by decision-makers, managers, and other users of Earth observations via the GEO Portal registry holdings. This access point is available for users seeking data, imagery, and analytical software packages relevant to all parts of the globe.

The GEOSS is simultaneously addressing nine areas of critical importance to society, ranging from managing energy resources and promoting sustainable agriculture to improving weather forecasts and responding to climate change and its impacts.

The GEOSS Components and Services Registry provides a formal listing and description of all the Earth observation systems, data sets, models, and other services and tools that together constitute the GEOSS. These various components are linked together using standards and protocols that allow data and information from different sources to be integrated. The GEOSS emerged from the Second Earth Observation Summit held in Japan in 2004 and is in the early stages of its 10-year implementation plan (2005-2015). It is supported by more than 100 governments and organizations throughout the world, including the "Group of Eight" leading industrialized nations.

Communication, Education, and Outreach

ACRF's outreach exhibit now features live data scrolling on four computer screens—one for each of the fixed sites, plus one for the mobile facility.

New Display Showcases Live Data

In a continuing effort to promote the use of continuous data from all its sites, ACRF engineering and communications staff teamed to develop an attractive visual display for ACRF outreach activities. The display features scrolling live data from the various ACRF sites along with slides that provide information about the associated site and its key field campaigns. Based on the overwhelmingly positive response, ACRF sites in Barrow, Darwin, and Lamont will feature their site-specific data displays in their primary office locations. In addition, an overall ACRF data display was developed for additional outreach opportunities.

The new four-screen data display made its debut at the American Geophysical Union meeting in December 2007, followed by the American Meteorological Society meeting in January 2008. It clearly drew attention, then questions, from visitors to the ACRF exhibit. Future plans for the data displays include incorporating the temperature and humidity charts into the ACRF web pages, and creating a view into the data such that users can pick which data plots they want to see.

Website Update Consolidates News, Feeds it in Small Doses

In 2008, the ARM website joined legions of other websites by adding a "Really Simple Syndication" or "RSS feed" capability to the ARM website. Like a modern-day paper boy, RSS is a web-based subscription service that delivers Internet news right to your doorstep—or web browser, in this case. The RSS feed alerts readers to the latest science and infrastructure news, events, feature stories, facility updates, research highlights, data announcements, and notable changes to the website. These news alerts include a headline, a short teaser sentence or two, and a link to the full article in the ARM News Center—another new feature implemented in 2008.

The ARM News Center consolidates all the categories mentioned above, which previously were displayed on a number of different ARM web pages. Users can view articles by selecting a specific news category or scan them all by choosing "All Categories." The News Center also has its own search feature for ARM news postings since 2003. Finally, the *Operations Update*—a bimonthly report of short highlights throughout the ACRF—was renamed *Facility Update* to better reflect the encompassing nature of the topics. Issues of this report, from its first edition in 2004, are included in the News Center.

Kids Create Clouds and Measure Raindrops at Science Potpourri in Alaska

Coincidentally during ISDAC (see *Featured Field Campaigns*), the University of Alaska at Fairbanks hosted their annual "Science Potpourri." This outreach event for the general public features hands-on experiments and demonstrations related to various Earth sciences. Three ISDAC team members sacrificed a rare day off during the campaign and spent a busy afternoon showing kids how to measure raindrops and make a cloud in a cup. Both kids and adults were intrigued by the two experiments and listened carefully to the directions for conducting similar experiments at home. They also looked closely at computer images of ice crystals while listening to how droplet measurement techniques have progressed to today's advanced probes and sensors.

Dr. Greg McFarquhar took time out from ISDAC to participate in the Science Potpourri hosted by the University of Alaska at Fairbanks. Here, he shows kids how to measure raindrops using a pan of flour and water from a spray bottle.

Teachers and parents were also enthusiastic to discover ACRF's "Climate Change: Science and Traditional Knowledge" DVD, as well as the educational resources available at ***education.arm.gov***. Traffic was steady throughout the day, with several hundred kids and adults passing through. The event was sponsored by EPSCoR, the American Association for the Advancement of Science-Arctic Division, Sigma Xi Alaska Chapter, American Chemical Society Alaska Section, and the Alaska Statewide High School Science Symposium.

ACRF Outreach Materials Chosen for Earth Day Display in Washington, D.C.

Since its inception in 1970, Earth Day has attracted increasing support, expanding across the globe as millions of people celebrate with events both large and small in nearly 200 different countries. This day is officially honored each year on April 22; however, many groups sponsor activities throughout the entire month of April. At DOE Headquarters in Washington, D.C., two ACRF posters were selected to join an Earth Day poster display representing programs from numerous DOE offices. The display was featured in the Forrestal Building's ground-level and first floor lobby areas throughout the week of April 21. The posters were then displayed at DOE Headquarters' Germantown facility the following week.

Posters for the AMF and ARM Education and Outreach were selected for the 2008 Earth Day display at DOE Headquarters.

ACRF posters on display included an overview poster about the AMF and an educational poster geared toward kids in grades K-12. The AMF poster features the system capabilities and baseline instruments and also lists several past deployment locations. The educational poster features the ACRF site "mascots"—a polar bear for the NSA, a sea turtle for the TWP, and a prairie dog for the SGP. It also includes information about the educational tools and materials available through the ARM Education website.

2008 Field Campaigns

Dates	Name	Status	Description
			North Slope of Alaska
January 1998 – Ongoing	Climate Modeling & Diagnostics Laboratory (CMDL*) Aerosol Observing System (AOS) **Note: CMDL was consolidated with other NOAA research laboratories in 2005, which are now known collectively as the Earth System Research Laboratory (ESRL).*	In Progress	The AOS, monitored by the NOAA ESRL, provides in situ aerosol measurements at the surface level. The principal measurements are those of the aerosol absorption and scattering coefficients as a function of particle size and radiation wavelength. Additional measurements include those of the particle number concentration, size distribution, hygroscopic growth, and inorganic chemical composition. The AOS measures aerosol optical properties to better understand how particles interact with solar radiation and influence the Earth's radiation balance. The measurements are useful for calculating parameters used in radiative forcing calculations, such as the aerosol single-scattering albedo, asymmetry parameter, mass scattering efficiency, and hygroscopic growth.
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 is operated by Biospherical Instruments, Inc., and instrumentation includes multi-channel filter radiometers and high-resolution, UV-visible spectroradiometers. 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 NOAA's ESRL. Preliminary data from the network are available within 1 week after collection and can be accessed via the project's website at ***www.biospherical.com/NSF***, which 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. With security, power, and ethernet communications provided at the Atqasuk site, the station runs continuously, and 15-second sample rate data are archived at UNAVCO (***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 2007 – June 2009	Evaluation of Heated Ventilators in the Arctic	In Progress	The harsh conditions at NSA require that electric heaters be installed inside the ventilators of the broadband radiometers to prevent hoarfrost and snow from affecting the measurements being obtained. This campaign will evaluate potential effects the ventilator heaters may be having on the basic measurements to improve the understanding, the quality, and the accuracy of the radiometer measurements at NSA. This campaign builds on the results of the Pyranometer Infrared Loss Study in 2007.
March 2008 – May 2008	Indirect and Semi-Direct Aerosol Campaign (ISDAC) – Hemispheric Flux Spectroradiometer	Completed	In connection with ISDAC, this campaign sought to further investigate the role of aerosol physics and chemistry in regulating cloud microphysical properties in the Arctic. Data collected from a spectroradiometer by Analytical Spectral Devices, Inc., provided retrievals of changing cloud optical and microphysical properties on short timescales and directly measured the shortwave component of the aerosol indirect effect.
April 2008 – May 2008	Surface Observation in Support of In Situ Observations within the Arctic Boundary Layer (ABL)	Completed	The main objectives of this campaign were to (1) investigate nucleation processes related to ice crystals and droplets, (2) study ice microphysical processes during ice fog events, (3) estimate climatological effects of ice crystals in freezing fog, (4) compare the underlined microphysics of observed fog (liquid or ice) with Convair-580 in situ data from ISDAC, and (5) develop remote sensing methods for ice fog forecasting. Using detailed surface observations obtained from surface instruments hosted at the Barrow Guest Facility, microphysical characteristics of ice particles and freezing droplets, nucleation processes, and their effect on extinction (and visibility) within the ABL were studied. The results from this campaign will lead to a complete data set related to ABL processes that have not been available previously and will improve understanding of model simulations and remote sensing analysis of condensation/precipitation processes.
April 2008 – June 2008	ISDAC – Humidified Tandem Differential Mobility Analyzer (HTDMA)	Completed	In conjunction with ISDAC, an HDTMA was installed at the NSA site to characterize the size-resolved hygroscopicity of an aerosol. When coupled with a concurrently measured aerosol size distribution, these data can be used to: (1) predict the humidity-dependent optical properties and cloud condensation nuclei (CCN) spectra of the aerosol population; (2) constrain the atmospheric processes responsible for changes in particle size and properties; and (3) isolate the properties and impact of a single particle type that is present in an external mixture. These measurements will be particularly valuable for quantifying the contribution of specific classes of particles to the total CCN concentration.

April 2008	NASA Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) Coordination with ARM	Completed	The NASA Langley Airborne High Spectral Resolution Lidar was deployed on the NASA King Air B200 for the ARCTAS mission in 2008. The measurements acquired during this mission will be used to characterize the vertical and horizontal distribution of aerosols and aerosol optical properties, infer aerosol type, and partitioning aerosol optical depth by type. The focus of the April deployment in Barrow, Alaska, will be measurements of Arctic haze to support related DOE and NOAA studies, and ongoing satellite retrieval measurements of aerosol and cloud spatial distribution and optical properties.
Southern Great Plains			
April 1996 – Ongoing	Climate Modeling & Diagnostics Laboratory (CMDL) Aerosol Observing System (AOS) **Note: CMDL was consolidated with other NOAA research laboratories in 2005, which are now known collectively as the Earth System Research Laboratory (ESRL).*	In Progress	The AOS, monitored by the NOAA ESRL, provides in situ aerosol measurements at the surface level. The principal measurements are those of the aerosol absorption and scattering coefficients as a function of particle size and radiation wavelength. Additional measurements include those of the particle number concentration, size distribution, hygroscopic growth, and inorganic chemical composition. The AOS measures aerosol optical properties to better understand how particles interact with solar radiation and influence the Earth's radiation balance. The measurements are useful for calculating parameters used in radiative forcing calculations, such as the aerosol single-scattering albedo, asymmetry parameter, mass scattering efficiency, and hygroscopic growth.
August 1997 – Ongoing	Atmospheric Sciences Research Center Rotating Shadowband Spectroradiometer (RSS)	In Progress	Once every minute between sunrise and sunset, the RSS simultaneously measures three irradiances: total horizontal, diffuse horizontal, and direct normal in near-ultraviolet, visible, and near-infrared range at 512 or 1024 adjacent spectral resolving elements (pixels). The resolution is pixel (wavelength)-dependent and differs from instrument to instrument. The reported irradiances are cosine-response-corrected and their radiometric calibration is based on incandescent lamp calibrators that are traceable to the irradiance scale national standard.
March 2000 – October 2007	In Situ Aerosol Profiles	Completed	In March 2000, a Cessna 172 was outfitted with a subset of the instrument package at the SGP surface site to obtain vertical profiles of aerosol optical properties over the surface site 2-3 times per week. The success of the program in its first few years resulted in an upgrade to a slightly larger Cessna in 2006. As of April 2006 and through the end of the campaign, the instrument package measured light-scattering, back-scattering, and absorption at 3 wavelengths for particles with diameters less than approximately 5 microns. It also measured submicron light-scattering at 1 wavelength for three humidities to provide an indication of the hygroscopic nature of the aerosol. Non-aerosol instruments incorporated into the aerosol package included a programmable flask package for obtaining samples of CO_2 and other trace gases at each flight level and continuous gas analyzers for CO_2 and ozone.
April 2002 – Ongoing	ARM Carbon Project	In Progress	The objective of this project, conducted by Lawrence Berkeley National Laboratory, is to improve the ability to predict exchanges of carbon, water, and energy at the landscape scale using modeling to better understand how the fluxes of carbon, water, and energy link to land use and climate. The mixture of land uses and simple topography at the SGP site make this an ideal region to test methods of scaling flux predictions from plot to regional scales by measuring stocks and fluxes of carbon, water, and energy at various spatial and temporal scales. The field campaign is measuring ecosystem H218O and C18OO stocks and fluxes through the use of three portable eddy co-variance towers, a 60-meter tower with eddy co-variance, precise CO_2 concentration measurements, and automated flask samplers to measure 13C fluxes.
February 2005 – Ongoing	Near Real-Time GPS Water Vapor Data Support NOAA Weather Forecast Research	In Progress	The SGP site hosts the world's largest concentration of GPS receivers dedicated to atmospheric research. Since 1993, NOAA's Forecast Systems Laboratory, other government agencies, and universities have used the facilities and resources of the SGP site 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 forecast accuracy over the coterminous United States. The ACRF evaluated and upgraded its GPS communications network to provide data in near real-time for operational forecasting by NOAA.
March 2006 – June 2011	Magnetic Field Observations	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.

May 2006 – October 2009	HydroKansas	In Progress	For 3.5 years, the Whitewater River (Kansas) watershed will serve as the focus of an 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.
June 2006 – August 2009	Observation-Based Precipitation Microphysics Study	In Progress	Understanding precipitation microphysics is important in accurate quantitative precipitation estimation and forecast. A 2D 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 (OU) purchased and deployed a 2DVD at the SGP Purcell boundary facility to measure hydrometeor drop-size distribution. A 2DVD from the National Center for Atmospheric Research was placed side-by-side with the university's 2DVD, providing data to improve the understanding of precipitation microphysics for the Great Plains region of the United States, to develop radar-retrieval algorithms/forward operators, and to verify polarimetric radar measurements.
October 2006 – May 2008	Aura Satellite Validation	Completed	The Solar Radiance Transmission Interferometer is a Fourier transform spectrometer (FTS) system, including an automatic solar tracker and a computer for control, data processing, and storage. This system generates very high-spectral-resolution infrared spectra of the Earth's atmosphere using the sun as the external source. Spectral data were collected during routine overpasses of the SGP site by NASA's Aura satellite, and weather permitting, other times of the day. The spectra will be analyzed for column amounts and vertical distributions of gases measured by the satellite.
November 2006 – March 2008; April 2008 – March 2009	Radon Measurements of Atmospheric Mixing (RAMIX)	Completed; In Progress	Radon is an effective tracer of atmospheric mixing because it is emitted relatively universally from the land surface with a short half-life, allowing for characterization of the mixing processes based on vertical profile measurements. In collaboration with NOAA's ESRL, this field campaign used atmospheric 222Rn (Radon) concentrations obtained from measurements at the SGP 60-meter tower to estimate the time-averaged atmospheric mixing between various atmospheric layers and during selected convective events. Mixing rates were also measured to estimate regional CO_2 exchange. The initial RAMIX effort was completed and RAMIX 2008 was initiated to collect airborne concentration 222Rn measurements to be combined with continuous tower-based measurements. Modeling efforts will be separately supported by the ARM Carbon Project at Lawrence Berkley National Laboratory and NOAA ESRL.
July 2007 – June 2008	Single-Frequency GPS Water Vapor Network	Completed	In this field campaign, a network of GPS stations provided observations collected to detect changes in moisture associated with multiple atmospheric processes. The collected data will be useful for studying water vapor structure, variability, temporal cycles, and evolution during cloud formation and convective events. Because of the unique density of the GPS stations, observations of atmospheric water vapor can be measured on horizontal scales as small as 1 kilometer.
November 2007 – May 2008	Combined Wind Profiler and Polarimetric Radar Study of Precipitation	Completed	A 915-MHz boundary-layer radar (BLR) at the SGP boundary facility at Purcell, Oklahoma, was 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. 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. In addition, data from the NOAA Profiler Network 404-MHz radar will be used in the study, as well as data from the 2007 campaign.
December 2007 – July 2008	Test Viability of 1.6 Micrometer Multifilter Rotating Shadowband Radiometer (MFRSR)	Completed	A comparison study was conducted to demonstrate the usefulness of a longer wavelength measurement of aerosol optical depth—other than the 870-nanometers wavelength now available with the MFRSR—and better define the retrieval of bimodal particle-size distributions. The 1.55-micrometer MFRSR at the SGP Guest Instrument Facility simultaneously ran with the two MFRSRs at SGP Extended Facility 13 and the Central Facility, and the normal incidence multifilter radiometer at the central cluster measuring at the normal 5 wavelengths. Accumulated data will allow a reasonable Langley calibration and comparison of optical depths. An earlier study conducted at Pacific Northwest National Laboraory did not include simultaneous water vapor measurements to correct the optical depth. Microwave radiometer retrievals will be used for correction in this study.
January – December 2008	Precision Gas Sampling (PGS) Validation	Completed	The purpose of this field campaign was to measure the surface fluxes and vegetation characteristics in three fields near the SGP Central Facility. With field locations forming roughly a 10-kilometer equilateral triangle, the flux measurements will be compared to Duke University Flux Helicopter overflights during the CLASIC field campaign. These and other carbon-cycle studies will be valuable to the North American Carbon Program's Mid-Continent Intensive Campaign.

January – July 2008	Thin Cloud Rotating Shadowband Radiometer (TCRSR)	Completed	This deployment of the TCRSR tested its potential capability to make more accurate, simultaneous measurements of the optical thickness and effective drop radius for clouds with low liquid water paths (< $100 g/m^2$) than is possible using other current methods. Both of these properties are essential to understanding cloud-climate interaction. The TCRSR prototype radiometer measures the angular distribution of scattered light in the forward scattering lobe of cloud drops in 6 narrow spectral bands, each approximately 10 nanometers wide and centered at 415, 500, 610, 660, 870, and 940 nanometers.
May 2008	Characterization of the Daytime Convective Boundary Layer (CBL)	Completed	This study, conducted by OU and funded by NSF, focused on quantifying the CBL depth, the entrainment zone thickness, the turbulence kinetic energy, and the energy dissipation rate under various states of wind shear and surface heating. In addition to the more conventional application of large eddy simulation (LES) and radar methodologies to study the CBL, a unique combination of these approaches were synthesized through the development and implementation of a radar simulator. Several coordinated field campaigns were conducted at the Central Facility to collect and synthesize data from LES, the radar simulator, and from a Vaisala LAP3000 915-MHz BLR. This consolidated strategy provided a unique opportunity to investigate the effectiveness and applicability of both LES and various other means of characterizing the CBL, especially those designed to work with BLR observations.
May 2008	Mobile Disdrometer Field Test	Completed	This collaborative campaign between the National Severe Storms Laboratory, OU, and the ARM Program field tested a prototype mobile disdrometer platform at the Kessler Field Farm Laboratory site. A pair of Ott Parsivel laser disdrometer instruments and an accompanying surface meteorology package was deployed adjacent to the OU and NSSL/NCAR 2D video disdrometer platforms. Results from this trial will be used to determine the feasibility of a small network of laser disdrometer instruments to sample drop size distributions within supercell storms in preparation for the upcoming Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2, 2009-2010). Comparing data collected by the laser and video disdrometer instruments along with measurements of surface wind speed and direction will be used to assess the suitability of the Ott Parsivel under realistic data gathering conditions including mobile facility deployments.
June – July 2008	Vaisala CL31 Ceilometer Demonstration	Completed	This campaign deployed a CL31 ceilometer at the SGP site, co-located with the current Vaisala ceilometer, micropulse lidar, and balloon-borne sounding system. Data collected from these sensors will be analyzed to compare and contrast the data from this new instrument and to help the ACRF to develop future ceilometer instrument requirements in anticipation of the current ceilometers approaching the end of supportable lifetime.
July 2008	Atmospheric Sounder Spectrometer for Infrared Spectral Technology (ASSIST)	Completed	This comparison campaign at the SGP site collected simultaneous measurements of sky radiation from the ACRF's Atmospherically Emitted Radiance Interferometer (AERI) and the ASSIST, and on relatively cloud-free days, a special radiosonde released at the MetOp satellite overpass time. To determine systematic and random differences, data collected will compare ASSIST radiances with AERI radiances and radiances calculated from the radiosonde observations and perform temperature and moisture profile retrievals through these comparisons.
August 2008 – May 2010	Oribiting Carbon Observatory (OCO) - Fourier Transform Spectrometer (FTS) Validation - Oklahoma	In Progress	The NASA OCO science team will deploy, operate, and maintain a ground-based solar-viewing FTS mobile laboratory at the SGP site in Lamont, OK, to validate space-based CO_2 retrievals. Long-term operation of both FTSs (Lamont, Oklahoma, and Darwin, Australia) will continue through the end of the OCO mission (2010).
August 2008	3D Water Vapor Retrieval Using a Scanning Network of Compact Microwave Radiometers	Completed	This campaign demonstrated a new remote sensing technique to retrieve the 3D water vapor field using a network of scanning, compact microwave radiometers. This water vapor field will be compared with retrievals using the existing high-density network of ground-based L1-GPS receivers at the SGP site, as well as with in situ moisture profiles routinely measured by Cessna aerosol flights and Raman lidar. The microwave radiometers were deployed in as close to an equilateral triangle with a 10-kilometer distance between adjacent nodes as logistics permitted. Each node performed a complete hemispherical scan in less than 600 seconds—the shortest decorrelation time of the atmosphere for these measurements.
Tropical Western Pacific			
September 2005 – November 2010	OCO–FTS Validation	In Progress	The NASA OCO science team deployed a ground-based solar-viewing FTS mobile laboratory at the ACRF Darwin site in November 2005. It will operate and maintain the laboratory to validate space-based CO_2 retrievals through the end of the OCO mission (2010).
June 2006 – June 2011	Geoscience Australia Continuous GPS Station	In Progress	The TWP site in Darwin is hosting a GPS station as 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			
March 2007 – December 2007	Simplified Soil Moisture Probes at Black Forest During the Convective and Orographically Induced Precipitation Study (COPS)	Completed	This field campaign attempted to close the gaps in process understanding related to Quantitative Precipitation Forecasting (QPF) by contributing comprehensive, high-quality data sets usable for model validation and data assimilation. Theoretical analyses identified the requirements that measured data must meet. One of the scientific goals of COPS was to better understand extreme events. Soil moisture probes used during COPS obtained data for studying how saturated soil conditions can influence heavy rains by (1) providing source of water vapor for precipitation and (2) preventing precipitation from entering the ground.
April 2007 – December 2007	Initiation of Convection and the Microphysical Properties of Clouds in Orographic Terrain	Completed	This field campaign attempted to close the gaps in process understanding related to QPF by contributing comprehensive, high-quality data sets usable for model validation and data assimilation. Theoretical analyses have identified the requirements that measured data must meet. One of the scientific goals of COPS is to better understand extreme events. For this improved understanding, the ARM Mobile Facility operated in the Black Forest region of Germany for 9 months. It obtained a comprehensive data set to link atmospheric models ranging from detailed cloud microphysical models used in short-range weather prediction to general circulation models.
April 2007 – December 2007	90/150 Microwave Radiometer (MWR) Profiler at AMF Black Forest During COPS	Completed	This field campaign attempted to close the gaps in the process understanding related to QPF by contributing comprehensive, high-quality data sets usable for model validation and data assimilation. Theoretical analyses identified the requirements that measured data must meet. The 90/150 MWR profiler data are of interest because they supplement other MWR measurements in the study of total column water vapor and liquid water content.
April 2007 – December 2007	Humidity and Temperature Profiling Radiometer (HATPRO) at Black Forest During COPS	Completed	This field campaign attempted to close the gaps in the process understanding related to QPF by contributing comprehensive, high-quality data sets usable for model validation and data assimilation. Theoretical analyses identified the requirements that measured data must meet. The HATPRO is a type of MWR whose data can also be used to determine atmospheric temperature profiles.
April 2007 – December 2007	Micro-Rain Radar at Black Forest During COPS	Completed	This field campaign attempted to close the gaps in the process understanding related to QPF by contributing comprehensive, high-quality data sets usable for model validation and data assimilation. Theoretical analyses identified the requirements that measured data must meet. The micro-rain radar is a sophisticated rain gauge for providing essential measurements of rain rate.
June 2007 – December 2007	Cloud Microwave Validation Experiment in Support of CLOWD	Completed	Cloud property retrievals using MWRs offer a promising method for obtaining needed observations of cloud liquid-water path, however, unresolved issues remain. To improve the understanding of existing uncertainties in the observations and spectroscopy in the microwave region, the ACRF deployed a new 90/150-GHz MWR with the AMF during the 9-month COPS observation period.
March 2007 – December 2007	GPS Water Vapor at Black Forest During COPS	Completed	This field campaign attempted to close the gaps in the process understanding related to QPF by contributing comprehensive, high-quality data sets usable for model validation and data assimilation. Theoretical analyses identified the requirements that measured data must meet. The GPS water vapor system supplemented the water vapor measurements made by the MWRs and the multi-wavelength raman lidar during COPS. These additional observations determine the 3D distribution of water vapor.
July 2007 – December 2007	ADvanced MIcrowave RAdiometer for Rain Identification (ADMIRARI) at Black Forest During COPS	In Progress	The scientific focus of this collaborative effort with the University of Bonn (Germany) was on the measurements of integrated water vapor and integrated liquid water. Five months of continuous measurements from the ADMIRARI will be analyzed using an optimal estimation retrieval technique. The mission will provide additional insight for the understanding of the onset of precipitation.

ARM Aerial Vehicles Program			
July 2006 – December 2010	Aircraft Carbon	In Progress	This campaign at the SGP site will develop the ability to measure CO_2 concentrations and sample for a suite of trace gases from the surface to mid-troposphere. Airborne measurements of trace gases will (1) provide valuable data for addressing carbon-cycle questions identified by the U.S. Climate Change Science Program and the North American Carbon Program, (2) facilitate the calibration of the NASA OCO, and (3) provide a basis from which to develop inverse methods to infer ecosystem carbon exchange and quantify anthropogenic combustion emissions.
April 2008	Indirect and Semi-Direct Aerosol Campaign (ISDAC)	Completed	An intensive cloud and aerosol observing system obtained airborne measurements during ISDAC in April 2008. With flights above the NSA site, many ancillary observing systems collected data to allow synergistic interpretation of ISDAC data and to provide an important contrast with the October 2004 Mixed-Phase Arctic Cloud Experiment (M-PACE). Cloud property measurements obtained during ISDAC will be used to evaluate cloud simulations and evaluate cloud retrievals from M-PACE, and the aerosol measurements will be used to evaluate aerosol retrievals. By running the cloud models with and without solar absorption by the aerosols, scientists can determine the semi-direct effect of aerosols on clouds. Research flights by the Convair-580 were coordinated with three NASA and one NOAA aircraft when possible, as well as with satellite overpasses. For more information, see the *Featured Field Campaigns* section.
Offsite Campaigns			
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 data set for looking at the diurnal changes of 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 H20 Project, CASES-97 will provide an accurate and comprehensive description for isolating and mitigating problems in land surface models 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.
September 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 instrument, datastreams, and data formats. Because data sets would be similar to those in the ACRF, a combined archive will be used to create a comparison to facilitate Arctic research.
June 2008 – July 2008	CO_2 Differential Absorption Lidar (DIAL)	Completed	This project deployed an ACRF rawinsonde system at a NOAA tall tower site in Iowa for 3 weeks alongside a NASA CO_2 DIAL, a NOAA CO_2 monitoring tower, and a temporary DOE mesonet of atmospheric CO_2 measurements to evaluate the accuracy, precision, and utility of CO_2 profiles measured by DIAL. The ability of the CO_2 DIAL system to measure the CO_2 difference between the typical atmospheric boundary layer and free troposphere and typical synoptic variability in CO_2 in both the free troposphere and the atmospheric boundary layer was tested. These observations may be merged into the broader context of the North American Carbon Program Mid-Continent Intensive Campaign.

FY 2008 Publications

Book Chapter

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