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ARM

CLIMATE RESEARCH FACILITY

U.S. DEPARTMENT OF ENERGY | Office of Science

2009

Department of Energy
Washington, DC 20585

December 1, 2009

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

In a year filled with change, the ARM Program welcomed a significant influx of money from the American Recovery and Reinvestment Act and began preparing for a major shift in its science component. Faced with these daunting developments, the ARM Climate Research Facility continued to implement successful field campaigns around the globe and enhance its user capabilities. Meanwhile, ARM scientists published 205 journal articles using ARM data and began moving forward with plans for their new place in the Department of Energy's climate research portfolio. Below are just a few highlights from 2009:

- Researchers from the United States, Italy, and Germany conducted a two-month field campaign in Chile, obtaining simultaneous measurements of infrared energy from broad portions of the electromagnetic spectrum at a site more than 5300 meters above sea level.

- ARM infrastructure staff completed detailed planning and placed nearly all contracts needed to execute a plan for purchasing $60 million in new instruments and upgrades that will enhance climate observation capabilities throughout the user facility.

- Based on data from the ARM Mobile Facility deployment in Niamey, Niger, in 2006, ARM researchers published a special series of eight articles in the *Journal of Geophysical Research-Atmospheres*.

- In the first long-term aircraft field campaign of its kind, the five-month RACORO campaign, coordinated by the ARM Aerial Facility, obtained statistical data about the properties of boundary-layer clouds and aerosols over the ARM Southern Great Plains site.

- Web 2.0 and social media tools were implemented on the ARM website to appeal to the next generation of scientists, assist researchers with field campaign planning, and provide news and information in a more interactive forum.

- To guide their efforts as part of a new research program – Atmospheric System Research – within DOE, a new science plan was developed. Also, the working group structures were reorganized into three groups.

- In December 2008, the ARM Mobile Facility successfully completed a complex deployment in China for studying aerosol indirect effects in the region. It then moved to Graciosa Island in the Azores where it began a 20-month deployment to obtain data for studying clouds, aerosols and precipitation in the marine boundary layer.

We hope you enjoy reading this annual report, which provides a brief overview of the program and describes many more accomplishments from 2009.

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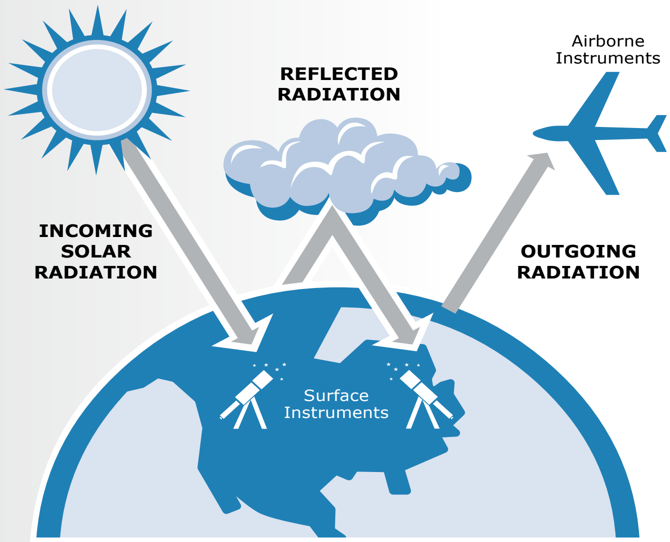
On the cover: Between January and June 2009, scientists conducted a first-of-its-kind aircraft research campaign, logging 59 flights and 259 research hours during RACORO. Using a heavily instrumented Twin Otter aircraft, they obtained comprehensive long-term measurements of cloud, radiation and aerosol properties of cloud fields over the ARM Climate Research Facility's Southern Great Plains site. For more information, see the *Featured Field Campaigns* section of this report.

PROGRAM OVERVIEW

The Importance of Clouds and Radiation to Climate Change



Researchers use data collected from ACRF 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.

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, significant uncertainties remain in the GCM treatment of clouds, aerosol, and their effects on the Earth's energy balance.

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 (ACRF)**, 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.

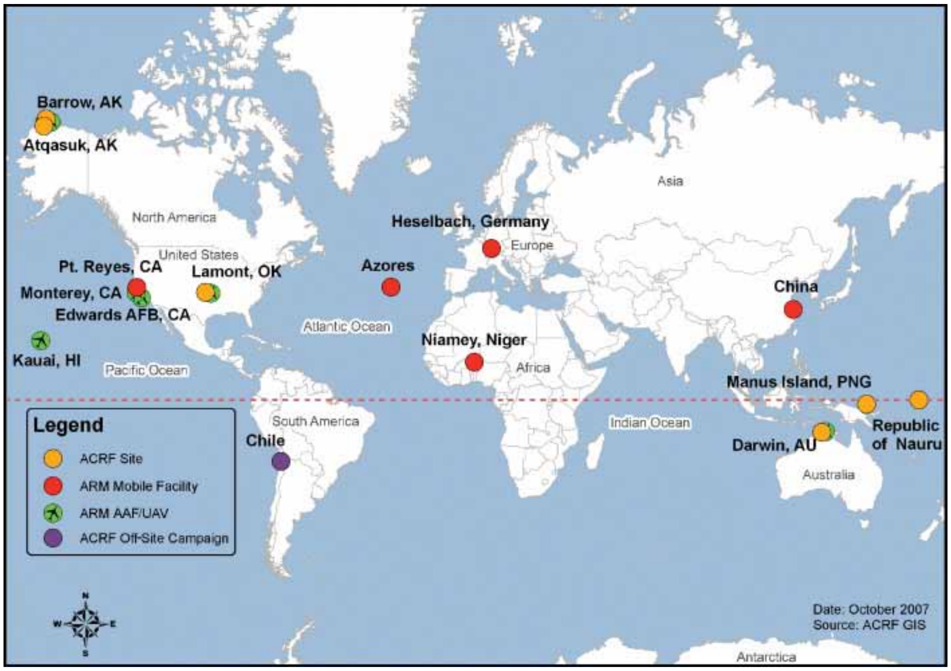
The scale and quality of the ARM Program's approach to climate research has resulted in the ACRF setting the standard for ground-based climate research observations, while ARM scientists lead the world in discoveries related to the interactions of clouds and radiation.

This report provides an overview of each of these components and a sample of achievements for each in fiscal year (FY) 2009.

ARM Pioneers Reflect on Two Decades of Progress. *Since the launch of the ARM Program in 1989, scientists have dramatically improved climate models and scientists' understanding of how to use them. This is due in large part to the ACRF's fixed, mobile, and aerial measurement capabilities. In an article in Earthzine in May, early leaders of the program reflected on the program's 20-year anniversary, describing the beginnings of this effort and how it evolved to become a major contributor to national and international research efforts related to global climate change.*

ARM Climate Research Facility

Through the ARM Program, DOE funded the development of several permanent, 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. To obtain the most useful climate data, instrumentation was established at three locales selected for their broad range of climate conditions:



Recovery Act Investments. In March 2009, the American Recovery and Reinvestment Act allocated $60 million to the ACRF. With these funds, the ACRF will purchase and deploy dual-frequency scanning cloud radars to all its sites, enhance several sites with precipitation radars and energy flux measurement capabilities, and invest in new aerosol sampling and aerial instrumentation. In all, 143 new instruments are planned that will enhance the ACRF capabilities for the global user community.

- **Southern Great Plains (SGP)** - includes a heavily instrumented Central Facility near Lamont, Oklahoma, and smaller satellite facilities covering 143 square kilometers in Oklahoma and Kansas.
- **Tropical Western Pacific (TWP)** - includes three sites spanning the equatorial region from Indonesia to the dateline: Darwin, Australia; Manus Island, Papua New Guinea; and Nauru Island.
- **North Slope of Alaska (NSA)** - includes one site at Barrow near the edge of the Arctic Ocean, and a smaller inland site at Atqasuk.

Each site operates advanced measurement systems on a continuous basis to provide high-quality research data sets. 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.

Measurements obtained at the permanent sites are supplemented with data obtained from intensive field campaigns using the ARM Mobile Facilities (AMF) or ARM Aerial Facility (AAF).

AMF Completes Deployment in China, Moves on to the Azores. *In December 2008, the AMF completed its most complex deployment to date, anchoring a four-site observation effort for the Study of Aerosol Indirect Effects in China. The combined data set was collected at four sites: the AMF at Shouxian; a supplementary facility at Lake Taihu; and an ancillary facility that operated in series at Zhangye and Xianghe. These data provide an extensive record of clouds, aerosols, radiation, and precipitation measurements for studying regional aerosol effects.*

In May 2009, the AMF began operating at its new location on Graciosa Island in the Azores. Surrounded by the Atlantic Ocean, Graciosa Island is ideal for sampling the transition from an overcast stratocumulus regime in the spring to the broken trade cumulus regime in the summer. On location through December 2010, this extended deployment will result in the first climatology of detailed vertical structure of low clouds and precipitation properties at a remote subtropical marine site.

In addition, data on surface and atmospheric properties are also gathered through forecast models, satellites, 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.

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 also made available for the science community via the ARM Archive (***www.archive.arm.gov***) to aid in further research.

ARM Science

Research by the ARM Program focuses on improving the quantitative models necessary to predict possible climate change on global and regional scales. It also includes support to archive and analyze climate change data, 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. From the United States and abroad, cloud and radiation scientists ranging from senior scientists to post-docs and students make up the ARM Science 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.

To focus their efforts on specific sets of issues related to climate modeling, the ARM Science Team divides its research into key areas, or Working Groups. The Working Groups include:

Aerosol – relate observations of radiative fluxes and radiances to atmospheric composition, and use these relationships to develop and test parameterizations to accurately predict atmospheric radiative properties.

Cloud 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.

Data Archive Releases Radiative Transfer Model Intercomparison Project. *This data set compares the radiation models embedded in the Atmosphere-Ocean General Circulation Models used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Researchers compared these radiation models to current line-by-line radiation codes in clear-sky, gas-only mode. Results show large differences in radiative forcing by well-mixed greenhouse gases using various combinations of those gases. These data can be found in the Data Archive under "Related Data Sets>General Circulation Model Intercomparison Data Sets."*

Atmospheric System Research Merges Cloud and Aerosol Science Expertise. *Effective October 1, 2009, research conducted through DOE ARM and Atmospheric Science Program will be merged and managed under a new name, Atmospheric System Research. A major benefit of the merger is expected to be a strengthening of the science programs by combining expertise in continuous remote sensing measurements of cloud properties and aerosol influences on radiation with expertise for in situ characterization of aerosol properties, evolution, and cloud interactions. The new working groups, co-chaired by an observations expert and a modeler, consist of:*

- *Aerosol Lifecycle*
- *Cloud Lifecycle*
- *Cloud Aerosol Interactions*

Cooperation and Oversight Enable Success

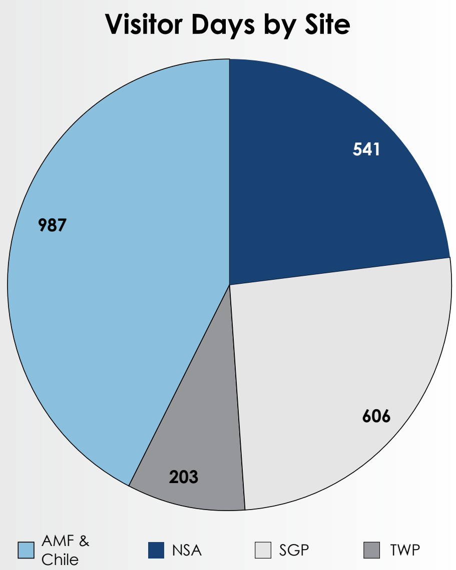
Nine DOE national laboratories and numerous government agencies, universities, private companies, and foreign organizations contribute to ARM Science and the ACRF. Each entity serves a vital role in managing and conducting the research, operations, and administration of the science program and user facility.

For ARM Science activities, direction and oversight is the responsibility of **DOE Headquarters**. A **Science and Infrastructure Steering Committee** provides input to DOE Headquarters on the state of the science. This includes strategies for developing data products and measurement systems, and identifying needed model improvements. **Working Group** representatives coordinate the ARM research agenda as appropriate.

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

Fiscal Year 2009 Budget Summary and Facility Statistics

FY 2009 Budget ($K)	
Total ARM Program	**52,618**
Infrastructure	*37,853*
Science	*14,765*
Recovery Act	**60,000**



User Statistics for the Period of October 1, 2008 – September 30, 2009			
ACRF Facility Component	**Unique Scientific Users**	**Unique Non-Scientific Users**	**Totals**
AMF+Chile*	20	21	41
NSA	30	39	69
SGP	62	89	151
TWP	40	13	53
Data Management Facility	27	49	76
Archive	744	75	819
Total	**923**	**286**	**1209**

**Chile is the location of an off-site campaign from August to October 2009.*

Operational Statistics for the Period of October 1, 2008 – September 30, 2009		
	Data Availability (%)	
SITE	**GOAL**	**ACTUAL**
AMF**	0.95	0.88
NSA	0.90	0.94
SGP	0.90	0.94
TWP	0.90	0.94
Site Average	**0.90**	**0.94**

***During this reporting period, the AMF was deployed in China from October through December 2008. It has been operating in the Azores since May 2009.*

KEY ACCOMPLISHMENTS

Featured Field Campaigns

In addition to providing continuous data collections from its fixed sites, the ACRF sponsors field campaigns for scientists to obtain specific data sets or to test and validate instruments. The following pages highlight key campaigns conducted in FY 2009. A summary of all ACRF campaigns that began in FY 2009 is available at the end of this report.

Routine AAF CLOWD Optical Radiative Observations

In the first long-term aircraft campaign of its kind, the Routine AAF CLOWD Optical Radiative Observations (RACORO) field campaign obtained five months of representative statistics of boundary-layer cloud properties. These clouds usually occur from the Earth's surface up to an altitude of about 2.5 kilometers (8000 feet) and are very important for understanding climate variations, but are often poorly simulated in climate models.

The CIRPAS Twin Otter takes off from Guthrie, Oklahoma, on one of its 59 research flights for RACORO. Cloud and aerosol probes are located under the wings, while radiometers are installed on both the top and bottom of the cabin.

Using a Twin Otter aircraft equipped with a comprehensive set of instruments to measure solar and thermal radiation, cloud microphysics, aerosol properties, and atmospheric state, the RACORO team logged 59 flights and 259 research hours above the SGP site centered near Lamont, Oklahoma. Data gathered during the RACORO campaign will provide researchers with a statistically relevant data set of boundary-layer cloud and aerosol properties for future study.

Planned and coordinated with the AAF team, the campaign began in late January and lasted through the end of June. This long-term effort presented challenges in operations and instrumentation that are not encountered in typical, short-term campaigns. For example, the seven-member RACORO science team worked in pairs for two-week shifts throughout the campaign. They participated in daily weather briefings and, based on circumstances, set the flight priorities to cover the broad range of science objectives possible with this campaign.

In June, the flight operations moved from Guthrie to Ponca City, Oklahoma to allow for coordination with NASA's King Air aircraft. Overlapping data from the NASA research platform provide important complementary data that supplements the five-month data set obtained from the Twin Otter and SGP site during RACORO.

"This is the first time that a long-term aircraft campaign has been undertaken for systematic in situ cloud sampling of cloud field properties and will go a long way toward improving our understanding of these cloud types," said Dr. Andrew Vogelmann, a scientist from Brookhaven National Laboratory and the principal investigator for the campaign.

Results: At the start of the campaign, conditions associated with La Niña that began in the fall carried over through the winter, producing an usually dry climatology in the area between January and March. It was several degrees warmer than average with 20-40% of the average precipitation. The lack of moisture resulted in fewer cloudy days at the start of the campaign than expected, but the RACORO team successfully adapted the operational plans to account for the seasonal variability that presented itself. For example, the team incorporated several clear-sky flight patterns that complemented RACORO objectives:

- surface albedo mapping
- aerosol and cloud condensation nuclei characterization
- boundary-layer turbulence.

Dr. Andrew Vogelmann (left), lead scientist for RACORO, reviews some of the scientific instruments on the Twin Otter with the chief scientist for the aircraft, Haf Jonsson.

As conditions transitioned to more spring moisture, the next few months resulted in some of the best cloud cases of the campaign. The long-term campaign enabled sampling of a wide range of low-level stratus and cumulus cloud fields under different environmental and aerosol conditions, which was the goal of the program. This statistical picture for different cloud states will help improve the scientists' understanding of the physical processes that operate within these clouds and their interactions with aerosols, so that their representations can be improved in climate models. The data will also be used to improve methods that remotely observe cloud properties from surface radiometers and satellites, which are essential for obtaining the type of long-term observations needed for cloud and climate studies.

Another success was the comprehensive extent of the aircraft measurements made during this extended campaign, including measurements of the clouds' microphysical properties, aerosol properties, radiative fields, and atmospheric state.

- Cloud microphysics observations included multiple measures of the critically important cloud liquid-water content, as well as multiple measurements that spanned the range of drop-size distributions.
- Aerosol observations provided measurements of the aerosol size distribution and of the concentrations of cloud condensation nuclei that are needed for studies of cloud-aerosol interactions.
- Radiative observations included broadband solar and thermal fluxes for energy budget analyses, as well as high-resolution spectral measurements that provide additional information needed to interpret the cloud field state and its radiative properties. In addition, a new method was tested for the efficient analysis of downwelling solar fluxes on a moving platform.
- Atmospheric state observations were made for atmospheric turbulence, temperature, and water vapor concentrations, including an ultra-fast response observation (100 Hz) to enable the resolution of water vapor gradients around clouds.

Boundary-layer clouds, such as this cumulus field sampled on May 24, are often tenuous and scattered, which makes properties—such as water content and water droplet size—hard to measure accurately with ground-based or satellite instruments.

The complete data set from RACORO is expected to be made publicly available at the Data Archive in January 2010, upon completion of final calibrations and quality reviews.

Radiative Heating in Underexplored Bands Campaign, Phase II

On a mountain rising from the Chajnantor Plateau in Chile's Atacama Desert, researchers conducted a nearly three-month effort to obtain rare and valuable measurements from the far reaches of Earth's atmosphere. Using several sophisticated optical instruments called spectrometers, phase two of the Radiative Heating in Underexplored Bands Campaign (RHUBC-II) obtained a detailed data set of measurements in the infrared portion of the electromagnetic spectrum. A subset of baseline ACRF instruments collected additional atmospheric data—such as temperature, pressure, humidity, and incoming and outgoing energy—from above the study site. Combined with data from the first phase of the study in 2007, these measurements will be used to refine radiative calculations for the middle-to-upper troposphere that are used in global climate models.

At an elevation of 5,383 meters on Cerro Toco (Toco Mountain) in Chile, RHUBC-II took place from August 15 through October 24, 2009.

The first phase of RHUBC-I took place in the spring of 2007 at the ACRF site in Barrow, Alaska, and was limited to water vapor bands in the far-infrared portion of the electromagnetic spectrum—wavelengths less than 27 microns. The drier, low-pressure conditions on Cerro Toco extended the maximum spectral range for RHUBC-II to nearly 43 microns. These drier conditions, coupled with the higher solar elevation angles, broadened the scope of RHUBC-II to cover essentially the entire spectrum, including the half-dozen strong water vapor bands in the infrared and near-infrared portions of the electromagnetic spectrum.

Sponsored by the ACRF, scientists from the University of Wisconsin-Madison and Atmospheric Environmental Research, Inc. led a research team that brought together different types of spectrometers to obtain—for the first time—simultaneous measurements from specific portions of the infrared spectrum. The spectrometers and their research organizations included:

The RHUBC-II instrument suite on Cerro Toco included both guest instruments and baseline ACRF instruments.

- Atmospheric Emitted Radiance Interferometer (AERI), an infrared spectrometer covering the wavelength range from 3.3 to 20 microns, provided by the ACRF
- Absolute Solar Transmittance Interferometer (ASTI), a solar tracking near-infrared spectrometer covering the range from 1 to 5 microns, provided by the University of Denver in Colorado
- Far-Infrared Spectroscopy of the Troposphere (FIRST), a far-infrared spectrometer covering the range from 6 to 100 microns, provided by NASA's Langley Research Center in Virginia
- Radiation Explorer in the Far Infrared (REFIR), a far-infrared spectrometer covering the range from 10 to 100 microns, provided by the *Istituto di Fisica Applicata Carrara* (Institute of Applied Physics) in Florence, Italy
- Smithsonian Astrophysical Observatory Fourier Transform Spectrometer (SAO FTS), a sub-millimeter spectrometer covering the range from 86 to 1000 microns, provided by the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts.

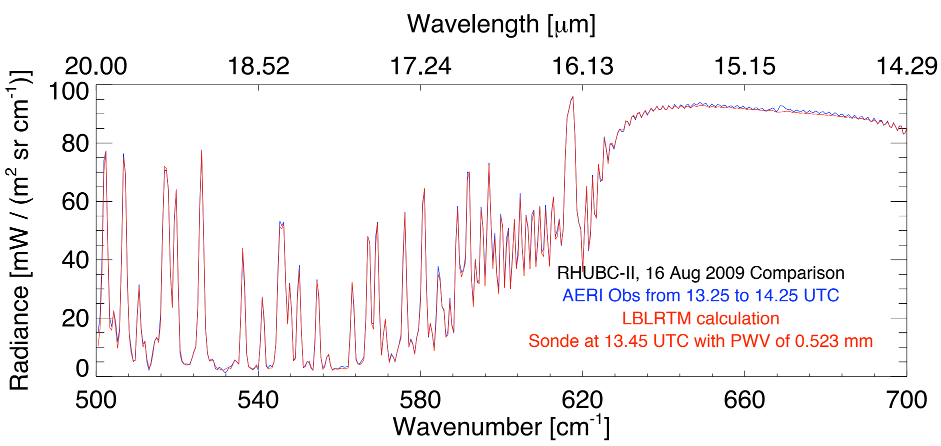
"Only three groups in the world make spectrally resolved radiance observations in the far-infrared—wavelengths 15 to 100 microns. Two of those groups are involved in RHUBC-II, while the other participated in the first phase of the study," said Dr. Dave Turner, a scientist from the University of Wisconsin-Madison and one of the principal investigators for the study. "This is the first experiment that I know of that is making spectrally resolved measurements of downwelling radiation from 1 to 1000 microns in wavelength simultaneously."

Co-principal investigators Dr. Dave Turner (left) and Dr. Eli Mlawer (right) on Cerro Toco.

In addition, a 3-D scanning 14-channel microwave radiometer, provided by the University of Cologne, operated side-by-side with the spectrometers throughout the campaign. Called a Humidity and Temperature Profiler, this instrument is sensitive to radiation from 5200 to 13600 microns.

Results: Except for a few days when clouds or snow precluded the desired measurements, the spectrometers operated in primarily clear skies. Due to their sensitivity, these instruments were turned off each night and turned back on in the morning, but the rest of the instruments operated continuously throughout the campaign. In addition, the team launched a total of more than 120 weather balloons throughout the campaign, providing a comprehensive vertical profile of the atmosphere above the site to supplement the spectrometer measurements. On just the fifth day of operations, precipitable water vapor above the site was recorded at an impressive 0.2 millimeters—about 100 times less than the mean value recorded in the United States.

Analysis of the RHUBC data is already underway by the campaign's principal investigators and associated scientists. Observations by the AERI on August 16 are being compared against the spectral radiance that was computed using a state-of-the-art line-by-line radiative transfer model (LBLRTM) in the 14- to 20- micron region. The LBLRTM encapsulates all of the known physics associated with modeling spectral radiative transfer through the atmosphere. Improving this model and similar models is the main goal of RHUBC, as these detailed physical models are used to create simpler and faster radiation parameterizations used in climate models. Initial comparisons between the AERI and the LBLRTM show excellent agreement. This was anticipated, because RHUBC-I data were used to improve the LBLRTM in this spectral regime, albeit the RHUBC-I conditions were 2 to 4 times moister than the RHUBC-II case.



A comparison of the AERI-observed spectral radiance in a portion of the far-infrared and a detailed physical calculation in low water vapor conditions on August 16 shows excellent agreement. This suggests that the physics incorporated within the model are accurately represented.

Research Highlights

Scientists around the world use data from the ACRF for their research. In FY 2009, ACRF data were cited in a total of 458 publications. The following pages feature a selection of ARM research highlights from these publications. For more publications information, search the ARM Publications Database:

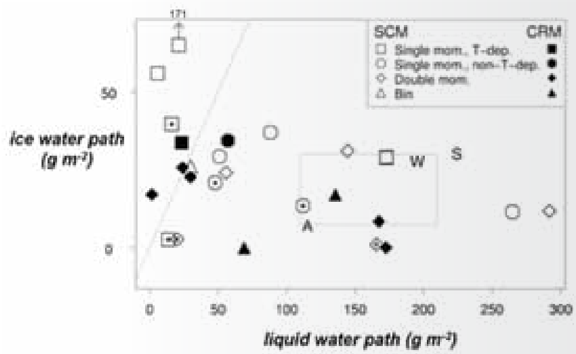
www.arm.gov/publications/publist/

2009 Publications Summary	
Category	**Total**
Abstracts or Presentations	206
Books	1
Book Chapters	1
Conference Papers	19
Journal Articles	205
Technical Reports	26
Total	458

Challenges in Modeling Arctic Mixed-Phase Clouds

Clouds that contain both super-cooled liquid and ice are called mixed-phase clouds. Mixed-phase clouds are particularly common in the Arctic, which is undergoing rapid climate change. Therefore, it is important for climate models to simulate mixed-phase clouds well. Using observations from the Mixed-Phase Arctic Cloud Experiment (M-PACE), which was conducted at the NSA site in 2004, researchers tested the ability of 17 single-column models and 9 cloud-resolving models to simulate Arctic mixed-phase clouds. This collection of models—one of the widest ever assembled for this type of study—included single-column models of the world's leading climate and weather prediction modeling centers. Simulation results varied widely, with only a few models consistent with ARM observations.

For the single-layer cloud, models typically simulated less liquid than observed, with the result that they underestimated the impact on the surface energy budget. Conversely, the models generally overestimated the amount of liquid but underestimated the amount of ice in multi-layer clouds. These contrasting results may point to the difficulties of simulating ice formation mechanisms that differ between single-layer and multi-layer clouds. The multi-layer cloud period also highlighted that models have difficulty correctly simulating cloud fraction, which is an important variable for determining the correct impact of clouds on the surface energy budget. Models that do a credible job of simulating the relative amounts of liquid and ice as well as other characteristics of these clouds tend to have more detailed representation of cloud microphysics, suggesting that improved representations of cloud microphysics can lead to improved simulations. The high-quality observations and broad participation of the modeling community in this study points to the importance of Arctic mixed-phase clouds as a key target for climate modeling centers to improve with future cloud parameterization developments.

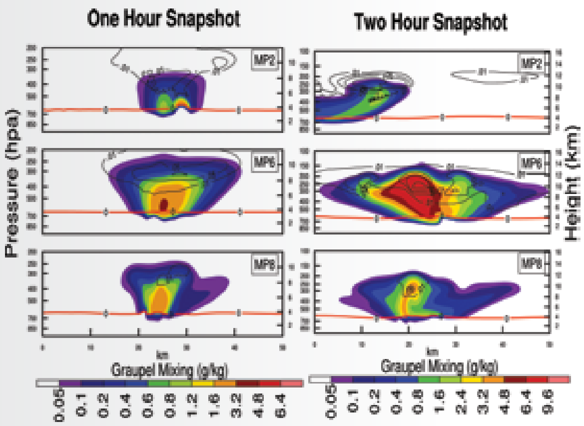


Scatterplot of the liquid water path and ice water path from observations (letters) and model simulations (symbols) for the single boundary-layer cloud observed during M-PACE. Aircraft observations are depicted by the letter "A," whereas the ground-based radar-lidar retrievals are depicted by "S" and "W."

(References: Klein SA, RB McCoy, H Morrison, AS Ackerman, A Avramov, G de Boer, M Chen, JN Cole, AD Del Genio, M Falk, MJ Foster, A Fridlind, JC Golaz, T Hashino, JY Harrington, C Hoose, MF Khairoutdinov, VE Larson, X Liu, Y Luo, GM McFarquhar, S Menon, RA Neggers, S Park, MR Poellot, JM Schmidt, I Sednev, BJ Shipway, MD Shupe, DA Spangenberg, YC Sud, DD Turner, DE Veron, K von Salzen, GK Walker, Z Wang, AB Wolf, S Xie, KM Xu, F Yang, and G Zhang. 2009. "Intercomparison of model simulations of mixed-phase clouds observed during the ARM Mixed-Phase Arctic Cloud Experiment. Part I: Single layer cloud." *Q J ROY METEOR SOC*, 135(641): 979-1002, doi:10.1002/qj.416.

Morrison H, RB McCoy, SA Klein, S Xie, Y Luo, A Avramov, M Chen, JN Cole, M Falk, MJ Foster, AD Del Genio, JY Harrington, C Hoose, MF Khrairoutdinov, VE Larson, X Liu, GM McFarquhar, MR Poellot, K von Salzen, BJ Shipway, MD Shupe, YC Sud, DD Turner, DE Veron, GK Walker, Z Wang, AB Wolf, KM Xu, F Yang, and G Zhang. 2009. "Intercomparison of model simulations of mixed-phase clouds observed during the ARM Mixed-Phase Arctic Cloud Experiment, Part II: Multi-layered cloud." *Q J ROY METEOR SOC*, 135(641): 1003-1019, doi: 10.1002/qj.415.)

Implications for Ice-Phase Cloud Microphysics for Next-Generation Climate Models



These one-hour and two-hour snapshots of mixing ratios for graupel (shades) and cloud ice (contours) from idealized thunderstorm experiments illustrate the wide discrepancy of the "ice-phase" cloud microphysics. The melting line is marked as a thicker, red line.

As high-performance computing resources and technology advance, the next generation of climate models will run at much finer "cloud-permitting" resolutions. At such high spatial and temporal resolutions, the information gained from traditional single-column model performance may be invalid. Based on observations gathered during the Tropical Warm Pool International Cloud Experiment (TWP-ICE), conducted in Darwin, Australia in 2006, this study conducted a suite of cloud-permitting evaluations for three sophisticated six-class, bulk cloud microphysics using the Weather Research and Forecasting (WRF) model. The systematical evaluation under this uniform platform of code and initial and lateral boundary conditions ensured that discrepancies in results were caused only by the different cloud parameterization and interactions with other physical parameterizations.

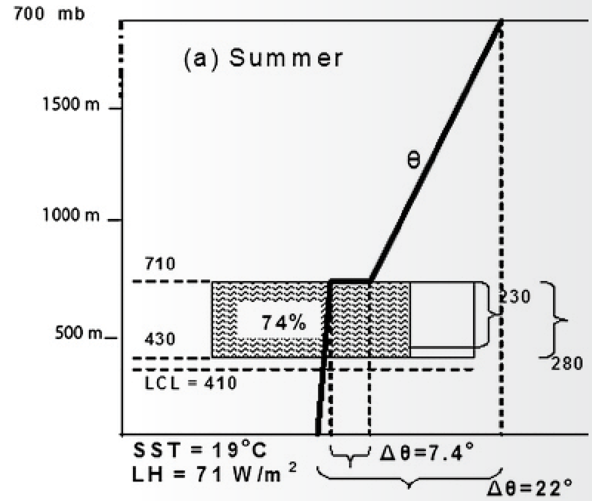
Preliminary evaluations using a simulated 2-D idealized thunderstorm illustrated the wide discrepancy of the "ice-phase" cloud microphysics. The TWP-ICE simulations confirmed that the "ice-phase" parameterization of cloud microphysics contributes most to the wide discrepancy between models and observations. A set of model evaluations in which the interactions between cloud and radiation parameterizations were "turned off" further illustrated the potential influence of the cloud-radiation feedback. The findings highlight the importance of ice-phase cloud parameterization, while the interactions between cloud and radiation play a secondary role in contributing to the wide discrepancy. The study also illustrates that evaluations of cloud microphysical parameterizations are vitally important to the success of the next generation of climate models.

(Reference: Wang Y, CN Long, LR Leung, J Dudhia, SA McFarlane, JH Mather, SJ Ghan, and X Liu. 2009. "Evaluating regional cloud-permitting simulations of the WRF model for the Tropical Warm Pool International Cloud Experiment (TWP-ICE, Darwin, 2006)." *J GEOPHYS RES-ATMOS*, 114, D21203, doi:10.1029/2009JD012729.)

Seasonal Variation of the Physical Properties of Marine Boundary-Layer Clouds

Marine boundary-layer (MBL) clouds can significantly regulate the sensitivity of climate models, yet they are poorly simulated in current models. Using measurements from the AMF while deployed at Point Reyes, California in 2005, reanalysis products, and several independent satellite data sets, this study aimed to characterize the seasonal variations of physical properties of these clouds and their associated processes. Cloud properties included the MBL cloud-top and cloud-base heights, cloud thickness, the degree of decoupling between clouds and MBL, and inversion strength off the California coast. Data from the Point Reyes deployment were used to validate an algorithm for deriving cloud-top and inversion height from satellite measurements off the California coast.

The study showed that MBL clouds over the northeast subtropical Pacific were more prevalent and associated with a larger in-cloud water path in the summer than in winter; also, cloud-top and cloud-base heights were lower in the summer than in the winter. Although the lower-tropospheric stability of the atmosphere was higher in the summer, the MBL inversion strength was only slightly stronger in the summer because of a negative feedback from the cloud-top altitude. Summertime MBL clouds were more homogeneous and associated with lower surface latent heat flux than those in the winter. Variations of low-cloud properties from summer to winter resembled the downstream stratocumulus-to-cumulus transition of MBL clouds in terms of depth, cloud-top and cloud-base heights, inversion strength, and spatial homogeneity. The observed variation of low clouds from summer to winter was attributed to the much larger seasonal cooling of the free-tropospheric air temperature than that of the sea surface temperature. These results provide a test case to understand and simulate MBL clouds in climate models.



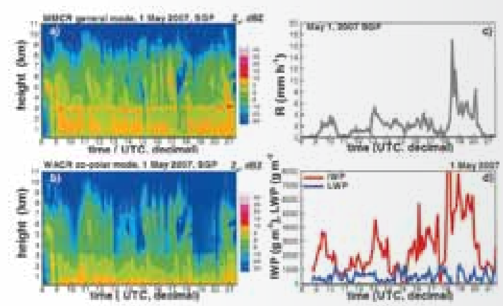
Marine boundary-layer clouds during summer off the California coast. Cloud amounts are shown in the shaded box, cloud-top and cloud-base heights and lifting condensation level (LCL) to the left, and cloud thickness and adiabatic liquid water thickness to the right of the cloud box.

(Reference: Lin W, M Zhang, and NG Loeb. 2009. "Seasonal variation of the physical properties of marine boundary layer clouds off the California coast." *J CLIMATE*, 22(10), doi:10.1175/2008JCLI2478.1.)

Estimating Cloud and Rainfall Parameters in a Vertical Column

Comprehensive characterization both of ice and water particles, or hydrometeors, in an atmospheric column is crucial for model parameterization and validation purposes. Simultaneous retrievals of cloud systems producing significant rainfall are challenging because optical instruments do not penetrate far into precipitation and radar measurements are dominated by precipitation. This study demonstrated a non-traditional attenuation-based approach using the vertically pointing ARM 8-millimeter wavelength cloud radar (MMCR) and the 3-millimeter W-band ARM cloud radar (WACR). The two frequencies allow separation of the liquid cloud and rainfall components from the same volume. This approach was based on the wavelength differences of 8-millimeter and 3-millimeter radiation attenuations due to small and large drops.

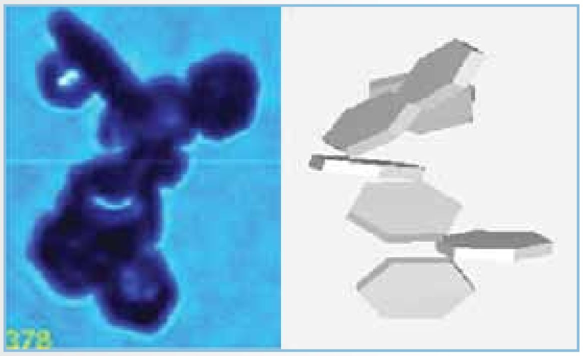
Measurements of ice particles were retrieved based on the absolute MMCR measurements. These measurements were corrected for the combined attenuation effects in the liquid and mixed hydrometer layers using constraint measurements from the weather surface scanning precipitation radars operating at non-attenuating or weakly attenuating frequencies. Time series of the cloud liquid water path, ice water path, and the mean rainfall rate were retrieved for the vertical column above the SGP Central Facility. Rainfall estimates from the impact Joss-Waldvogel disdrometer, which is collocated with the ARM radars, were used to constrain retrievals and reduce the retrieval variability due to assumptions about drop-size distributions. These results will help researchers to better understand precipitation formation processes and provide data sets for model verifications.



Panels (a) and (b) show measurements of a stratiform precipitating event by the MMCR and WACR, respectively, and the corresponding estimates of mean rain rate (c) and cloud ice water path and liquid water path (d).

(Reference: Matrosov SY. 2009. "A method to estimate vertically integrated amount of cloud ice and liquid and mean rain rate in stratiform precipitation from radar and auxiliary data." *J APPL METEOROL CLIMATOL*, 48, 1398-1410.)

Simulating Cirrus Sparkle



On the left is an image from the aircraft observation of an ice crystal made of a collection of plates; on the right is a similar crystal as modeled by Um and McFarquhar (2009).

Clouds reflect sunlight away from the earth, which tends to cool the earth, but they also absorb energy from the ground, which has a warming effect. Determining how the reflection and absorption properties of clouds change in a warming climate is important for predicting future temperature increases. Understanding the role of cirrus clouds in this interplay has been limited by the inability of computer models to simulate the complex crystals of which they are made. Unlike the roughly spherical water droplets in other cloud types, cirrus clouds are composed of ice crystals that occur in five predominant shapes: bullet rosettes, columns, plates, aggregates, and irregular. As the crystals fall, they collide and combine, creating even more-complex aggregations of crystals. The complex crystal shapes scatter sunlight in many directions, affecting how much light ultimately strikes the ground or is reflected away. Models already exist for how the simpler shapes impact the light; climate scientists needed a model for the aggregates.

During the Tropical Warm Pool-International Cloud Experiment in 2006, researchers used a high-flying aircraft to sample ice crystals from cirrus clouds, recording crystal images from which the different types and fractions of each type were identified. Then they created computer models of the aggregate crystals to more accurately calculate the scattering properties of ice clouds. Results indicated that aggregate ice crystals scatter less light in the forward direction and more to the sides or backward than the component crystals. Aggregates of plates make up a large portion of the ice crystals in the freshly generated outflows from convection. Because bulk scattering properties of cirrus are averaged over the shape and size distributions of the crystals, accounting for these differences will have a noticeable effect on models of cirrus clouds and the climate models that incorporate them. Researchers may also need to adjust their methods to take into account the variation of aggregation indices with geographic location and meteorological conditions.

(Reference: Um J and GM McFarquhar. 2009. "Single-scattering properties of aggregates of plates." *Q J ROY METEOR SOC*, 135: 291-304.)

Infrastructure Achievements

Maintaining multiple instrumented sites around the world is no easy feat. The ACRF uses a team of science, engineering, and technical personnel to ensure effective operations, keep up with technology developments, deliver high-quality data, and provide outreach to a global audience.

Site Operations

Internet Upgrade Speeds Data Transfer from Tropics

In October 2008, a new higher-speed Internet connection was hooked up for the ACRF site in Darwin, Australia, at no extra cost. This upgrade enables spectral data—the base for determining reflectivity, vertical velocity, and spectral width—obtained by the MMCR to be transmitted via the Internet, thereby eliminating the need to ship hard disks across the globe to the Data Archive at Oak Ridge National Laboratory. In addition to the efficiency and costs savings of Internet data transfer, the increased bandwidth has improved Internet communications and email performance for all three of the TWP sites that use the server in Darwin.

MMCR data transmission improved with an upgraded Internet connection.

Each MMCR generates huge volumes of data—approximately 600 megabytes per hour. Since the installation of the radar at the Darwin site in 1999, these data were recorded onto disks and shipped to the Archive approximately every two weeks. The MMCR data currently accounts for more than 30 percent of the total volume at the ACRF Data Archive, and dealing with such a large volume of disks is labor intensive. The seemingly minor Internet upgrade at the TWP resulted in a great improvement to site operations and communications capability. In addition, transferring the data over the Internet is much more secure and reliable due to the decreased risk of lost or damaged disks during shipment.

Site Operations Centralized Through New Tracking System

With more than 300 instrument systems operating at remote sites around the globe, ACRF Instrument Mentors can now use the centralized Operations Support System (OSS) to review or provide updates to instrument tracking information in a central database accessible to operations staff throughout the user facility. By consolidating information previously recorded in separate tracking systems for the various ACRF fixed sites, this important new capability will increase efficiency of operations throughout the user facility. In superseding these other systems, the OSS site-wide application improves single-point management and tracking of ACRF assets.

Tracking more than 300 instrument systems distributed around the world is a challenging task.

Recognizing the importance of moving to a central tracking system, development and implementation of this new management capability was a monumental task. Initial efforts involved interviewing various operations personnel from all the sites to determine site-specific needs. After tasks associated with those needs were prioritized, work began to develop the system and migrate historical information from the other databases into the new system. The OSS is now the standard site-wide application for tracking inventory and events related to ACRF systems and components. Three additional features are in the design or development phase for this system: management of shipping and receiving; documentation and tracking of instrument calibration; and remote entry, collection, and the associated synchronization of OSS events.

Operations capabilities at the ACRF site in Barrow now include a telehandler that can perform a variety of difficult tasks, particularly in winter.

North Slope Operations Get a Big Lift

In August, operations staff at the NSA site in Barrow welcomed a much-anticipated arrival—a “telehandler”—that will make operations at the Arctic site easier and more efficient. The unit will be used to move racks of helium, lift heavy instruments to decks for field campaigns, and move large liquid nitrogen or liquid helium dewars to instrument locations. Fresh off the summer barge from Anchorage, the vehicle immediately went to work unloading a shipping container holding 10 racks of helium bottles, with each rack weighing about 2300 pounds.

Based on a typical forklift design, the telehandler can support a payload of 6000 pounds and is equipped with a general purpose bucket and 4-foot forks. This unit also features a telescoping boom that can reach up to 42 feet, plus three different steering modes: two-wheel, “crab,” and coordinated. It also includes stabilizers that provide ± 5 degrees of leveling, plus a frame-leveling system with ± 10 degrees of adjustment. As part of the Arctic Package, the unit will also accommodate a snow blower attachment—handy for removing snow drifts that can pile several feet high on the access roads and around the instruments at the North Slope during the winter.

Instrument Enhancements

Rick Petty, DOE Program Director for the AAF, emphasizes the goals of the three-day airborne instrumentation workshop.

Airborne Instrumentation Workshop Seeks Latest Scientific Advances

The AAF sponsored a workshop on aircraft instrumentation at the University of Illinois in Urbana-Champaign, Illinois, on October 14-16, 2008. About 65 people from the United States, Canada, and Europe attended the workshop, which featured more than 40 presentations and about a dozen posters covering airborne instrumentation for remote sensing and in situ measurements of aerosols, clouds, radiation, and atmospheric state parameters. The goals of the workshop were to:

- identify state-of-the-art measurement techniques for aerosols, clouds, radiation, and atmospheric state parameters
- determine emerging instruments and developing technologies in these areas that can be made flight-ready and reach maturation within an approximate one-year time period
- identify measurements needs for existing gaps in airborne instruments capabilities needed to answer key science questions in climate science.

At the conclusion of the workshop, a steering committee reviewed the workshop discussions to develop guidance for the 2011 call for proposals.

New Cloud Radar Joins Mobile Facility on Graciosa Island

As a prelude to great things to come throughout the user facility, a new 95-gigahertz scanning W-band cloud radar was installed in late September at the AMF deployment site in the Azores. This new radar joins the instrument suite that has been collecting data at the airport on Graciosa Island since May 2009. Data from the 20-month AMF deployment on Graciosa will result in the first climatology of the detailed vertical structure of cloud and precipitation properties at a remote subtropical marine site. The added scanning capability provides 3-D information about clouds that scientists have identified as particularly problematic in climate change scenarios.

Much like an operational weather radar, the rotational capabilities of the new scanning cloud radar allow the antenna to scan any portion of the sky.

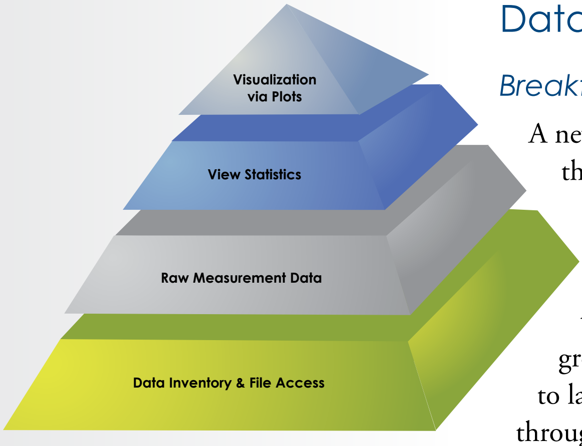
The ACRF lead radar engineer worked closely with researchers at McGill University to develop scanning patterns for a variety of cloud types. The new scanning radar will remain on Graciosa until early December for side-by-side operations with the mobile facility's baseline W-band ARM cloud radar (WACR). It will then come back to the states to join the second mobile facility currently under development. The deployment in the Azores represents an important operational test period for the new radar, as 18 more scanning radars are being developed through funding from the American Recovery and Reinvestment Act.

Instruments for Airborne Research Undergo Calibration Campaigns

This summer, the ACRF sponsored a series of calibration studies in the United Kingdom and Canada for two key instruments used for airborne cloud research—the cloud extinction probe and the Cloud Particle Imager (CPI). Both of these instruments were used in past ACRF field campaigns to support studies of both tropical and arctic clouds: the Tropical Warm Pool International Cloud Experiment in 2006 and the Indirect and Semi-Direct Aerosol Campaign in 2008, respectively. The CPI will also be used in the Small Particles in Cirrus field campaign starting in fall 2009. The recent calibration efforts explored the potential for these instruments to provide additional valuable information to the data collected during these campaigns.

Scientists work on the CPI calibration effort at the University of Manchester.

The CPI provides high-resolution images of ice crystals, and scientists at the University of Manchester believe the instrument can also give information about the size distribution of ice crystals. Scientists performed the CPI calibration in August at the University of Manchester. They also used the university's cloud chamber to compare the performance of three different versions of the CPI and conduct an aggregation experiment. The cloud extinction probe measures how light decreases in intensity when it encounters specific media, such as liquid droplets, ice particles, or aerosol particles. This field campaign, from August through October, involved the use of a laboratory calibration process at Environment Canada to study the effect of particle size on measurements of attenuated light for this first airborne version of the instrument.



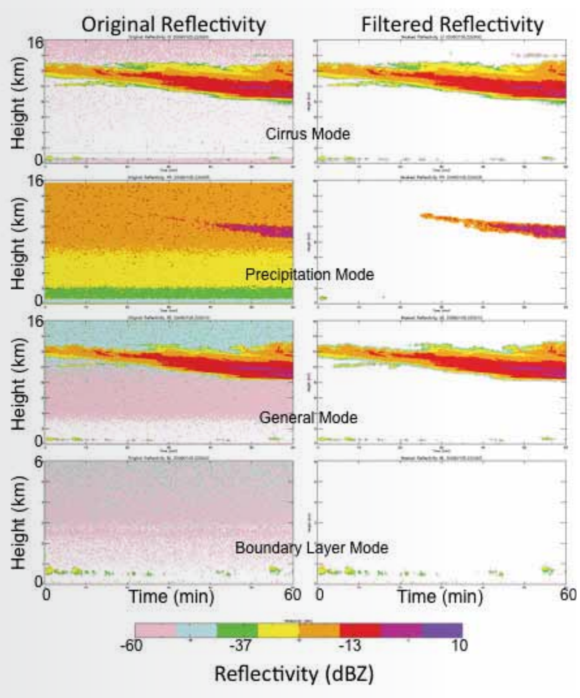
The Statistical Browser is the first example of a results-based user interface to a data collection on the scale of the Data Archive in terms of bytes, number of data files, number of measurement types, and longevity.

Data Delivery

Breakthrough User Interface Delivers Statistical Views of Data

A new software interface developed for the ACRF Data Archive allows users, for the first time, to view and obtain "statistical views" of measurements collected by ARM as part of the data selection and access process. The new interface allows users to drill down from multi-year, yearly, and monthly statistical graphs, with results presented in an accessible, tabular format. In addition to aligning more closely with the user's perspective, this tool breaks new ground by demonstrating a new results-based interface that is applicable to large-scale data collections. The Statistical Browser prototype is available through the data access tools on the ARM website.

The statistical views enable users to gain a sense of large-scale patterns contained in the data to aid in selecting data for closer examination. The statistical views summaries are aligned with the logic of climate research focused on modeling long-term trends and patterns. For educators at both undergraduate and graduate levels, the simple displays can be used as an introduction to more complex analyses. The Statistical Browser is currently available for a select number of data products, and user comments will be considered by the Data Archive team for future developments to the browser tool.



These data plots illustrate the results of the smart filter in removing clear sky information from MMCR data.

Smart Filter Clears the Way for Speedy Data Transfer

The development of a sophisticated "smart" filter has successfully reduced the volume of MMCR data by up to 15 times. Recognizing that unneeded "clear sky" information contributed substantially to the already large data files produced by the MMCR, researchers began developing an algorithm to remove that information and reduce the data volume. After several months of successful data collection using the new algorithm, the filter was applied for the MMCR in Darwin, Australia, and for the W-band ARM cloud radar deployed with the AMF in China. Because the "smart" filter removes unnecessary "clear sky" information from the final output files, data transfer and processing is much faster while not impacting the value of the data for scientific discoveries.

The Microphysical Active Remote Sensing of Clouds evaluation product, which uses the filtered data as input, was released for evaluation by the scientific community and included a year of data (May 2007 through May 2008) from the SGP site; additional years will be added in the future. This evaluation product, combined with the substantially smaller filtered data sets, will greatly speed data processing and use of the information-rich MMCR spectral data.

Best Estimate Data for Sensible and Latent Heat Fluxes at the SGP Site

Accurate estimates of sensible and latent heat fluxes are needed to understand interactions between the land surface and the atmosphere and are especially important for understanding boundary layer processes. At the SGP site, surface and latent heat fluxes are measured by the Energy Balance Bowen Ratio (EBBR) system. During stability transition conditions, often near sunrise or sunset, there are large uncertainties in these measurements. In these cases, an alternative estimation technique, known as a bulk aerodynamic calculation, is more reliable than the EBBR values. The Bulk Aerodynamic (BA) EBBR Value-Added Product (VAP) was designed to provide quality control on the EBBR measurements, identify periods of large uncertainty in the measurements, and implement the bulk aerodynamic calculation for those periods. The BAEBBR VAP thus provides a best estimate of surface sensible and latent heat fluxes for all conditions, making it more useful for analysis and model evaluation.

Each EBBR system produces estimates of the vertical fluxes of sensible and latent heat from observations of net radiation, soil surface heat flux, and vertical gradients of temperature and relative humidity.

In the past year, significant enhancements were added to the original BAEBBR VAP process. The VAP was updated to use site-specific height values for the automatic exchange mechanism levels and wind speed measurement, instead of fixed values. Vegetation height information from SGP site operations is provided monthly, and the monthly VAP processing is automated. In addition to the mentor quality control checks on the input EBBR data, a set of quality control checks were implemented on five primary measurements produced by the BAEBBR VAP. Data from this product are now available at the Data Archive beginning in 1993, with new data added monthly for the 14 SGP extended facilities with EBBR measurements.

Communication, Education, and Outreach

ARM Climate Research Facility Exhibit Showcases Arctic Research

Coinciding with the 32nd Antarctic Treaty Consultative Meeting, the ACRF represented DOE at an international exhibition showcasing polar research efforts around the world. In celebration of the 50th anniversary of the treaty, as well as the conclusion of the 2007-2008 International Polar Year, the U.S. State Department invited several U.S. agencies and the treaty delegations from around the world to highlight their scientific endeavors related to polar science and education. This event presented a unique opportunity for the ACRF to gain exposure among a variety of international organizations. Approximately 400 delegates from 47 countries attended the meeting in Baltimore, Maryland, from April 6-17.

On display at the Antarctic Treaty Consultative Meeting in April 2009, the ACRF exhibit featured research activities at the NSA sites.

Featuring its research at the NSA, the ACRF exhibit included two posters: one highlighting the measurement capabilities of the NSA sites at Atqasuk and Barrow and the other highlighting scientific field campaigns conducted at the North Slope during International Polar Year. The exhibit also included a live data display from the Barrow site and several handouts describing the user facility, its sites, and an educational newsletter featuring Arctic research.

Carlos César, President of the Regional Government of the Azores, signs a weather balloon during the AMF opening ceremony.

President of the Regional Government Speaks at Opening Ceremony in the Azores

On June 30, officials from the Regional Government of the Azores recognized the deployment of the AMF on Graciosa Island during an official opening ceremony held at the site. Notable among the participants was Carlos César, President of the Regional Government of the Azores, and several other government officials. Media outlets for print, television, and radio covered the ceremony, which was part of a two-day visit by the Regional Government to the island of Graciosa. In all, about 50 people attended the event.

Jeanette Rébert, U.S. Consul to the Azores, and President César gave brief opening remarks recognizing the various people and organizations that partnered to make the campaign possible. They also highlighted the importance of the project and how it fits into the shared goal of increased cooperation between the United States and Portugal, especially the Azores. Science and operations personnel then described the AMF and showed visitors around the instrument field. The AMF is located at the airport on Graciosa Island for the Clouds, Aerosol and Precipitation in the Marine Boundary Layer field campaign. Operations began in May and continue through December 2010.

Turning a New Page with Facebook

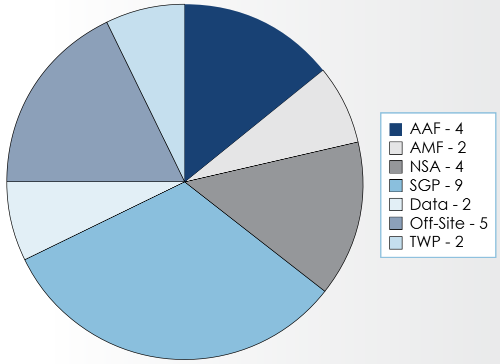
As a scientific user facility for the global change research community, the ACRF strives to provide data and share its climate observation capabilities with researchers around the world. In a continuing effort to reach new users, the ACRF turned another page in its outreach strategy with a presence on Facebook.

Savvy Internet users of all ages increasingly use Web 2.0 interactive communication tools to track topics of interest and share information with colleagues near and far. Recent statistics show that unique visitors to Facebook accounts are growing at a pace of more than 10 million per month. With its new Facebook page, the ACRF joins thousands of other organizations taking advantage of this outreach method to share news and information with a global audience.

Outreach Supports International Deployments. *From May 2009 through December 2010, the AMF is located on Graciosa Island in the Azores. As part of public outreach to support the deployment, segments of the ARM Program video overview were translated into Portuguese and made available via a kiosk in the airport at the deployment site. "As someone who spends a lot of time in these little island airports, I can promise it is going to get a lot of attention and reach many listeners," said Ms. Jeanette Rébert, Deputy Principal Officer at the U.S. Consulate in the Azores.*

2009 FIELD CAMPAIGN SUMMARY

The ARM Climate Research Facility routinely hosts field campaigns at all its sites, plus special data collection efforts and off-site campaigns. Many of these activities span several years. The figure here shows the total number of field campaigns and special data set collections that occurred in FY 2009, including these ongoing efforts. The subsequent table summarizes just those campaigns that began in FY 2009. For more information, visit the Field Campaign webpage at ***www.arm.gov/campaigns.stm***.



Total 2009 Field Campaigns

Field Campaigns Beginning in 2009

Dates	Campaign Name	Status	Description
		ARM Aerial Facility	
October 2008 - September 2010	ARM Airborne Carbon Measurements	In Progress	This campaign is a two-year multi-institution and multi-agency airborne study of atmospheric composition and carbon cycling above the SGP, with scientific objectives that are central to carbon-cycle and radiative-forcing goals of the U.S. Climate Change Research Program and the North American Carbon Program. The goal of these measurements is to improve understanding of: (a) the carbon exchange of the ARM region; (b) how CO_2 and associated water and energy fluxes influence radiative forcing, convective processes, and CO_2 concentrations over the ARM region, and (c) how greenhouse gases are transported on continental scales.
January - June 2009	Routine AAF CLOWD Optical Radiative Observations (RACORO)	Completed	The AAF conducted routine flights at the SGP site to sample low-altitude liquid-water clouds in the boundary layer. The purpose was to obtain representative statistics of cloud microphysical properties needed to validate retrieval algorithms and support process studies and model simulations of boundary-layer clouds and, in particular, CLOWD-type clouds (Clouds with Low Optical Water Depth).
May - October 2009	Calibration of the Cloud Extinction Probe	In Progress	In the absence of calibrating standards for transmissiometers, this campaign uses a laboratory installation for calibration of the Extinction probe and to accomplish theoretical estimations of the effect of particle sizes on the measured extinction coefficient based on Mie calculations. The results of calibrations will be used to develop a correction algorithm for the measured extinction coefficient. See the Infrastructure Achievements section for more information.

August 2009	Calibration of DOE CPI at University of Manchester	Completed	The CPI provides high-resolution ice crystal images, and such images have been used in many studies based on the ISDAC and TWP-ICE data sets. A recent study (Connolly et al. 2007) suggests that the CPI may be able to accurately measure particle-size distributions given sufficiently large averaging times. The scientific focus of this campaign is to derive a scaling factor for DOE using the facility at the University of Manchester, and then to apply this scaling factor to the TWP-ICE and ISDAC CPI data so that size distributions can be generated and placed in the DOE archive. See the Infrastructure Achievements section for more information.
ARM Mobile Facility			
May 2009 – December 2010	Azores: Clouds, Aerosol and Precipitation in the Marine Boundary Layer	In Progress	The AMF is currently deployed in the Azores to sample the transition from the overcast stratocumulus regime in the spring to the broken trade cumulus regime in the summer. Scientists will use data from the AMF to study processes controlling the radiative properties and microphysics of marine boundary-layer clouds, a high-priority science question. See the Infrastructure Achievements section for more information.
North Slope of Alaska			
January 2009 - December 2010	Effect of Sea Ice on Arctic precipitation	In Progress	The link between sea ice evaporation and precipitation is a fundamental component of climate dynamics and has been cited as an essential element of global warming, abrupt climate change, Dansgaard-Oeschger events, the Pleistocene ice ages, and "snowball earth." The objective of this project is to quantify how moisture evaporated from the Arctic Ocean and surrounding seas contribute to precipitation in the Arctic regions, and how such moisture supplies are controlled by sea ice extent.
March - April 2009	OASIS Campaign Aerosols Measurements in Barrow	Completed	Four instruments were placed in space assigned to ACRF NSA Operations within the Barrow Arctic Research Center building for the purpose of studying the physical and chemical properties of Barrow aerosols, including changes in particle diameters under different ambient effects; scattering and absorption; and temporal particle-size distribution.
March - June 2009	Barrow MMCR Calibration Campaign	Completed	This campaign collected corollary data sets from a variety of radars and precipitation instruments to develop an optimal calibration method compatible with the evolving sophistication in cloud radars such as the MMCR.

April - October 2009	ISDAC - Second Year Supplemental Surface Spectral Irradiance Measurements	In Progress	This campaign is documenting how cloud phase transitions influence the surface shortwave radiation budget through spring and summer, and into autumn. Such phase transitions are identifiable immediately in the spectral signature of the surface irradiance in the 1.6- and 2.2-micron windows. Data from this campaign will result in a set of radiometrically calibrated irradiance spectra, recorded at 1-minute intervals throughout the daylight period.
September 2009-August 2012	Barrow Webcam for the International Tundra Experiment (ITEX)	In Progress	ITEX measures individual plant responses to natural local environmental conditions throughout the summer and plant responses to enhanced warming using open top chambers. Measurements starting in 1994 and additional analyses may indicate responses to cloud cover and incoming radiation. The web camera at the ACRF site in Barrow will provide daily and archived images of the ITEX ground site located about 1 kilometer to the south.
Off-Site Campaigns			
October – December 2008	Low-Latitude Marine Stratocumulus Liquid Water Paths	Completed	This campaign explored potential use of the 183-gigahertz radiometer for retrieving high-quality liquid-water path measurements in low-latitude stratocumulus regions under low-humidity conditions, such as in the Southeast Pacific. The analysis also helped address long-standing questions on how precipitation and aerosol indirect effects vary with liquid water path for these climatically important clouds.
February - October 2009	Loan of ACRF Nephelometers for NOAA Aircraft Mission	In Progress	The ACRF nephelometers have been used as hot spares for the NOAA aerosol vertical profiling campaign "Airborne Aerosol Observatory" based in Champaign, Illinois.
August - October 2009	Microwave Oxygen Absorption Study (MOAS)	In Progress	In conjunction with the atmospheric state measurements from the radiosondes launched during RHUBC-II in Chile, the MOAS observations at the greatly reduced ambient pressure (under 520 millibar) on Cerro Toco (5383-meter elevation) will allow thorough investigation of the spectroscopy of the 60-gigahertz oxygen absorption band.
August - October 2009	Radiative Heating in Underexplored Bands Campaign, Phase 2 (RHUBC-II)	In Progress	Located at an altitude of 5383 meters on Cerro Toco in Chile, the RHUBC-II international team of scientists is using a variety of sophisticated optical spectrometers to obtain a detailed data set of measurements in the infrared portion of the electromagnetic spectrum. These data will ultimately improve the mathematical formulas used to calculate energy transfer in climate models. See the Featured Field Campaigns section of this report for more information.

Southern Great Plains			
January - June 2009	Surface Radiation Comparison Transfer Measurements for RACORO	Completed	This campaign provided corollary data sets to the RACORO campaign, which gathered statistics on the cloud, aerosol, and radiative properties of optically thin, low liquid-water-path cloud fields. The RACORO airborne observations, among other things, will be used to test and refine ARM surface remote sensing capabilities.
March - December 2009	Utility of 915-MHz Wind Profilers for Measurements of Vertical Velocities	In Progress	The main objective of this field campaign is to gain a better understanding of the role that convective clouds and convective parameterization play within global climate models, specifically, the role precipitation plays as: a sink of total water in the atmospheric column; a contributor to the energy balance through latent heating effects; and a feedback on the local environment impacting the subsequent formation of clouds. This project contributes to the collaboration between ARM and the NASA Global Precipitation Measurements ground validation program.
March 2009 - February 2010	Precision Gas Sampling Validation	In Progress	The focus of this project is the prediction of landscape-scale fluxes of CO_2, water, and sensible heat that drive variations in carbon cycle and regional climate (e.g., cloud formation and precipitation). Variation in these fluxes caused by land use, management, and changing climate requires models that are parameterized and tested against measurements made in multiple land-cover types and over seasonal- to inter-annual time scales. This continuation of earlier work focuses on measurements necessary to test and validate regional-scale carbon and climate modeling.
April 2009 - December 2010	Radon Measurements of Atmospheric Mixing (RAMIX 2009-2010)	In Progress	This collaborative campaign with NOAA-Climate Monitoring and Diagnostics Laboratory will measure atmospheric Radon (222Rn) concentrations from the SGP 60-meter tower with the objectives of (1) estimating the time-averaged atmospheric mixing between the different atmospheric layers and during selected convective events, and (2) using the measured mixing rates to estimate regional CO_2 exchange. To accomplish these objectives, the continuous tower-based measurements will be combined with planned airborne concentration 222Rn measurements and surface 222Rn flux measurements and modeling.

May - June 2009	VORTEX2: Verification of the Origins of Rotation in Tornadoes Experiment	Completed	Approximately 50 scientific vehicles ranged from Texas to North Dakota obtaining atmospheric measurements before and during severe thunderstorms and tornadoes. VORTEX2 coordinated these soundings with special soundings from other sources, including soundings from the National Weather Service, Texas Tech University in Lubbock, and the SGP site in Oklahoma. Coordinated launch times among all of these platforms will enable scientists to characterize the mesoscale variability in the environment.
May - July 2009	Solmirus' All Sky Infrared Visible Analyzer (ASIVA)	Completed	For this field campaign, the ASIVA instrument featured a wide-angle (106 degree x 156 degree) field of view lens, providing good overlap with the Total Sky Imager (TSI) instrument in determining cloud fraction. Data products included radiometrically calibrated images taken at 1- to 5-minute intervals, cloud masks computed by a variety of techniques, and cloud fraction determination. A final report details the results of this field campaign with special emphasis on comparison with data from the TSI instrument.
May - July 2009	Ground-based Cloud Tomography Experiment at SGP	Completed	This campaign tested a promising new technique for measuring 3-D cloud microphysical structure: cloud microwave tomography. Five microwave scanning radiometers were arranged along a 12-kilometer north-south line centered at the SGP Central Facility and were programmed to scan continuously in that vertical plane. Several other ARM datastreams were used either as ancillary data or as validation, including both remote sensing and in-situ measurements from RACORO to evaluate the tomographically retrieved cloud structure.
July - August 2009	NASA Coordinated Airborne CO_2 Lidar Flight Test Campaign	Completed	Coordinated CO_2 Laser Absorption Spectrometer (LAS) flights over/near the SGP site were conducted along a 48-kilometer leg at various altitudes and under various atmospheric conditions to evaluate the performance of the different LAS instruments for remote CO_2 column measurements.

www.arm.gov