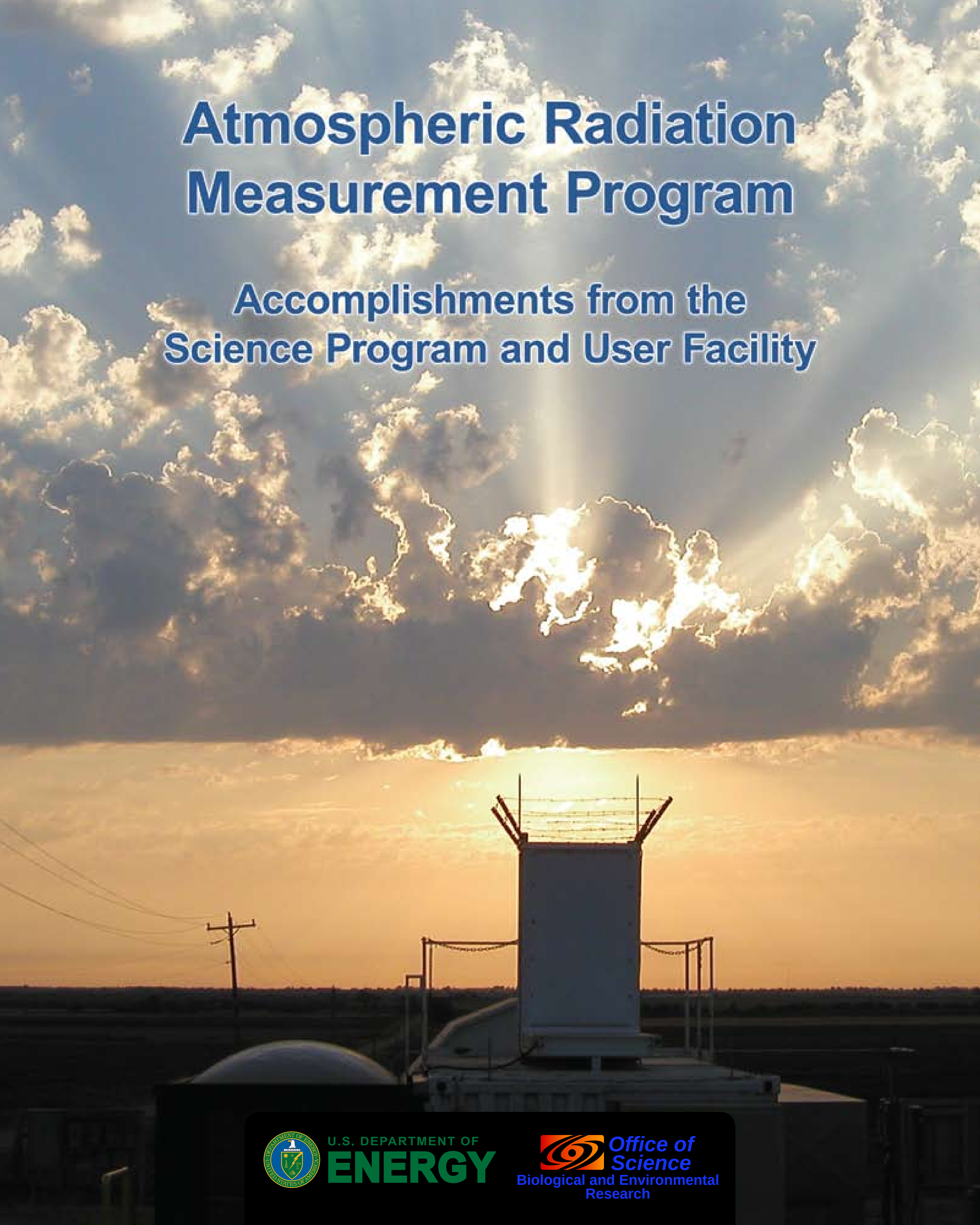
Atmospheric Radiation Measurement Program

Accomplishments from the Science Program and User Facility



U.S. DEPARTMENT OF ENERGY

Office of Science
Biological and Environmental Research

The Importance of Radiation and Clouds 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, aerosols, and their effects on the Earth's energy balance.

The 2007 assessment (AR4) by the Intergovernmental Panel on Climate Change (IPCC) reports a substantial range among GCMs in climate sensitivity to greenhouse gas emissions. **The largest contributor to this range lies in how different models handle changes in the way clouds absorb or reflect radiative energy in a changing climate.**

The ARM Climate Research Facility and the ARM Science Program

In 1989, the U.S. Department of Energy (DOE) Office of Science created the Atmospheric Radiation Measurement (ARM) Program within the Office of Biological and Environmental Research (BER) 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, BER has adopted 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 Climate Research Facility has become the standard for ground-based climate research observations while ARM scientists lead the world in research related to the interactions of clouds and radiation. Highlights in this summary illustrate how the ARM Program has achieved specific advances in:

- measurements of key components of the Earth's climate system,
- radiation calculations in climate models, and
- the representation of clouds in climate models.

As this and future work is implemented in more climate models, ARM research will help to reduce uncertainties in climate predictions.

Accomplishments

- **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.

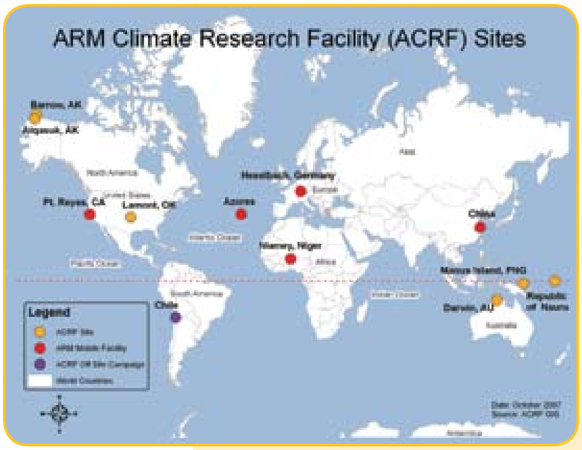
This summary includes a few of the key accomplishments of the BER ARM Program.

Key Accomplishments

Establishing a new standard for climate research observations. ARM was the first climate research program to deploy a suite of cutting-edge instrumentation for obtaining continuous measurements of cloud and aerosol properties. This strategy revolutionized our ability to collect long-term statistics of detailed cloud properties and now serves as a model for programs around the world.

The ACRF paradigm of long-term continuous measurements is essential to the enhancement and evaluation of climate models that must simulate the evolution of atmospheric properties for long continuous periods, from decades to centuries. This measurement approach permits unparalleled examination of atmospheric-process behavior and model-performance evaluation over extended periods and a wide range of meteorological conditions.

Obtaining aerial measurements to supplement ground-based observations. Observations at fixed and mobile sites are supplemented periodically with observations from aircraft. These data have yielded insights into a range of science issues, including the absorption of radiation by clouds and detailed composition of aerosol and cloud properties. Detailed cloud properties, such as ice crystal sizes, are critical because they dictate the life cycle of a cloud and its interaction with radiation. Airborne measurements obtained during ACRF field campaigns in the Arctic, the tropics, and midlatitudes revealed new information about ice crystal sizes and shapes in various cloud types. These observations led to greatly improved techniques for retrieving cloud properties from the ground, and also revealed serious errors in the treatment of ice particle formation in models.



Pioneered Measurement Strategy in Diverse Climate Regimes. *Atmospheric measurements are obtained at fixed ACRF sites in the U.S. Southern Great Plains, the Tropical Western Pacific, and on the North Slope of Alaska. The ACRF also includes an aerial vehicles component and a mobile facility, which has been deployed to coastal California, Niger, Germany, and China.*

Continuous Atmospheric Data for Researchers Worldwide.
Each ACRF site includes a broad array of instruments for observing the surface radiation balance and the atmospheric properties that drive that balance.

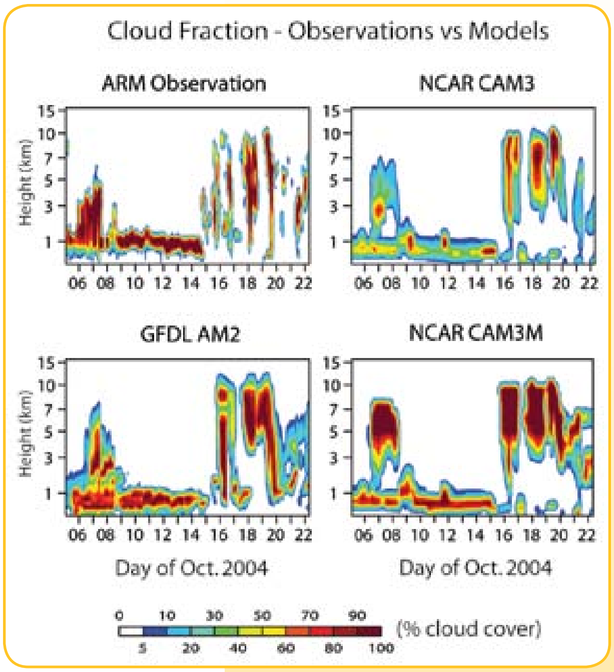
Developing a new paradigm for using observations to improve climate models. The detailed and comprehensive measurements obtained at the ACRF sites are critical for model evaluation and improvement. ARM scientists developed a unique process to bridge the gap between observations and GCMs in which a subset of ACRF observations are combined to provide input to a GCM, while other ACRF observations, such as cloud profiles, are used to evaluate the model's performance. This technique led to specific improvements in GCMs, including the treatment of ice crystals in cirrus clouds.

Achieving significant improvements in water vapor measurements. While carbon dioxide is a key contributor to climate change, the dominant greenhouse gas in the Earth's atmosphere is water vapor. Using detailed ACRF measurements of water vapor and associated radiative transfer calculations, ARM scientists reduced uncertainty in the measurement of water vapor from 13% to less than 4% during the past decade. This marked reduction led to vastly improved estimates of water vapor absorption in radiative transfer models that are now employed in many weather forecast models and GCMs used by the IPCC.

Improving the representation of radiation in climate models. Scientists used ACRF observations to significantly improve calculations of how radiant energy is distributed in the atmosphere. These improvements are encapsulated in the Rapid Radiative Transfer Model. Because this model offers greater accuracy and efficiency, it has been incorporated into several climate and numerical weather prediction models. Advancements in radiation calculations in these global models led to improved forecasts of temperature and humidity in the upper atmosphere.

Accomplishments

Providing unique observations of the radiative impact of aerosols. While the effect of greenhouse gases is well characterized in GCMs, uncertainty remains regarding the effect of aerosols, such as dust and smoke. This is particularly true regarding their effect on radiation transfer in the atmosphere—by redirecting incoming solar radiation back into space or by redirecting outgoing infrared radiation toward the surface. Extensive aerosol observations from the ACRF sites and ARM Mobile Facility have quantified the impact of aerosols on the radiation budget in diverse climatic regions. ACRF made the first column radiation absorption measurements of the impacts of Saharan dust, which is known to have an impact on hurricane development.



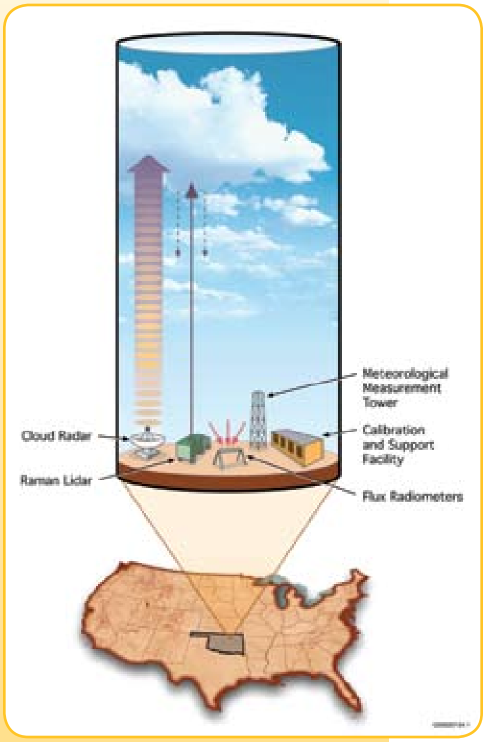
Bridges from Data to Models. *Studies of detailed physical processes and application of specialized models provide an important connection between observations and GCMs.*

Unraveling the impact of aerosols on clouds. The largest source of uncertainty associated with the radiative forcing of aerosols is their impact on the radiative properties of clouds. These effects include the modification of cloud particle size, cloud phase (liquid/ice), and the formation of precipitation. Recent studies by ARM scientists at multiple ACRF sites show that as much as 15% of the variability in cloud droplet sizes is due to aerosol effects.

Providing detailed information about the effects of clouds on radiation. With the retrieval of cloud properties on a continuous basis and the improvement of radiative transfer models, scientists can now derive vertical profiles of radiative fluxes at the ACRF sites. Work in this area provides a remarkably detailed data set for studying the redistribution of radiative energy in the atmosphere and makes it possible to evaluate cloud and radiative profiles in climate models.

The Importance of Aerosols. A change in the atmosphere's radiation balance due to alterations in the atmosphere is called "radiative forcing." The IPCC AR4 identifies aerosols as the largest source of uncertainty in radiative forcing.

Improving GCMs. The use of ACRF data to understand physical atmospheric processes has led to multiple improvements in GCMs.



Unique Source of Cloud Observations. *ACRF sites provide a wealth of information on clouds and their radiative impacts. This information positions ARM scientists to have a direct impact on reducing the spread in temperature predictions by GCMs.*

Translating detailed atmosphere observations for climate modelers. Many ACRF instruments generate information that requires specialized skills to understand and apply. ACRF staff and collaborators in the research community are working together to take this complex information and generate simple physical parameters that are readily accessible by the climate modeling community. One recently developed product is the Cloud Modeling Best Estimate, which combines a set of cloud observations from various ACRF instruments on a common grid. This product is expected to greatly facilitate the use of ACRF cloud data by climate modelers and has been adopted as a standard evaluation tool by the National Center for Atmospheric Research Community Atmosphere Model.

Implementing a major improvement in the radiative effects of clouds in GCMs. Climate models have a particularly difficult time representing fine-scale cloud systems. This is because the models use a spatial domain on the order of 100 kilometers, whereas clouds occur at scales within 10 meters. Examination of cloud fields observed at the ACRF sites, combined with efforts to represent the radiative effects of those cloud fields, led to the development of a new cloud radiation scheme adopted for use in several climate and weather forecasting models.

Developing a revolutionary new approach to climate modeling. Typically, GCMs are run at a very coarse resolution due to the time and cost required to produce simulations at a finer scale. This approach is particularly problematic for accurately simulating cloud processes because they are so dynamic in both space and time. To improve model forecasts, ARM scientists developed the Multiscale Modeling Framework that embeds finer-resolution cloud models into the GCM, replacing the complex equations formerly used to represent clouds. This breakthrough nested-model approach, specific for clouds, was shown to successfully transfer the small-scale variability of cloud properties into the large-scale GCMs.

Participants and Collaborators

Department of Energy Laboratories

Argonne National Laboratory, Argonne, IL
Brookhaven National Laboratory, Upton, NY
Lawrence Berkeley National Laboratory, Berkeley, CA
Lawrence Livermore National Laboratory, Livermore, CA
Los Alamos National Laboratory, Los Alamos, NM
National Renewable Energy Laboratory, Golden, CO
Oak Ridge National Laboratory, Oak Ridge, TN
Pacific Northwest National Laboratory, Richland, WA
Sandia National Laboratories, Albuquerque, NM

Other Government Offices and Laboratories

NASA - Ames Research Center, Moffett Field, CA
NASA - Earth Observing System Project Science Office, MD
NASA - Goddard Institute for Space Studies, New York, NY
NASA - Goddard Space Flight Center, Greenbelt, MD
NASA - Jet Propulsion Laboratory, Pasadena, CA
NASA - Langley Research Center, Hampton, VA
NOAA - Aeronomy Laboratory, Boulder, CO
NOAA - Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, TN
NOAA - Climate Monitoring and Diagnostics Laboratory, Boulder, CO
NOAA - Earth System Research Laboratory, Boulder, CO
NOAA - Geophysical Fluid Dynamics Laboratory, Princeton, NJ
NOAA - National Centers for Environmental Prediction, Camp Spring, MD
NOAA - National Environmental Satellite, Data and Information, Washington, D.C.
NOAA - National Marine Fisheries Service
NOAA - National Severe Storms Laboratory, Norman, OK
NOAA - Office of Global Programs, Silver Spring, MD
NOAA - Surface Radiation Research Branch, Boulder, CO
NSF - National Center for Atmospheric Research, Boulder, CO
UCAR - University Corporation for Atmospheric Research, Boulder, CO
USAF - Air Force Research Laboratory, Hanscom Air Force Base, MA
US Navy - Naval Research Laboratory, Washington, D.C.

Private Organizations

Atmospheric and Environmental Research, Inc., Lexington, MA
Bay Area Environmental Research Institute, Sonoma, CA
General Atomics, San Diego, CA
Greenwood Group, Ponca City, OK
Mission Research Corporation, Santa Barbara, CA
Science Applications International Corporation, San Diego, CA
SeaSpace Corporation, San Diego, CA

International Collaborators

Airborne Research Australia, Flinders University, Australia
Bureau of Meteorology, Australia
Canada Centre for Remote Sensing, Canada
Commonwealth Science and Industrial Research Organization, Australia
Dalhousie University, Canada
Environment Canada, Canada
European Centre for Medium-Range Weather Forecasts, United Kingdom
Government of Nauru, Republic of Nauru
Hadley Centre for Climate Prediction, United Kingdom
Institute for Atmospheric Optics, Russia
Institute for Atmospheric Physics, Russia
Japan Marine Science and Technology Center, Japan
Laboratoire de Meteorologie Dynamique, France
McGill University, Canada
Meteorological Service of Canada, Canada
National Institute of Polar Research, Japan
National Research Council, Canada
National Weather Service, Papua New Guinea
University of British Columbia, Canada
University of Hohenheim, Germany
University of Manchester, United Kingdom
University of Reading, United Kingdom

Universities

Boston University, Boston, MA
Clark Atlanta University, Atlanta, GA
Colorado State University, Fort Collins, CO
Columbia University (Lamont-Doherty Earth Observatory), Palisades, NY
Desert Research Institute, Reno, NV
Florida State University, Tallahassee, FL
Georgia Institute of Technology, Atlanta, GA
Harvard-Smithsonian Center for Astrophysics, Cambridge, MA
Iowa State University, Ames, IA
Oklahoma State University, Stillwater, OK
Pennsylvania State University, University Park, PA
Rutgers University, NJ
State University of New York at Albany, Albany, NY
State University of New York at Stony Brook, Stony Brook, NY
Stevens Institute of Technology, Hoboken, NJ
University of Alaska, Fairbanks, AK
University of California, Los Angeles, CA
University of California (Scripps Institution of Oceanography), San Diego, CA
University of California, Santa Barbara, CA
University of Colorado, Boulder, CO
University of Denver, Denver, CO
University of Illinois at Urbana-Champaign, Champaign, IL
University of Maryland, College Park, MD
University of Massachusetts, Amherst, MA
University of Miami, Coral Gables, FL
University of Michigan, Ann Arbor, MI
University of North Dakota, Grand Forks, ND
University of Oklahoma, Norman, OK
University of Utah, Salt Lake City, UT
University of Washington, Seattle, WA
University of Wisconsin, Madison, WI
University of Wyoming, Laramie, WY

This summary represents a sampling of key ARM accomplishments in the past two decades. A comprehensive report providing further details and references for these accomplishments is available on the ARM website at ***www.arm.gov/publications/programdocs/doe-sc-arm-0803.pdf***

The ARM website at ***www.arm.gov*** includes extensive information about the ACRF, further examples of ARM research, and a publications database that lists nearly 2000 peer-reviewed journal articles whose authors have made use of the ACRF for climate research. Some key links include:

- About ACRF: ***www.arm.gov/acrf/***
- ACRF Sites: ***www.arm.gov/sites/***
- Research Highlights: ***www.arm.gov/science/research/***
- Publications Database: ***www.arm.gov/publications/publist/***

U.S. DEPARTMENT OF ENERGY

Office of Science
Biological and Environmental Research

DOE/SC-ARM/P-08-017
October 2008