United States Department of Energy

ARM

Atmospheric Radiation Measurement Program


Canada
United States
Alaska
Russia
Nauru
Papua
New Guinea
United
Kingdom
Australia
Japan
Finland
France
Netherlands

Participants

DOE Laboratories

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

Private

- Atmospheric and Environmental Research, Inc., MA
- General Atomics, CA
- Greenwood Aviation, OK
- Mission Research Corp., CA
- SeaSpace Corp., CA
- Vaisala, Finland

Universities

- Boston University, MA
- Clark Atlanta University, GA
- Colorado State University, CO
- Desert Research Institute, NV
- Florida State University, FL
- Georgia Institute of Technology, GA
- Harvard-Smithsonian Center for Astrophysics, MA
- Lamont-Doherty Earth Observatory, NY
- Pennsylvania State University, PA
- Rutgers University, NJ
- State University of New York at Albany, NY
- State University of New York at Stony Brook, NY
- Stevens Institute of Technology, NJ
- University of Alaska, Fairbanks, AK
- University of California, Los Angeles, CA
- University of California, San Diego, CA
- University of California, Santa Barbara, CA
- University of Colorado, CO
- University of Denver, CO
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- University of Michigan, MI
- University of North Dakota, ND
- University of Oklahoma, OK
- University of Utah, UT
- University of Washington, WA
- University of Wisconsin, WI
- University of Wyoming, WY

International Collaborators

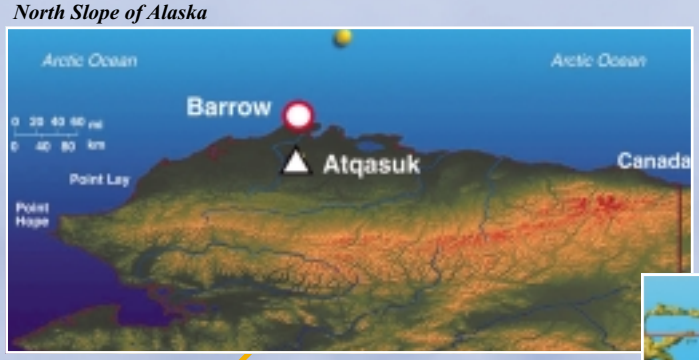
- Airborne Research Australia, Flinders University, Australia
- Bureau of Meteorology (BOM), Australia
- CSIRO, Division of Atmospheric Research, Australia
- Canada Centre for Remote Sensing (CCRS), Canada
- Dalhousie University, Canada
- McGill University, Canada
- Meteorological Service of Canada
- University of British Columbia, Canada
- Laboratoire de Meteorologie Dynamique, France
- Japan Marine Science Technology Center, Japan
- Meteorological Research Institute (MRI), Japan
- National Institute of Polar Research, Japan
- Tohoku University, Japan
- Nauru
- Clouds and Radiation (CLARA) Study, Netherlands
- Papua New Guinea
- Central Aerological Observatory, Russia
- Institute for Atmospheric Optics (IAO), Russia
- Institute for Atmospheric Physics (IAP), Russia
- European Center for Medium-Range Weather Forecasts, (ECMWF), United Kingdom
- Hadley Center for Climate Prediction, United Kingdom

Other Government Offices and Laboratories

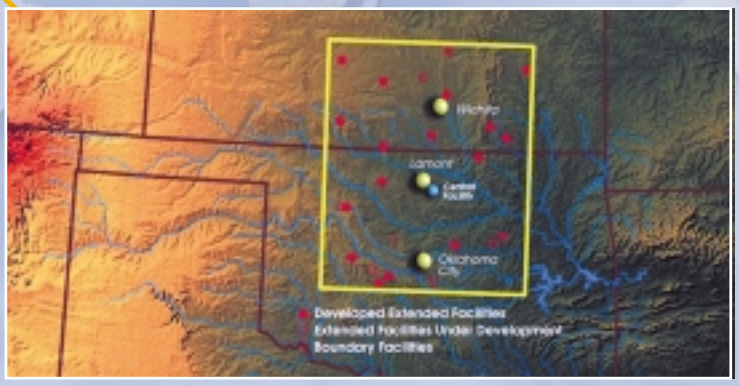
- Air Force Phillips Laboratory
- Illinois State Water Survey
- NASA Ames Research Center
- NASA Earth Observing System (EOS) Project Science Office
- NASA Goddard Institute for Space Studies
- NASA Goddard Space Flight Center
- NASA Jet Propulsion Laboratory
- NASA Langley Research Center
- National Centers for Atmospheric Research
- National Marine Fisheries Service
- National Science Foundation
- National Severe Storms Laboratory
- Naval Research Laboratory
- North Slope Borough government
- NOAA Aeronomy Laboratory
- NOAA Climate Monitoring and Diagnostics Laboratory
- NOAA Environmental Technology Laboratory
- NOAA Geophysical Fluid Dynamics Laboratory
- NOAA National Centers for Environmental Prediction
- NOAA National Environmental Satellite, Data, and Information
- NOAA Office of Global Programs
- NOAA Pacific Marine Environmental Laboratory
- NOAA Surface Radiation Research Branch

ARM Site Locations

North Slope of Alaska



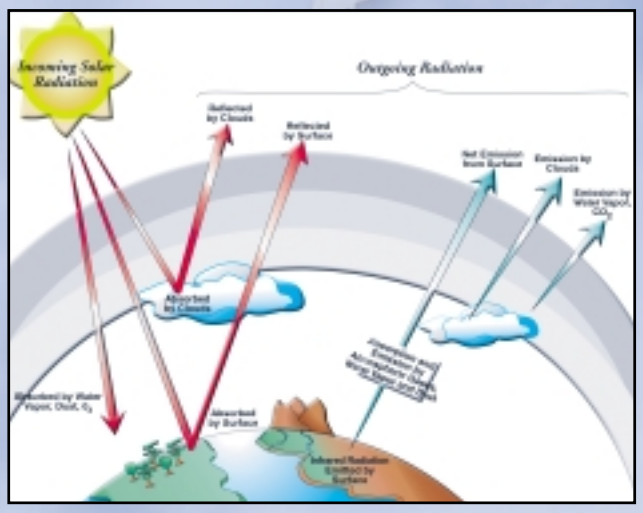
Tropical Western Pacific



Introduction

In 1978, the U.S. Department of Energy initiated the Carbon Dioxide Research Program to address the effects of increased concentrations of carbon dioxide in the atmosphere. Since then, DOE research programs have made significant progress toward understanding the potential impact of energy usage on the earth's environment. More recently, DOE has developed programs that are an integral part of the extensive national and international effort to understand global climate change.

Large-scale numerical models are key elements of current climate research and the effort to accurately predict future climate. Models of the global climate system include realistic geography, the annual cycle of the seasons, and variable cloud cover. However, important uncertainties remain in these computer models. DOE's Atmospheric Radiation Measurement (ARM) Program was created to address the impact of clouds on the energy balance of the climate system, which is one of the most important of these uncertainties, and to improve the treatment of clouds and radiation in climate models. This program is part of the ongoing effort by DOE to resolve scientific uncertainties about global climate change that may result from the addition of carbon dioxide and other so-called greenhouse gases to the atmosphere. Increased concentrations of these gases warm the atmosphere (somewhat like a greenhouse) by absorbing heat

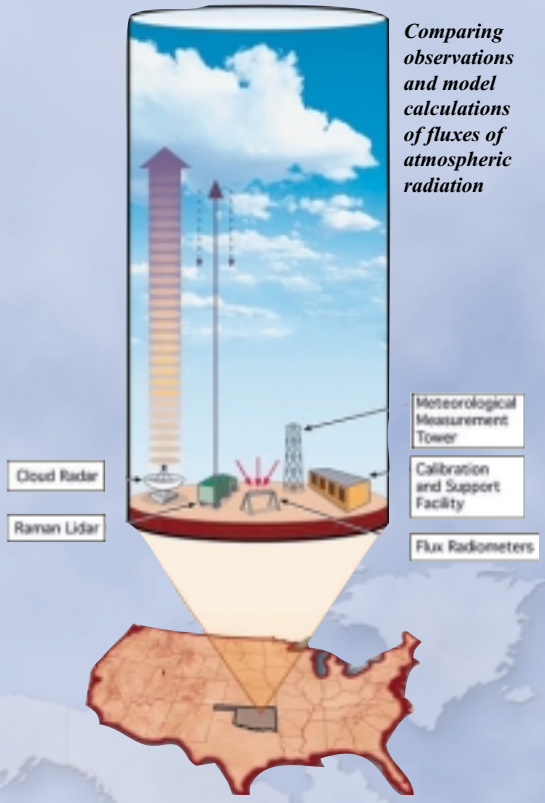


in the form of infrared radiation emitted from the earth's surface, which would otherwise escape to space. The amount of warming is still uncertain but is estimated to be about 1°-6°K (2°-12°F) by the end of this century.

Role of Clouds and Water

Water in all three phases (vapor, liquid, and ice) is the crucial component of the climate system. Water vapor is the most important greenhouse gas in the atmosphere because of its ability to absorb emitted thermal radiation. Slight warming of the climate system by the addition of greenhouse gases from human activity (such as carbon dioxide) may be amplified by factors of three or more by simultaneous increases in water vapor concentration in a warmer atmosphere.

Clouds, both water and ice, are the single largest factor in regulating the absorption of solar energy by the earth and an important factor in regulating the loss of infrared energy from the earth. The formation of clouds is the result of complex interactions between the temperature and moisture structure of an atmospheric column, the wind fields in and around the column, and the availability of small particles that are the kernels of cloud drops or ice crystals. These processes are not well understood and have the potential to amplify or moderate climate change forced by increasing greenhouse gases. In 1989, the U.S. Global Change Research Program identified cloud feedbacks in the climate system as the highest priority within global climate research. That is still true today. The ARM Program is designed to address the cloud question and help understand the physical processes that control cloud formation and feedback.



Comparing observations and model calculations of fluxes of atmospheric radiation

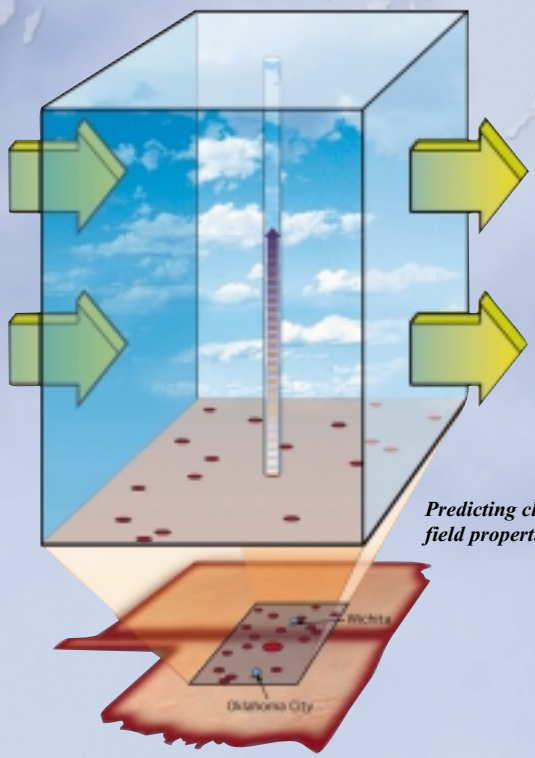
Modeling the impact of clouds is difficult because of their complex and differing effects on weather and climate. Clouds reflect incoming sunlight and therefore cool the climate system, but they also absorb and radiate infrared radiation leaving the earth and therefore warm the system. High cirrus clouds, for example, may act to warm the atmosphere, while low-lying stratus clouds, which are found frequently over oceans, generally act to cool the system. To successfully model and predict climate, we must be able to both describe the effect of clouds in the current climate and predict the complex chain of events that might modify the distribution and properties of clouds in an altered climate.

ARM Experimental Program

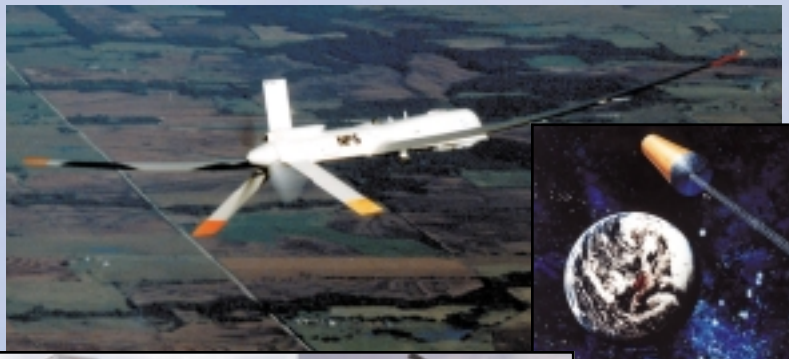
ARM has developed a new experimental framework intended to increase our understanding of clouds and other atmospheric processes, which will lead to improvements in general circulation models. Large arrays of instruments are operated over extended time-periods to help scientists understand the processes associated with clouds and radiation. These instruments collect data for analyses that will help determine the effects and interactions of sunlight, radiant energy, and clouds on temperature, weather, and climate.

ARM uses many ground instruments to gather data, which are supplemented by manned and unmanned aircraft, and satellites. Additionally, ARM collaborates extensively with other agencies, universities, and private firms in gathering and sharing data. The result is a more complete picture of the atmosphere than was previously available to climate modelers. This collaborative approach also allows ARM to leverage its investment in instruments, sites, data, and science.

Knowledge gained from these extensive measurements is helping improve the accuracy of the computer models used to predict global and regional climate changes. As a result, ARM is improving our ability to predict how much the climate might change, how fast the change might occur, and what the effects of the change might be. This information is valuable as a basis for sound economic, social, and political decisions about climate change.

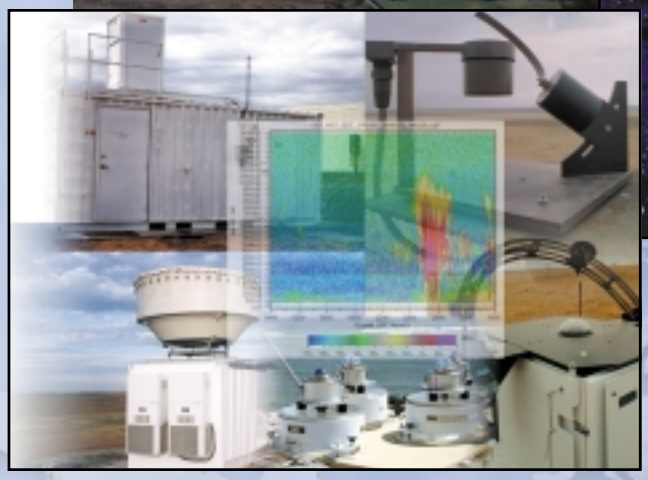


Predicting cloud field properties



ARM acquires data from unmanned aerospace vehicles and geostationary satellites

NOAA photo



ARM Instrumentation

Research Program

The ARM Program sponsors a broad range of research through a peer-reviewed grant program. Fundamental research on radiation transport in the atmosphere, particularly focused on the effects of clouds, is one of the core activities. Other important components are data analysis studies and research on the use of ground-based lidar, radar, and radiometer measurements to determine the properties of the atmosphere and clouds. The ARM Program also supports modeling studies of clouds and the climate system.

The ARM Program holds an annual science team meeting each spring that attracts 250 to 300 scientists engaged in cloud-climate research. These scientists come from universities, government laboratories, and private companies to share research results. The meeting has an international flavor, often attracting scientists from Canada, Australia, Japan, and several European countries.

Sites

To obtain the necessary measurements to meet the program goals, ARM has developed sites in three primary locales, each representing climatically significant regimes. Each Atmospheric Radiation and Cloud Station contains instruments to measure solar and terrestrial radiation, clouds and other meteorological phenomena and provides data to study the way clouds affect radiative processes and other atmospheric processes unique to the area. Manned and unmanned aircraft offer mobile platforms that provide data for the study of clouds and atmospheric radiation from above, below, and inside cloud layers. Observations and data are being collected continuously at these sites.

Aerial view of Southern Great Plains

Aerial view of Barrow

- The U.S. Southern Great Plains site was the first field measurement site established by ARM. Establishment of this site began the data flow. The U.S. Southern Great Plains site has a highly instrumented central facility near Lamont, Oklahoma, and smaller sites scattered over approximately 142,450 square kilometers of north-central Oklahoma and south-central Kansas. The site experiences a wide variety of cloud types and surface flux properties as well as large seasonal variations in temperature and specific humidity. ARM began taking continuous measurements at this location in 1994, and has operated a complete suite of instruments since 1996.
- The Tropical Western Pacific locale spans an area roughly between 10°S and 10°N latitude and 135°E and 150°W longitude. It 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. ARM has collected data at ARCS on Manus Island and Papua New Guinea since 1996, and Nauru since 1998. A third ARCS at Darwin, Australia, began operating in April 2002 in cooperation with the Australian Bureau of Meteorology, and will obtain data typical of tropical land convection and monsoon circulations.
- The North Slope of Alaska site, which has been operational since 1997, has its principal facility near Barrow and a smaller facility near Atqasuk. This site provides important information because fundamentally different climate processes occur at high latitudes. Ice and snow are the predominant forms of water in the Arctic, and they scatter, transmit, and absorb sunlight and radiant heat much differently than liquid water. Due to the generally cold temperatures, the atmospheric water vapor concentrations in the Arctic are quite low, allowing heat energy from the surface to escape through the atmosphere more easily than in other regions. High latitudes have great climatic significance because of the planetary heat loss from the poles and the extensive sheets of ice that affect solar absorption and sea level. In addition, model studies indicate that the Arctic is the most sensitive area on the earth for potential greenhouse warming.

Tropical Western Pacific instrumentation

Panoramic view of Nauru

Instruments

To meet the experimental needs of the program, ARM has developed or acquired instrumentation that provides highly accurate, continuous measurements of atmospheric conditions. These instruments gather atmospheric data that are both consistent and complete. ARM instruments, both conventional and technologically advanced, provide continuous, detailed radiometric and cloud observations; aerosol characterizations; and wind, temperature, and humidity measurements. Together, these instruments give a comprehensive picture of climate at the three important locales.

ARM has significantly advanced the state of the art in instrumentation for climate research. Some of the specialized field-hardened instruments with unprecedented accuracy and capability include:

- Atmospheric Emitted Radiance Interferometer: The AERI is essential for experiments on the effects of greenhouse gases, clouds, and fine particles on atmospheric absorption and emission of infrared radiation.
- Cloud Radar: This state-of-the-art radar developed in collaboration with NOAA, determines vertical location by profiling cloud layers from near ground to the tropopause providing information on cloud occurrence, amount of condensed water, and particle size.
- Raman Lidar: This instrument, located at the ARM Southern Great Plains site, is an active, ground-based laser remote sensing instrument that profiles water vapor, aerosols, and thin clouds using a laser in a similar manner to radar.

Data Accessibility

The ARM Program generates massive amounts of data. These data must be effectively managed so that participants in the ARM Program and the general scientific community can analyze and use them effectively in their research. The ARM Data Quality office, established in 2000, helps to coordinate evolution and implementation efforts to ensure the quality of the data collected by its field instrumentation. The data systems for the ARM Program collect, process, and transfer data streams to the ARM Archive for long-term storage and delivery to users.

The ARM Data Archive, launched in 1992 at Oak Ridge National Laboratory in Oak Ridge, Tennessee, serves as the chief repository for ARM data and provides a gateway for access to them. ARM data are accessible at no cost to anyone with Internet access. Users interact with the Archive through a World Wide Web site, ordering specific data sets from a robotic data storage system.

Collaborations

In a collaborative effort of unprecedented magnitude, ARM brings together an impressive team of scientists from a wide range of backgrounds to address the issues of global climate change. These collaborations include 9 DOE laboratories, 6 private laboratories, 24 other government offices and laboratories, 30 universities, and 21 international collaboratories. By collaborating and sharing knowledge, scientists are able to receive and analyze data faster, which will help them unlock some of the mysteries of our climate.

Collaborations, such as the Surface Heat Budget of the Arctic Ocean (SHEBA), Nauru99, and Water Vapor field campaigns are providing important data to help scientists gain a clearer understanding of the physical properties of clouds.

In one of the larger and more complex operations ever supported in the Arctic by the National Science Foundation, an icebreaker was frozen into the perennial pack ice and left to drift

for a full year. The ship served as a floating scientific research station, supporting the Surface Heat Budget of the Arctic Ocean (SHEBA) project. The ARM Program, worked in conjunction with NASA, the Office of Naval Research, and the Japan Marine and Technology Center to share data from satellites, research flights, and the SHEBA site. Scientists at the ice station studied the atmosphere, ocean, sea ice and snow cover to determine how these media interact through the surface heat budget, and how the interactions affect climate.

Nauru99—a campaign sponsored by the ARM Program—was an international research collaboration conducted on and around the island of Nauru in the Tropical Western Pacific during the summer of 1999. Through this international research campaign, involving ARM, NOAA, and the Japan Marine Science and Technology Center, scientists gathered data on oceanic and atmospheric processes to better understand the influence of the tropics—our world's "heat engine."

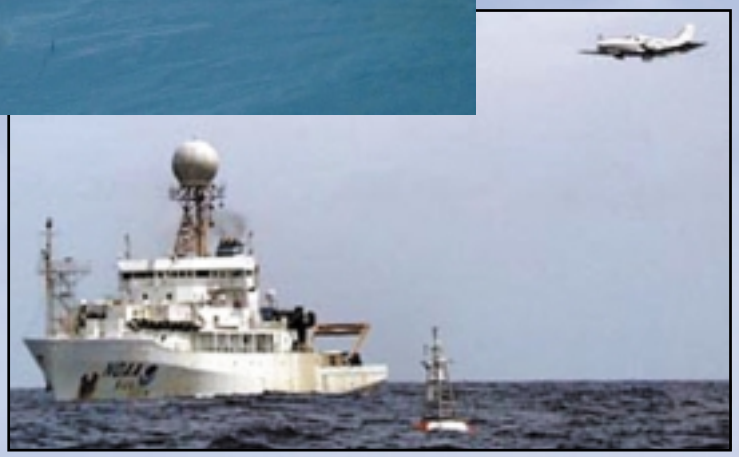
In 2000, the ARM Program's Water Vapor Working Group conducted a collaborative effort with NASA at the Southern Great Plains site, which focused on the accurate measurement of upper tropospheric water vapor. In addition to ARM instruments, guest instruments from Germany's Max Planck Institute, NASA Goddard Space Center, the University of Wisconsin and NASA Langley Research Center gathered data during the campaign. This effort was the fourth in a series of water vapor measurement experiments at the Southern Great Plains.

The extensive field data gained from these types of collaborations are being analyzed and applied to improve computer models of the earth's climate, and thus, enhancing the capability of researchers to predict global change.

The Future

The ARM Program will continue to operate its current ground-based sites and use state-of-the-art instruments to provide continuous measurements of the atmosphere. In addition, a new mobile ARM facility is under development that will be used to collect data in other locations of climatic significance. The ARM Program will also expand its science activities in the modeling of detailed phenomena such as clouds and global climate. The ARM sites have become a standard for new sites that are under development by other nations across the globe; the result will be an international network of research sites. New links will be forged with national and international programs in hydrology, human health, and satellite remote sensing. The activities that were initiated by ARM and are now spreading across international boundaries will have a lasting impact on our ability to simulate climate, and thus help us mitigate and adapt to expected climate changes in the decades ahead.

SHEBA Camp



Nauru99 Campaign

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