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2015 **ANNUAL REPORT**

ARM
CLIMATE RESEARCH FACILITY

U.S. DEPARTMENT OF
ENERGY


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E-5

From the ARM Program Manager

Developing the Next-Generation ARM Facility

For more than 20 years, the Atmospheric Radiation Measurement (ARM) Climate Research Facility has blazed the trail in providing the world's atmospheric scientists with continuous observations of cloud and aerosol properties and their impacts on Earth's energy balance. The result is an unprecedented data set that has proved invaluable for understanding the atmosphere and improving the predictive capabilities of earth system models.

Over the past year, plans have been put in place to create a powerful new capability for furthering ARM's mission and achieving the vision outlined in the Decadal Vision, the strategy for the ARM Facility for the next 5 to 10 years. The result is a significant reconfiguration for the ARM Facility that will provide more complete data sets to support process studies and model development. The combined observational and modeling elements will enable a new level of scientific inquiry.

To achieve the next-generation ARM Facility, plans underway include the following:

- Establishing observation "megasites" at the Southern Great Plains and North Slope of Alaska sites
- Enhancing ARM measurement excellence to support U.S. Department of Energy climate science research
- Producing routine high-resolution model simulations over domains coincident with ARM sites
- Developing data products and software tools that facilitate analysis and enable the evaluation of models using ARM data
- Strengthening interactions with the broader atmospheric science and modeling communities.

Changes being implemented at the megasites will provide additional spatial sampling of atmospheric and surface information to support a new ARM capability—the routine operation of high-resolution process models at ARM sites. The result will be even more comprehensive scientific data and the processes and tools for scientists to more easily use ARM data for climate model development.

During 2015, ARM initiated a two-year pilot study to develop the processes to use the enhanced data from the ARM megasites to constrain a large-eddy simulation model, a high-resolution mathematical model used to simulate atmospheric motions and cloud processes.

While this type of observation-model integration is not new at ARM sites, the creation of the two megasites will enhance the observations available for model integration and evaluation. The application of this observation-model synergy on a routine basis will better exploit the long-term nature of ARM observations to improve understanding of atmospheric processes.

The ARM Facility will first set up this coupled observation-modeling framework at the Southern Great Plains site, with a focus on shallow cumulus clouds. The pilot study project is in the process of developing the model configuration and workflow, as well as establishing criteria for related data products to force and evaluate the simulations. When complete, the project will provide a library of routine high-resolution model simulations combined with the detailed ARM observations that will provide powerful new research capabilities.

Many of the articles in this annual report share the progress that has been made in developing the next-generation ARM thus far. This is a multiyear effort, and we look forward to reporting more exciting changes in the years to come.

Sally McFarlane
U.S. Department of Energy
ARM Program Manager

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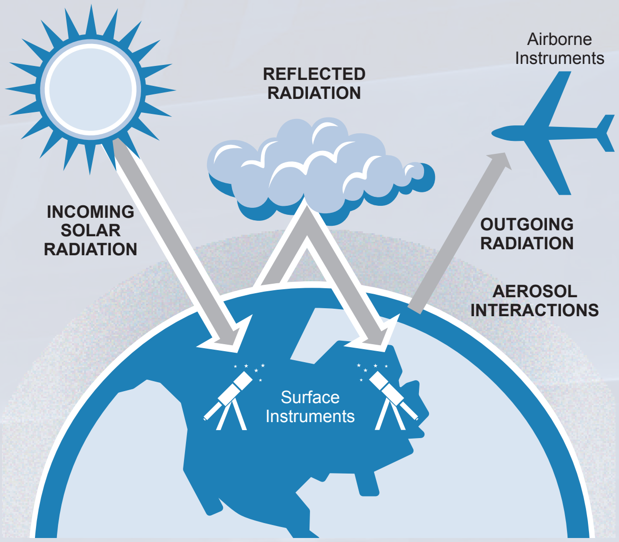
Facility **OVERVIEW**

The Importance of Clouds and Radiation to Climate Change

The Earth's surface temperature is determined in large part 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 are the primary tool for quantifying future climate change; however, significant uncertainties remain in the global climate models' 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 solar and infrared radiation in the atmosphere.



Researchers use data collected from ARM 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.

Designated a national user facility in 2003, the ARM Climate Research Facility provides the climate research community with strategically located in situ and remote-sensing observatories designed to improve the understanding and representation in climate and earth system models of clouds and aerosols as well as their interactions and coupling with the Earth's surface. The scale and quality of the ARM Facility's approach to climate research has resulted in ARM setting the standard for ground-based climate research observations.

Researchers use data collected from ARM ground-based and airborne instruments to study processes that affect aerosol and cloud formation, their properties, and their lifetime in the atmosphere and how those conditions affect incoming and outgoing radiative energy.

The ARM Facility is undergoing a reconfiguration that will provide more complete data sets to support process studies and model development. ARM's Southern Great Plains site near Lamont, Oklahoma, and the North Slope of Alaska site in Barrow, combined with the mobile facility at Oliktok Point, are undergoing enhancements to create "megasites." An important component of the next-generation ARM Facility will be routine model simulations and associated joint analysis with observations. Processes are being developed to use the enhanced data from the megasites to constrain a large-eddy simulation (LES) model, a high-resolution mathematical model used to simulate atmospheric motions and cloud processes. These model simulations will combine with the detailed ARM observations to provide powerful new research capabilities.

This report provides an overview of the ARM Facility and a sample of achievements for fiscal year 2015 (FY2015).

Strong collaborations between nine DOE national laboratories enable the ARM Facility to successfully operate in remote locations around the world. This unique partnership supports the DOE mission to provide for the energy security of the nation. Without the support of the following laboratories, the ARM Facility would not be the state-of-the-art facility that it is today.

Sandia National Laboratories
Pacific Northwest NATIONAL LABORATORY
OAK RIDGE National Laboratory
NREL
BERKELEY LAB
Los Alamos NATIONAL LABORATORY
Argonne NATIONAL LABORATORY
BROOKHAVEN NATIONAL LABORATORY

ARM Climate Research Facility

Through the ARM Facility, DOE funded the development of several long-term, 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 is located at three locales selected for their broad range of climate conditions and importance for studying climate processes:

- **Southern Great Plains** (SGP)—includes a heavily instrumented Central Facility near Lamont, Oklahoma, and smaller satellite facilities covering a 150-kilometer-by-150-kilometer area in Oklahoma and Kansas.
- **North Slope of Alaska** (NSA)—includes a site at Barrow near the edge of the Arctic Ocean.
- **Eastern North Atlantic** (ENA)—the newest ARM site, located on Graciosa Island in the Azores.

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 3-dimensional cloud and precipitation radars, Raman lidar, infrared interferometers, aerosol observing systems, and several frequencies of microwave radiometers, among others.

Measurements obtained at the fixed sites are supplemented with data obtained from intensive field campaigns using an ARM Mobile Facility (AMF) or ARM Aerial Facility (AAF). Once collected, the data from these facilities are carefully reviewed for quality and are stored in the ARM Data Archive for use by the atmospheric science community.

Using these data, scientists are studying the effects and interactions of sunlight, radiant energy, clouds, and aerosols to understand their impact on temperatures, weather, and climate. As part of this effort, ARM personnel apply scientific methods developed in the research community to create enhanced value-added data products. All ARM data products are made available for the science community via the ARM Data Archive (***http://www.archive.arm.gov***) to aid in further research.

In FY2015, the Facility began embarking on a reconfiguration, including the creation of two "megasites" at the Southern Great Plains and North Slope of Alaska sites. In addition, the Eastern North Atlantic and third ARM Mobile Facility at Oliktok, Alaska, expanded measurement capabilities by adding radars and lidars to the baseline operations. Oliktok also provides unique opportunities for operating unmanned aerial systems and tethered balloon systems for scientific research.

An important component of the next-generation ARM Facility will be routine model simulations and associated joint analysis with observations. Processes are being developed to use the enhanced data from the megasites to constrain a LES model, a high-resolution mathematical model used to simulate atmospheric motions and cloud processes.

The Facility will first set up this coupled observation-modeling framework at the Southern Great Plains site and is in the process of a two-year pilot study to develop the model configuration and workflow, as well as develop related data products to force and evaluate the simulations. The resulting library of routine high-resolution model simulations, combined with the detailed ARM observations, will provide powerful new research capabilities.

Hellos and Goodbyes: IMB Organizational Changes

After many years of service, Raymond McCord and Doug Sisterson are transitioning from the ARM Infrastructure Management Board (IMB). While on the board, McCord and Sisterson helped establish the ARM Program into a national scientific user facility now known as the ARM Climate Research Facility. Under their tenure on the IMB, the ARM Facility grew from three fixed locations to include three mobile facilities, over 90 instrument types, and a strong aerial component that now supports over 70 field campaigns a year with a fully integrated data archive.

Doug Sisterson, Argonne National Laboratory (left) and Raymond McCord, Oak Ridge National Laboratory (right)

Two long-time ARM community members will join the IMB on October 1. Giri Palanisamy, Oak Ridge National Laboratory, will represent Oak Ridge and the ARM Data Services and Operations Group. Stephen Springston, Brookhaven National Laboratory, will represent the aerosol measurements perspective and Brookhaven.

New User Executive Committee Formed

To better link to the ARM user community, a new ARM User Executive Committee was established as an independent body charged with providing objective, timely feedback to the leadership of the ARM Facility with respect to the user experience. Reporting directly to the ARM Technical Director in his capacity as chair of the ARM Infrastructure Management Board, the Committee serves as the official voice of the user community.

Dave Turner, National Oceanic and Atmospheric Administration/National Severe Storms Laboratory, was elected as chair, and Larry Berg, Pacific Northwest National Laboratory, was elected as co-chair. These are two-year terms with co-chair succeeding to chair at the conclusion of the first term.

Members of the UEC, listed below, were selected to represent a set of science thematic areas.

Larry Berg
Pacific Northwest National Laboratory

Andrew Gettelman
National Center for Atmospheric Research

Gannet Hallar
Desert Research Institute

Pavlos Kollias
McGill University

Ernie Lewis
Brookhaven National Laboratory

Chuck Long
NOAA/Earth System Research Laboratory

Matthew Shupe
University of Colorado at Boulder/ Cooperative Institute for Research in Environmental Sciences

Dave Turner
NOAA/National Severe Storms Laboratory

Hailong Wang
Pacific Northwest National Laboratory

Robert Wood
University of Washington

New Advisory Group Focuses Efforts on Unmanned Aerial Systems

Through activities at the ARM Facility, the Climate and Environmental Sciences Division of the Office of Biological and Environmental Research within DOE is at the forefront of utilizing unmanned aerial systems (UAS) as a tool to address science questions relating to Arctic research. Presently, the ARM site at Oliktok Point on the North Slope of Alaska contains restricted airspace in the Arctic, which makes it ideal for conducting UAS operations on a routine basis.

The UAS Advisory Group was formed in February and consists of five recognized experts in UAS technology, management, and science applications. This team provides scientific and technical advice to Sandia National Laboratories and Pacific Northwest National Laboratory leadership as they plan tethered balloon and UAS operations at the Oliktok Point site. The group will also provide input on potential UAS deployments at other locations of interest to the ARM Facility, as needed.

Current UAS Advisory Group members are:

Timothy Bates
NOAA/Pacific Marine Environmental Laboratory

John Cassano
University of Colorado at Boulder/ Cooperative Institute for Research in Environmental Sciences

Matthew Fladeland
NASA Ames Research Center

Jerry Harrington
Pennsylvania State University

Martin Stuefer
University of Alaska Fairbanks

New Aerosol Measurement Science Group Created

Established in FY2015, a new Aerosol Measurement Science Group provides enhanced coordination of ARM Facility observations of aerosols and atmospheric trace gases with the needs of its users. The group's main objective is to ensure advanced, well-characterized measurements and data products for improving climate science and models. This group facilitates communication between the ARM Facility and the science user community to optimize the collection and processing of aerosol observations at ARM sites. Reporting directly to the ARM Technical Director, the committee interacts with members of the ASR Aerosol Life Cycle Working Group to ensure that the range of user needs are being met.

Aerosol Measurement Science Group members are:

Allison McComiskey, Co-chair
NOAA/Cooperative Institute for Research in Environmental Sciences

Doug Sisterson, Co-chair
Argonne National Laboratory

Allison Aiken
Los Alamos National Laboratory

Jerome Fast
Pacific Northwest National Laboratory

Connor Flynn
Pacific Northwest National Laboratory

Steve Ghan
Pacific Northwest National Laboratory

Fred Helsel
Sandia National Laboratories

Chongai Kuang
Brookhaven National Laboratory

Laura Riihimaki
Pacific Northwest National Laboratory

Art Sedlacek
Brookhaven National Laboratory

Stephen Springston
Brookhaven National Laboratory

Cooperation and Oversight Enable Success

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

The ARM Facility is directed by DOE Headquarters. An Infrastructure Management Board coordinates the scientific, operational, data, financial, and administrative functions of the ARM Facility. An 11-member Facility Science Board, selected by the ARM Program Manager, serves as an independent review body to ensure appropriate scientific use of the ARM Facility. Scientific guidance for the Facility is provided by the science team of the Atmospheric System Research Program, a DOE-funded observation-based climate research program, as well as by scientists at other government, academic, and private organizations. A newly established ARM User Executive Committee provides feedback on the Facility's activities and serves as the official voice of the user community in its interactions with ARM management.

New ASR Program Manager Selected

Dr. Shaima Nasiri was selected as the Atmospheric System Research (ASR) Program Manager in August 2015, sharing programmatic responsibilities with Ashley Williamson, after a one-year assignment on an Intergovernmental Personnel Act agreement with Texas A&M University. As an ASR program manager, Nasiri focuses on operational aspects of the program, such as research needs; evaluation of contractors, DOE laboratories and grantee research proposals; performance via scientific and technical judgment; and merit reviews, site visits/reviews, and panel reviews. In this role, Nasiri also provides DOE leadership to the ARM Facility through the Science and Infrastructure Steering Committee.

Shaima Nasiri, ASR Program Manager, U.S. Department of Energy

ASR Awards Two Teams for Science at ARM Sites

Two teams were awarded DOE Office of Science grants to play leadership roles within the ASR community in developing emerging research strategies for new ARM research sites in Alaska and the Azores, off the coast of Portugal. Gijs de Boer, a scientist with the Cooperative Institute for Research in Environmental Sciences (CIRES), at the University of Colorado, Boulder, leads the Oliktok Point site science team, and Rob Wood, University of Washington researcher, leads the Eastern North Atlantic site science team.

Gijs de Boer, Oliktok Point science team leader (left), and Robert Wood, Eastern North Atlantic science team leader (right)

Science Board Ensures ARM Supports Quality Research

Hosting more than 70 campaigns a year around the world, the ARM Facility continues to be an important resource to the scientific community. The ARM Science Board, an independent review body with 11 highly-respected scientists from the external climate research community, annually reviews up to 20 of the most complex proposals for use of ARM mobile and aerial facilities.

In 2015, the board was joined by six new members:

Larry Carey
University of Alabama

Christine Chiu
University of Reading

Bart Geerts
University of Wyoming

Gannet Hallar
Desert Research Institute

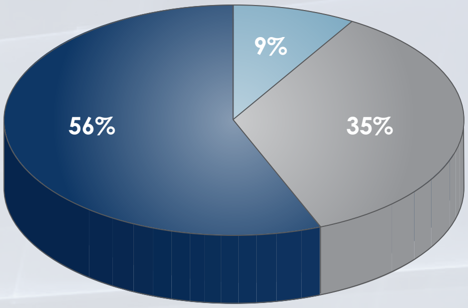
Vernon Morris
Howard University

Lynn Russell
Scripps Institution of Oceanography

Fiscal Year 2015 Budget Summary and Facility Statistics

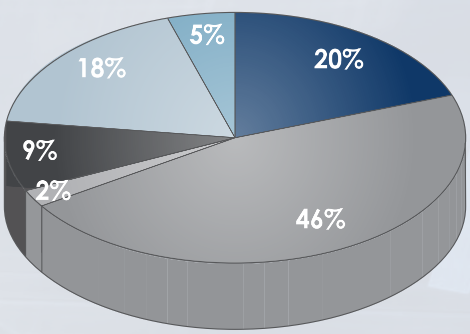
FY2015 infrastructure **$66,739K**

User Statistics for the Period of October 1, 2014–September 30, 2015



Facility Access Type	Unique Scientific Users
On Site	104
Remote	423
Data	673

Users by Affiliation for the Period of October 1, 2014–September 30, 2015



Description	Users
DOE Laboratories	235
University	557
Industrial	27
Other Federal Agency	108
Foreign	219
Other	54

Operational Statistics for the Fixed ARM Sites

FY2015	Q1	Q2	Q3	Q4
Goals (hours)	1987.20	1944.00	1965.60	1987.20
Actual (hours)	2075.52	2102.40	2103.92	2068.16

Site average is calculated for fixed sites only and reported on a quarterly basis.

Key **ACCOMPLISHMENTS**

Featured Field Campaigns

In addition to providing continuous data collections from its fixed sites, the ARM Facility sponsors field campaigns for scientists to obtain specific data sets or to test and validate instruments. The following pages highlight key campaigns conducted in FY2015. A summary of all ARM Facility campaigns that began in FY2015 is available later in the report.

ARM Cloud Aerosol Precipitation Experiment (ACAPEX) Covers Land, Sea, and Sky

The stormy winter months along the western United States build a snowpack that supplies 70 percent to 90 percent of the region's water supply. Being able to accurately model the variability and extremes of this precipitation is critical for predicting floods and droughts. From January 12 through March 8, 2015, the ACAPEX campaign studied two elements that are major contributors to this variability—atmospheric rivers and aerosols. Atmospheric rivers are long, concentrated bands of water vapor originating from the tropics that often result in extreme precipitation when they make landfall. Aerosols, tiny airborne particles, affect the rainfall and ice of more shallow clouds that carry the remainder of the region's precipitation.

ACAPEX was part of CalWater 2015, an interagency, interdisciplinary field campaign. The goal of the joint effort was to monitor the evolution and structure of atmospheric rivers near their development point, the long-range transport of aerosols in the eastern North Pacific, potential interactions with atmospheric rivers, and how long-range and local aerosols influence clouds and precipitation on the West Coast.

The research team from Scripps Institution of Oceanography, Pacific Northwest National Laboratory, National Oceanic and Atmospheric Administration (NOAA), and National Aeronautics and Space Administration (NASA) used several platforms at once to sample four atmospheric rivers that made landfall in northern California. Scientists deployed the second ARM Mobile Facility onboard a NOAA research ship, while the ARM Aerial Facility worked with two NOAA airborne research facilities and one from NASA to collect data from various altitudes directly overhead. The ARM Aerial Facility also collected measurements of aerosols and clouds under non-atmospheric river conditions to understand the broader aerosol-cloud-interaction processes.

Though the data continue to be analyzed, one conclusion is already clear. Many aerosol types come together during these atmospheric rivers, mixing like ingredients in home-made soup. Each type of particle had a different effect on clouds. Researchers are looking for new insights into how precipitation processes associated with atmospheric rivers can also be influenced by these particles.

"We collected these data to improve computer models of rain that represent many complex processes and their interactions with the environment," said Pacific Northwest National Laboratory's Ruby Leung, atmospheric scientist and lead investigator for ACAPEX. "We want to capture atmospheric rivers better in our climate models to project changes in extreme events in the future."

CalWater 2015 was featured in the January 20 edition of *Nature* at the start of ACAPEX, which was the ARM Facility contribution to CalWater.

On land, sea, and sky, ACAPEX and CalWater 2015 studied the life cycle of atmospheric rivers and the clouds and precipitation they influence.

Fifth Airborne Carbon Measurements (ARM-ACME V) Campaign Prospects for Data Gold in Alaska

When it comes to data to support climate models, nothing is more golden than long-term observations from multiple locations. Building off its years of measurements over the Southern Great Plains site, the ARM-ACME V campaign headed to Alaska to look at atmospheric composition and carbon cycling. Understanding the Arctic is critically important to improving climate models because atmospheric temperatures are warming there faster than predicted. Permafrost is thawing at an accelerated pace as a result of rising air temperatures, and this degradation releases carbon dioxide and methane—two greenhouse gases that affect the amount of heat that can reach or leave the Earth.

Based out of Deadhorse, Alaska, scientists deployed the ARM Aerial Facility over the North Slope of Alaska from June 1 through September 15, 2015. The aircraft instrumentation collected a unique set of measurements of trace gas concentrations, aerosols, and cloud properties with the ultimate goals of discovering why current climate models underestimate how rapidly the Arctic is warming. By characterizing atmospheric gas mixing ratios (i.e., volume of gas per volume of air), scientists hope to improve the estimates of gases like carbon dioxide and methane being emitted from natural sources such as permafrost degradation and anthropogenic sources such as oil and gas exploitation.

"Because we flew so often over a longer period of time, about every four days over three months, we were able to see changes at synoptic and seasonal scales," said Sébastien Biraud, research scientist at Lawrence Berkeley National Laboratory and principal investigator for the experiment. "As a surprise, we still observed enhanced methane concentrations, even though the snow covering the ground acted like a lid on a bottle."

To improve understanding of the carbon cycle in the Arctic, ARM-ACME V will share collected observations with other research groups including NASA's Carbon in Arctic Reservoirs Vulnerability Experiment, NOAA's Global Greenhouse Gas Reference Network, the National Science Foundation's Long Term Ecological Research site, and San Diego University. The ARM-ACME V research team will also process the collected data and compare measurements to model results to pinpoint inconsistencies.

"Because we flew so often over a longer period of time, about every four days over three months, we were able to see changes at synoptic and seasonal scales."

—Sébastien Biraud, scientist at Lawrence Berkeley National Laboratory

The ARM-ACME V campaign deployed the Gulfstream-1 over the North Slope of Alaska to help scientists understand why temperatures are warming faster in the Arctic than predicted.

The third ARM Mobile Facility at Oliktok Point on Alaska's North Slope played a key role in helping scientists collect data on greenhouse gases in the Arctic.

Up to the Challenge: Evaluation of Routine Atmospheric Sounding Measurements Using Unmanned Systems (ERASMUS)

Atmospheric processes of remote places like the Arctic, Antarctica, and African deserts could yield a wealth of information to improve climate models, if scientists had a way to take routine measurements in the challenging environments. Along Alaska's Beaufort Sea, the ARM Facility hosted the ERASMUS campaign to demonstrate how small, low-cost, unmanned aerial systems can be used to study and measure clouds and aerosols. During two two-week deployments (summer 2015 and spring 2016), these systems will collect hard-to-gather data complementary to those concurrently collected at the third ARM Mobile Facility at Oliktok Point. Besides testing the performance of the unmanned aerial systems, ERASMUS will look at how temperature and humidity evolve during transitions between clear and cloudy skies, variations in aerosol properties that far north, the role of moisture in arctic clouds, and how their structure evolves over time.

The ERASMUS team will utilize two very different systems, both capable of operating autonomously while scientists and operators remain on land. The DataHawk is a very small and lightweight aerial system outfitted with instruments to measure temperature, humidity, and pressure and to estimate wind speed. It weighs in at just over 2 pounds and features an almost 40-inch wingspan. It is easy to transport and set up and does not need special preparation to operate—all key characteristics when flying in such remote locations. Scientists used this aircraft in the August 2015 ERASMUS observational period to measure the evolution of temperature, humidity, and winds over the lowest 2 kilometers of the atmosphere.

The second aircraft, the Pilatus, features unique observing capabilities for measuring atmospheric aerosol particles and energy transfer. With a 10.5-foot wingspan and a nearly 50-pound weight, the substantially larger Pilatus is scheduled to operate during the early spring 2016 launch.

ERASMUS should yield data to improve understanding of the lower arctic atmosphere, as well as information on environmental constraints and operational limitations for planning future measurement campaigns using unmanned aerial systems.

Scientists from the University of Colorado at Boulder are collaborating with others from NOAA, NASA, and DOE national laboratories on this DOE Office of Science-funded field campaign.

"These measurements should provide some unique insights into the lower arctic atmosphere that we did not previously have available to us as atmospheric scientists."

—Gijs de Boer, scientist at University of Colorado at Boulder

The ERASMUS campaign is evaluating the DataHawk, a very small and lightweight unmanned aerial system, for use in taking atmospheric measurements in harsh and remote environments.

Unmanned aerial systems take measurements in the lower atmosphere while scientists stay on the ground.

Plains Elevated Convection at Night (PECAN) Experiment Looks at Clouds That Go Bump in the Night

Most climate models grossly underestimate the amount of precipitation in the central United States. These models also show the precipitation falling primarily in the day when in reality precipitation in this region typically falls at night, often in thunderstorms. A better understanding of the various atmospheric processes that cause this weather phenomenon would significantly improve climate and weather models.

From June 1 through July 15, 2015, the ARM Facility provided an array of instrumentation and its largest research site in the Southern Great Plains in support of the multi-agency PECAN experiment to collect detailed measurements of what triggers clouds and precipitation when most people are asleep. This set of resources has never been put in the field before and is only possible because of interagency cooperation. The main focus of the experiment was to understand the initiation, growth, evolution—and ultimately the predictability—of nighttime storms resulting from convection that isn't related to warm air rising from the ground as it is in the daytime.

The PECAN experiment covered a large section of the Great Plains, including most of western and central Kansas, northern Oklahoma, and southern Nebraska. Scientists used six fixed sites throughout the area and augmented them with four mobile profiling systems and a fleet of mobile radars that were moved nightly to locations where

Researchers during PECAN had to be ready each night to capture data on storms over the Great Plains. Image courtesy of Richard Clark.

Scientists positioned a fleet of 16 portable weather stations to measure storm activity. Image courtesy of National Weather Service Dodge City.

“We are just starting to get into the analysis, but I think we collected a fantastic data set.”

—Dave Turner, scientist at the NOAA National Severe Storms Laboratory

storms were forecast. Three aircraft took measurements aloft in and around storms. These combined instruments provided a comprehensive data set on the atmospheric conditions before and during nighttime storms. The data set will become public domain and serve as a leading data source for prediction studies by weather and climate scientists.

“We are just starting to get into the analysis, but I think we collected a fantastic data set,” said Dave Turner, scientist at the NOAA National Severe Storms Laboratory and lead investigator for the ARM-funded support for PECAN. “These data should enable us to address a good number of hypotheses. Ultimately, the goal is to improve our understanding of how these storms evolve so the weather service can issue a better forecast that will protect people in extreme events.”

The organizations collaborating on the PECAN experiment included 27 universities and 11 research laboratories supported by the National Science Foundation, NOAA, NASA, and DOE.

High-res Sonde Data May Help Improve Diurnal Cycle Forecasts

In summer 2015, scientists generated a “robust” data set at the ARM Facility’s Southern Great Plains site by lofting 19 weather balloons on each of 12 selected days. Their goal was to enhance the accuracy of weather and climate models used to predict Oklahoma’s diurnal cycle of rainfall and cloud development. Called Enhanced Soundings for Local Coupling Studies, the field campaign ran concurrently with the Plains Elevated Convection at Night (PECAN) campaign. Hourly radiosondes during the day were checked every three hours by sending “trailer” balloons 10 minutes later, verifying that representative atmospheric profiles were being captured. One nightly balloon coincided with NASA’s afternoon Earth-observing satellite that senses atmospheric temperature and humidity profiles.

The data set is expected to help researchers investigate the hypothesis that initial development of the nocturnal boundary layer in the Southern Great Plains depends strongly on the characteristics of the daytime boundary layer.

Weather balloons, or sondes, were launched hourly from 6:30 a.m. to 6:30 p.m. for 12 selected days between June 15 and August 31, 2015.

Completing and Analyzing GoAmazon 2014/15 Data

U.S. and Brazilian climate scientists and others completed both GoAmazon 2014/15 intensive operational periods and related campaigns in 2014. In 2015, they started analyzing preliminary data, while instruments at the ARM site continued recording near Manaus through year-end. The result will be an unprecedented aerial and land-based data set helping researchers study how unspoiled aerosol and cloud life cycles are influenced by pollution from Manaus during Amazon Basin “dry” and “rainy” seasons.

More than 100 instruments collected data at the DOE-funded ARM Facility at Manacapuru. Scientists plan to use the data to enhance the accuracy of existing climate models to characterize aerosols and clouds more accurately.

ARM’s Aerial Facility Gulfstream-1 aircraft added valuable data to GoAmazon by flying through the Manaus pollution plume.

Campaign Results

The vast majority of the research findings are realized several years after data are collected during a field campaign. In FY2015, these two past ARM field campaigns had a significant number of publications highlighting their scientific impact.

MAGIC Continues to Inspire Insights

Because they cover so much of the Earth and reflect large amounts of sunlight, marine clouds play an especially critical role in climate and climate research. However, most non-satellite investigations of such clouds have been relatively short-term (~one month) in fairly small regions. And satellites can only peer so deep into cloud cover and can miss key processes near the surface. The Marine ARM GPCI* Investigation of Clouds (MAGIC) field campaign placed the second ARM Mobile Facility onboard the Horizon *Spirit* cargo ship, traversing the route between Los Angeles and Honolulu in 2012 and 2013.

During 20 round trips and nearly 200 days at sea, the second ARM Mobile Facility obtained continuous measurements of clouds and precipitation, aerosols, and atmospheric radiation; surface meteorological variables; and atmospheric profiles from radiosondes launched by weather balloons every six hours. By collecting this massive data set, MAGIC sought to improve how climate models represent the transition between stratocumulus and cumulus clouds through a better understanding of the small-scale physical processes, such as turbulence, convection, and radiation, associated with this transition. Now, two years after the close of the campaign, the data continue to inspire researchers to reach new heights.

"MAGIC was the first true extended at-sea deployment of an ARM Mobile Facility," said Ernie Lewis, atmospheric scientist at Brookhaven National Laboratory, who led the campaign. "For the first time, we could start to see what was happening in the clouds without the influence of any land in the vicinity."

Heads in the Clouds

Researchers from Brookhaven National Laboratory and Canada's McGill University used the MAGIC data to look more closely at clouds and precipitation along the transect. They found that clouds tended to form most often in the lowest thousand meters above the ocean and during the warm season versus the cold. When these clouds produced precipitation, it frequently evaporated before reaching the ocean surface. In addition, the clouds dissipated quickly, depending on conditions. These aspects of cloud behavior are counter to what is currently found in global climate models, indicating areas for improvement.

Researchers at NASA's Jet Propulsion Laboratory reached a similar conclusion. They used the MAGIC data combined with satellite information to delve into the boundary layer and tease out how stratocumulus clouds, which tend to cool the Earth, transition to cumulus, which tend to warm it. Changes as small as a 4 percent difference in cloud type could result in a heat increase as large as doubling atmospheric carbon dioxide concentrations. They discovered that the transition between cloud types was more gradual than expected and involved an increase in heat, rain, dry wind, and the height of the boundary layer, with a decrease in warm dry air. In a complementary study, the researchers used data from the radiosondes to validate temperature and moisture information gathered by satellite. Their results show errors in the interpretation of

MAGIC Featured in EOS

The MAGIC field campaign was featured in the July 1 edition of *EOS Earth & Space Science News*. The article highlighted the data on ocean clouds collected through MAGIC, which put the second ARM Mobile Facility (AMF2) on a cargo container ship, Horizon Lines' Spirit, traveling nearly 20 round trips between Los Angeles, California, and Honolulu, Hawaii, gathering information on the transition zone between two different cloud types. It can be read at: **https://eos.org/project-updates/dispelling-clouds-of-uncertainty**.

Researchers are using data collected by the AMF2 during the MAGIC field campaign to document and understand the intricate physical processes associated with cloud transition, drizzle, and aerosol-cloud interactions.

satellite data, which is routinely used in climate modeling, and pinpoint ways to resolve them.

Researchers at the University of Maryland and Hebrew University in Jerusalem also looked at clouds when they undertook the daunting task of disentangling the effects of aerosols and meteorology on cloud properties, some of which could not be measured until recently. Data from MAGIC allowed scientists to simplify, improve, and expand a new method to calculate cloud-based updrafts from satellite measurements for the first time. This new method will allow global climate models to more accurately simulate cloud properties, even when ground-based measurements are lacking.

The Details are in the Drizzle

Scientists have struggled to understand cloud processes over a maritime environment because these clouds are often drizzling, and the radar signal used to measure cloud processes is reflected from drizzle droplets, making it difficult to separate the cloud and drizzle processes. An international team of researchers from the U.K. University of Reading, Finnish Meteorological Institute, NOAA, University of Wisconsin, and Argonne National Laboratory used MAGIC data to test a new method that will provide information on clouds and drizzle simultaneously, even when precipitation does not reach the surface. The approach can also be used to determine how precipitation starts, how aerosol affects drizzle, and how precipitation influences cloud formation and variability.

Researchers from Science Systems and Applications, Inc., teamed with NASA's Langley Research Center to use MAGIC data to learn how circulation patterns over the northeast Pacific affect cloud condensation nuclei. These nuclei are the tiny aerosol particles around which clouds and precipitation, such as drizzle, form. The research team found that the number of nuclei decreased as the wind intensified. The work can be used to explore more deeply the sources, fates, and composition of aerosols and their impacts on clouds.

"Climate models tend to give us a wide range of results, and we don't really know the problems that are causing this variation," said Lewis. "The research fueled by MAGIC data is helping us diagnose model errors so we can fix them, and I think we'll be reaping the rewards for years to come."

*Note: GPCI = GCSS Pacific Cross-section Intercomparison, a working group of GCSS; GCSS = GEWEX Cloud Systems Study; GEWEX = Global Energy and Water Cycle Experiment, a core project of the World Climate Research Programme.

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"For the first time, we could start to see what was happening in the clouds without the influence of any land in the vicinity."

—Ernie Lewis, scientist at Brookhaven National Laboratory

MC3E – A Legacy of Learning

Large storm clouds influence the Earth's climate system by redistributing heat and moisture in the atmosphere and delivering rain to the surface, yet current climate models struggle to accurately reproduce storm systems. To help resolve this issue, DOE and NASA collaborated on the Midlatitude Continental Convective Clouds Experiment (MC3E) at ARM's Southern Great Plains site in central Oklahoma in April and May 2011. The collaboration leveraged the most comprehensive array of ground-based instruments in the central United States along with an extensive radiosonde array, remote sensing and aircraft measurements, and ground validation remote sensors. The effort provided one of the most complete data sets for storms and their environment to date. This data set is providing a legacy for those seeking to learn the secrets of storms.

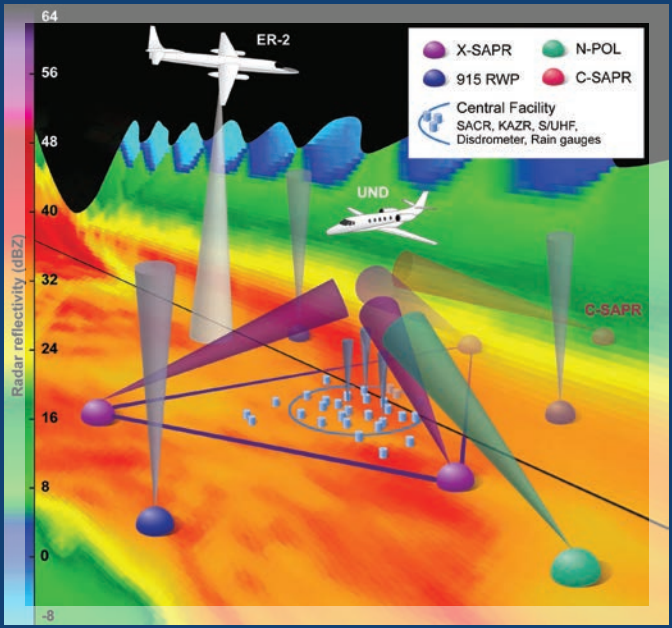
Mysteries in the Clouds

Global climate models need to account for processes that occur over scales from millimeters to thousands of kilometers. Models that simulate interactions between individual cloud and precipitation particles feed models that detail clouds or large eddies of air over broader regions. These in turn can inform regional and global-scale models. Researchers at the University of Kansas, McGill University, and Brookhaven National Laboratory coupled large-eddy simulations with cloud measurements made during MC3E. They found that the fine details documented by the scanning radar can provide useful data for models on how the structure of clouds, precipitation, and associated processes evolve over time. In another study, researchers at Lawrence Livermore and Brookhaven National Laboratories and Stony Brook University compared two typical convective systems for the region and identified similarities and variations in the conditions in which the storms formed and persisted. The results of these two efforts advance our understanding of precipitation and other processes that influence storm life cycle.

To better understand the properties of storms, researchers at the University of North Dakota examined the complex physical properties associated with ice particles in the upper portions of storms. The work indicated that the aircraft measurements made during MC3E can serve as an important data set to validate ground-based and satellite measurements as well as model simulations.

Now Playing in 3-dimensional

Until MC3E, most ground-based cloud radars were limited to profiling the column of air directly above them. Efforts under MC3E used ARM's scanning cloud radar (SACR) to provide information on the 3-dimensional structure of clouds and precipitation. Researchers at McGill University teamed with scientists at Brookhaven National Laboratory



The MC3E campaign employed radars, a network of radiosondes, two instrumented aircraft, and other sensors to measure the properties of storms over the central United States.

“MC3E provided us with a unique opportunity. We had a tremendous set of assets in one place. The wealth of data they produced continues to provide dividends.”

—Michael Jensen, scientist from Brookhaven National Laboratory

to document the life cycle of shallow cumulus clouds, from formation through precipitation and dissipation. Their work can be used to help relate the evolution of clouds to aerosol properties and larger-scale meteorological conditions.

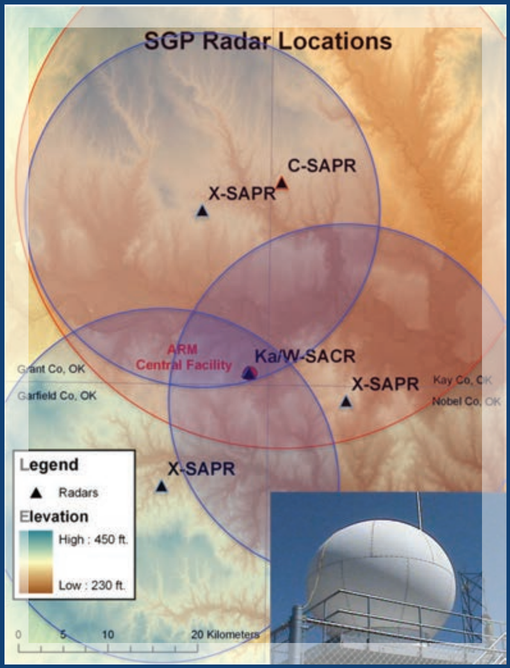
A major component of the MC3E campaign was a six-site radiosonde network designed to set the boundaries of atmospheric pressure, temperature, humidity, and winds in models. Over the course of the 46-day campaign, researchers launched a total of 1,362 radiosondes. To ensure other researchers could make the best use of the extensive data set, a team from Brookhaven, Argonne, and Lawrence Livermore National Laboratories; and Colorado State University detailed the instrumentation used and data processing approach including quality checks and bias corrections.

“MC3E provided us with a unique opportunity,” said Michael Jensen, atmospheric scientist from Brookhaven National Laboratory, who led the campaign. “We had a tremendous set of assets in one place. The wealth of data they produced continues to provide dividends.”

Raindrops on Radar

Researchers at the National Center for Atmospheric Research, North Carolina State University, and NOAA looked at new ARM radar data from MC3E to study how raindrops form in a storm cloud. As raindrops fall, their size and shape evolve depending on a host of processes such as how they collide. Their growth behavior affects not only the rainfall rate at the surface but also the dynamics of a storm. The work suggests that radar data may be useful for distinguishing among various raindrop growth and decay processes.

Another team from Brookhaven and Argonne National Laboratories, the University of Oklahoma, and NASA’s Goddard Space Flight Center compared data from ARM’s scanning precipitation radars (SAPRs) to data generated by the National Weather Service’s operational Doppler weather surveillance radar (WSR-88D). The WSR-88D radar is often used to estimate rainfall for operational weather forecasting. The results show that the SAPR, which operates in the C band (the frequency used by



Researchers used data from the ARM scanning precipitation radars such as the X-SAPR (inset) during MC3E to understand a host of properties associated with storms.

many weather radars) performs well when quantifying rainfall compared to the WSR-88D. This comparison highlights the capabilities of the ARM radars, which may be deployed in remote regions where there are few other measurements.

Researchers at the Scripps Institution of Oceanography, on the other hand, looked at what triggers a global climate model to initiate a storm. The performance of these so-called convection triggers can affect how realistically climate models simulate the time and location where storms will occur. Using data from MC3E, the researchers evaluated model performance and identified three types of triggers that allow global climate models to deliver results that most closely align with real-world measurements.

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More than 3,000 measurements dating from 2000 to the end of 2010 at ARM's North Slope of Alaska site helped researchers measure for the first time the effects of carbon dioxide on the Earth's temperature.

Research Highlights

Scientists around the world use data from the ARM Facility for their research. In FY2015, ARM data were cited in a total of 624 publications. Some of the most impactful papers are featured in this section. For more publications information, search the ARM Publications Database, ***http://www.arm.gov/publications.***

A First: Carbon Dioxide's Increasing Greenhouse Effect Quantified at the Earth's Surface

For decades, scientists have predicted—based on laboratory measurements—that the increase in greenhouse gases such as carbon dioxide from fossil fuel emissions would lead to an increase in energy and ultimately temperature at the Earth's surface. Complex global climate models have confirmed likely scenarios, but this prediction had never been experimentally quantified outside a laboratory, until now.

A study featured in *Nature* used 11 years of data collected at ARM sites in Oklahoma and Alaska. Scientists were able to link carbon dioxide levels and associated greenhouse effect to increased energy at the Earth's surface. The research provides further confirmation that the calculations used in today's climate models are on track when it comes to representing the impact of carbon dioxide.

"Numerous studies show rising atmospheric carbon dioxide concentrations," said Daniel Feldman, scientist at Lawrence Berkeley National Laboratory, who led the research team. "This study provides the critical link between those concentrations and the addition of energy to the system, or the greenhouse effect."

Researchers used data from the Atmospheric Emitted Radiance Interferometer and other incredibly precise instruments at the two ARM sites in different climates to measure thermal infrared energy that travels down through the atmosphere to the Earth's surface. These instruments can detect background infrared energy emitted from carbon dioxide. The combination of measurements enabled the scientists to isolate the effects on surface warming attributed solely to carbon dioxide. Their results agreed with theoretical predictions that the observed rising greenhouse effect is a result of human activity.

"With 3,300 measurements from Alaska and 8,300 from Oklahoma obtained on a near-daily basis, measurement is the core of the study," said Jim Mather, ARM Technical Director. "The complex data collected by ARM on a continuous basis is what allows this kind of work to be done."

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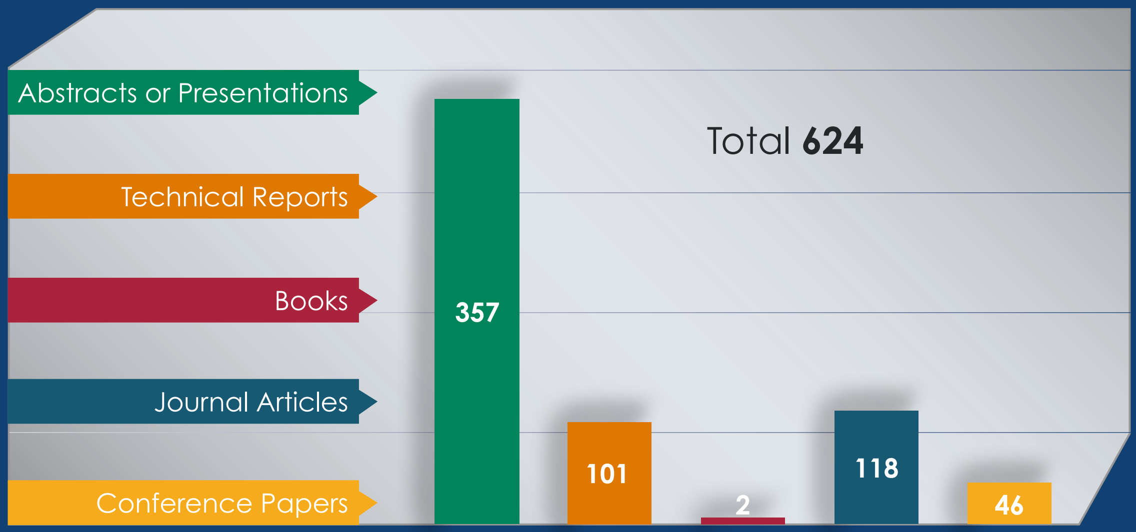
2015 Publications Summary



Ice Cubed: Scientists Gather Largest Set of Actual Ice Crystal Measurements to Resolve Uncertainties in Climate Models

Clouds may look soft and fuzzy at times, but ice clouds contain sharp crystals that can scatter light and affect the movement of heat through the atmosphere. Uncertainties about the size and physical properties of these ice crystals have stymied modelers seeking to understand climate. Now researchers have developed an ever-growing particle database that is essential for representing the full range of ice crystal properties in climate models.

"Past studies quantified the lengths and widths of natural ice crystals based on laboratory measurements and data taken within clouds," said Junshik Um, atmospheric scientist at the University of Illinois at Urbana-Champaign, who led a research team trying to quantify the dimensions of the crystals. "But such studies were based on a limited number of crystals within a set temperature range in a single geographic area. Our study extends these efforts by using a much larger number of ice crystal images taken under a variety of conditions and locations."

Scientists used high-resolution ice crystal images recorded by a cloud particle imager during three ARM field campaigns in three different locations and climate: the tropics, the Arctic, and the mid-latitudes or temperate areas of the globe. Using recently developed software called the Ice Crystal Ruler, the researchers measured length and width of various parts of the crystals as a function of temperature, location, and type of cloud. They found that temperature had a strong influence on the length and width of ice crystals, regardless of location, and type of cloud had some influence. Future studies will look at the effect of humidity and the method of gathering crystals to continue to build the database and inform climate modeling.

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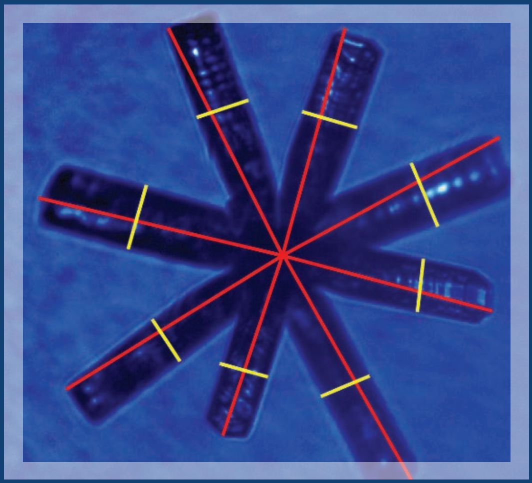
Time-Step Tango: Innovative Approach Untangles Causes of Surface Temperature Bias in General Circulation Models

General circulation models (GCMs) are indispensable tools to assess the impact of human activity on climate. To accurately predict global and regional climate in the near and far future, GCMs must be firmly grounded in today's reality in terms of global heat and moisture. Yet many GCMs persist in calculating a land surface temperature that is much warmer than actual measurements over the midlatitudes, the Earth's temperate zones where many people live.

One area where surface temperature is frequently overestimated is the Great Plains of the United States Now researchers are beginning to untangle the reasons why, using an innovative approach.



Scientists used an Ice Crystal Ruler to measure the length and width of ice crystals around the world. Such detailed measurements can improve climate model calculations.

An innovative time-step analysis is helping researchers understand why general circulation models overestimate surface temperatures over the midlatitudes based on data gathered from ARM's Southern Great Plains site.

"A number of mechanisms have been proposed to explain this temperature bias over the Southern Great Plains," said Kwinten Van Weverberg, meteorologist for the United Kingdom's Met Office in Exeter, who led a research team to discover the source of the bias. "Scientists have looked at deficiencies in how the model simulates convection, clouds near the surface, and the heat exchange between soil, vegetation, and the atmosphere. Our work suggests that the underlying problem may be in the way cloud processes are represented."

The research team from the Met Office and Lawrence Livermore National Laboratory tested a time-step analysis to quantify model bias. They found that in some cases the problem could be traced back to deficiencies in calculating cloud properties. They also discovered that once the model calculated a temperature error, that error tended to grow as the simulation progressed. Their work relied heavily on detailed measurements of temperature, cloud properties, and surface radiation gathered at the ARM Southern Great Plains site during the Midlatitude Continental Convection Cloud Experiment.

The test proved the validity of the time-step method. Researchers will apply the method during the Clouds Above the United States and Errors at the Surface (CAUSES) project, which will further study surface and cloud-related factors that contribute to the warm bias of GCMs.

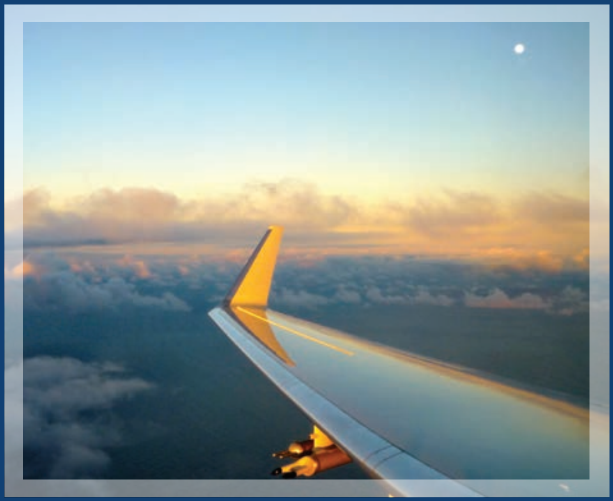
Reference

Van Weverberg K, CJ Morcrette, H Ma, SA Klein, and JC Petch. 2015. "Using regime analysis to identify the contribution of clouds to surface temperature errors in weather and climate models." *Quarterly Journal Royal Meteorological Society*, doi:10.1002/qj.2603.

Delineating the Sharp Edges of Clouds, Down to the Micrometer

The way that clouds mix with the air around them has been a source of controversy for decades, influencing models from cloud to climate scales and sending scientists searching for an ever-more exacting way to take measurements inside clouds. Now research supported in part by the ARM Facility is giving scientists the ability to settle the matter. The study by a team of scientists from Michigan Technological University, Germany's Mainz University, and the National Center for Atmospheric Research (NCAR) was reported in *Science* magazine. The findings show that the uneven or inhomogeneous mixing inside clouds is contrary to what most models assume.

"What we discovered is that sharp boundaries form on clouds as dry air completely evaporates some water drops and leaves others unscathed," said Raymond Shaw, physics professor from Michigan Tech, who led the study. "When clouds mix with dry air from their surroundings, one might guess that all droplets will evaporate just a little bit until the air becomes saturated. But we observed instead that a subset of droplets evaporates completely, leaving the remaining ones almost unchanged. The differences in how the liquid water in a cloud is divided into droplets, in a few large drops or a lot of small ones, influence how much sunlight makes it through the clouds into the lower atmosphere and how clouds reflect, buffer, or trap heat."



The HOLODEC, developed in part with funding from the ARM Facility, can be flown through clouds to record 3-dimensional images of the intricate workings inside. The results of a study using the instrument were recently published in *Science*. Photo courtesy of NCAR.

It can be challenging to accurately measure liquid droplets in clouds, particularly when those droplets are the size of micrometers, hundreds of times smaller than a grain of sand on the beach. Using the Holographic Detector for Clouds, or HOLODEC, a 3-dimensional imaging system mounted in an airborne laboratory, scientists can take measurements directly inside clouds. The holograms provide an unprecedented view of the 3-dimensional distributions of droplets at centimeter-to-micrometer scales within the cloud.

"Our results in this study wouldn't have been possible without the assistance of the ARM Facility to improve instrument performance for fieldwork," said Shaw.

Reference

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Location, Location, Location: The Power of Long-Term, Co-located Data

Who would have thought something so tiny that 1,000 could pass side-by-side through the eye of a needle could pack such a punch? Yet tiny aerosol particles affect climate by scattering and absorbing radiation. Aerosols also affect clouds by influencing their radiative properties, precipitation efficiency, thickness, and lifetime. And, despite all their power in the atmosphere, aerosols remain one of the greatest sources of uncertainty in climate modeling. Scientists even struggle to find sufficient data with which to evaluate a model's estimates. The ideal data set would include measurements of meteorology, radiation, and the chemical and physical properties of aerosols, and all measurements would be taken from the same location at the same time.

Now, thanks to new capabilities at ARM's Southern Great Plains site near Lamont, Oklahoma, scientists have additional information about the chemical properties of aerosols that are particularly important for understanding sources of aerosols and processes controlling other aerosol properties in the atmosphere. The new aerosol data can also be coupled with other ARM measurements to evaluate how well climate models represent the seasonal and multiyear variations in aerosol impacts on temperature at this site, giving scientists the tools to understand those powerful, tiny aerosols.

Since late 2010, the Aerosol Chemical Speciation Monitor has been measuring organic aerosol, sulfate, nitrate, ammonium, and chloride, key types of aerosols that can impact the atmosphere. In a recent study, scientists analyzed these measurements to quantify the daily, weekly, monthly, and seasonal variations in these aerosols over a 19-month period. Focusing on organic aerosols, which proved the dominant

"As the ARM data set continues to expand, it will be useful for observing changes in aerosol composition and concentration over multiple years."

—Qi Zhang, associate professor at the University of California at Davis

Scientists used the Aerosol Chemical Speciation Monitor, part of ARM's Aerosol Observing System at the Southern Great Plains site, along with other instruments to gather data on meteorology, radiation, and aerosol properties from the same location over time.

type for much of the year, researchers teased out distinct sources (e.g., biomass burning), changes in the aerosols, and their physical and chemical properties.

"Our studies demonstrate that co-located measurements of meteorology, radiation, and aerosols would be useful to evaluate treatments of aerosol processes in climate models," said Qi Zhang, associate professor at the University of California at Davis, a key member of the research team that also included scientists from Brookhaven National Laboratory and Pacific Northwest National Laboratory. "As the ARM data set continues to expand, it will be useful for observing changes in aerosol composition and concentration over multiple years."

Reference

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Clearer Skies for Cloud Modeling

In May, Cyril Morcrette was awarded the L F Richardson Prize by the Royal Meteorological Society for his work in evaluating cloud forecasts. Although weather and climate models often rely on different metrics to make accurate forecasts, Morcrette created a unified methodology that can be used to evaluate cloud predictions at both scales. Data provided by the ARM Facility played a key role in his work.

Morcrette is a science manager in the atmospheric processes and parameterizations team at the Met Office, the United Kingdom meteorological agency. He was awarded the L F Richardson Prize this year for the paper *Evaluation of two cloud parameterization schemes using ARM and Cloud-Net observations,* published in the April 2012 issue of the *Quarterly Journal of the Royal Meteorological Society*. The prize is awarded annually to an early-career member who has published a meritorious paper in a Royal Meteorological Society journal during the last four years.

Cyril Morcrette, climate researcher at the Met Office, won the L F Richardson Prize for his work on evaluating cloud models.

BAMS Features Results of 21-Month ARM Deployment

Featured in the March 2015 *Bulletin of the American Meteorological Society (BAMS),* the 21-month ARM Mobile Facility deployment in the Azores was the longest of its type in a non-tropical marine environment. This data set collected during the Clouds, Aerosols, and Precipitation in the Marine Boundary Layer (CAP-MBL) field campaign provided valuable insights into the complex interactions of clouds, aerosols, and precipitation on the remote marine environment of Graciosa Island about 850 miles west of Portugal.

Low clouds were observed typically at the Graciosa site during the 21-month ARM Mobile Facility deployment.

The CAP-MBL study sheds light on some of the key characteristics of the clouds, meteorology, aerosols, and precipitation in the Azores. Results included the seasonal cycle, diverse histories of air masses encountered, strong variability compared with other low-cloud regimes, and important bi-directional interactions between aerosols, clouds, and precipitation. While low clouds occur most frequently, the broad range of different types of clouds in the area is almost as diverse as those found around the Earth as a whole, making it an excellent location for gathering these measurements. Because of this, the CAP-MBL deployment ultimately led to the establishment of a fixed ARM site on Graciosa Island in late 2013.

Combined with the data from the mobile deployment, the continuing accumulation of data is expected to build on the current understanding and provide an unprecedented data set for evaluating and improving cloud-resolving models.

Infrastructure **ACHIEVEMENTS**

Site Operations

Maintaining multiple instrumented sites around the world is no easy feat. The ARM Facility 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.

AWARE Requires "Challenging" Deployment in Harsh Environment

In August 2015, a team of experts completed months of work in high, dry, cold Pagosa Springs, Colorado, then dismantled, packed and shipped instruments, data systems, equipment, and enclosures to McMurdo Station, Antarctica, for the ARM West Antarctic Radiation Experiment (AWARE). Their goal was to develop, assemble, outfit and test all instruments to make sure they could withstand 12 months of 24-hour operation on Earth's highest, driest, coldest, and windiest continent.

Scientists will be on the ice with the equipment for a total of 14 months in two locations to collect and analyze quantitative data about energy components, changing air masses, and cloud microphysics. In response to recent satellite data showing that Antarctic ice shelves have collapsed, triggering unknown quantities of ice loss, their goal is to gather additional data from multiple sources to improve earth system models to predict how climate will continue to change.

The unprecedented deployment begins in November 2015 when a team from Los Alamos National Laboratory, Hamelmann Communications, and the Australian Bureau of Meteorology personnel sets up the instruments. A technician will maintain the instruments, and weather balloons will be launched daily by local personnel. AWARE data will constitute the most comprehensive set of atmospheric, cloud, and energy balance measurements from Antarctica.

ARM Gets FAA Approval for Aerial Research in the Arctic Sky

It's called Warning Area W-220 by the Federal Aviation Administration (FAA), but to DOE's ARM Facility's Oliktok Point site, it's a 700-mile stretch of arctic sky where climate researchers have approval to collect weather data by air.

"Gaining the warning area was a big win for DOE's ARM facilities. It opens up the Arctic for new Office of Science research efforts," according to Mark Ivey, manager of ARM North Slope Alaska sites at Oliktok Point and Barrow and scientist at Sandia National Laboratories who spearheaded approval efforts.

"AWARE is by far the most challenging deployment we've done."

—Kim Nitschke, ARM Mobile Facilities manager

Flynn, Schmid Receive NASA Group Achievement Award

ARM Aerial Facility Technical Director Beat Schmid and ARM Aerosol Working Group Translator Connor Flynn received the prestigious 2015 National Aeronautics and Space Administration (NASA) Group Achievement Award. The award recognized the collaborative team from the NASA field campaign Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC4RS) deployed during the summer of 2013. Schmid and Flynn supported the Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR), an instrument flown during SEAC4RS. 4STAR was developed jointly by NASA Ames Research Center and Pacific Northwest National Laboratory.

Beat Schmid

Connor Flynn

Left to right: Mobile facility managers Kim Nitschke and Paul Ortega scouted Antarctica with AWARE co-investigator Johannes Verlinde to determine the ideal locations and nfrastructure.

The inaugural use of the new airspace was a mock search-and-rescue mission conducted by a contractor for the U.S. Coast Guard that included the use of an unmanned aerial system. The Coast Guard exercise also provided lessons for the ARM Facility, according to Ivey.

"We worked though the first activation of the warning area with two FAA reps on-site," he explained. "We used the wiki (collaborative web technology) to communicate information and also had one member of our team at a NORAD radar scope in Anchorage. These experiences will be critical in establishing safe operational procedures for future ARM scientific campaigns using the warning area."

Darwin, Australia, Site Operations Closes

After more than 12 years of climate data collection in Darwin, Australia, the third Tropical Western Pacific site for DOE's ARM Facility closed December 31, 2014. A collaboration between the Australian Bureau of Meteorology and ARM, the site also provided technical support for the two equatorial Tropical Western Pacific facilities at Manus Island and Nauru.

Darwin data provided a contrast between dry and monsoon seasons and a transitional period between the two and provided "long-term observations" that are "unpreceded," according to Chuck Long, former Tropical Western Pacific site scientist. The closing of the site concludes ARM's long-term presence in the region, but there will always be a need for tropical research and ARM mobile facilities could return to the region for additional campaigns.

All Tropical Western Pacific observational data are still available in the ARM Data Archive as a valuable resource, according to Paul Ortega, site operations manager from Los Alamos National Laboratory. "The vast amount of data gathered will be used for many years to help us better model and predict climate function and is a testament to the hard work, commitment, and dedication of a large number of personnel," he asserted. These instruments are now being integrated across the ARM Facility, including the megasites.

ARM Adding Radar in Remote Areas to Worldwide Network

The ARM Facility is deploying state-of-the-art cloud radars to Antarctica and to existing sites in Alaska and the Azores to collect data that will help refine and evaluate existing climate models. Modified to work in 150 mph winds and sub-50°Fahrenheit temperatures, cloud radars are part of the suite of instruments for AWARE. They will collect sophisticated cloud-measurement data at the melting edge of climate change.

ARM's third mobile facility already operates more than two dozen instruments at Oliktok Point, Alaska, and new scanning cloud radar, precipitation radar, and Doppler lidar will help scientists refine studies of arctic mixed-phase clouds. The radars will discern finer details of signals from 30 meters to 17 kilometers above the Earth, improving cloud-sampling capabilities with pulse compression by toggling between two modes to distinguish heavy rain signals from those of cloud structures.

A helicopter crew lowers a rescue swimmer into the Arctic Ocean in a joint exercise with the Coast Guard and private firms to assess using manned and unmanned aerial systems for search and rescue near Oliktok Point, Alaska. The test was held in DOE airspace recently approved for research by the FAA. Image courtesy of Coast Guard Petty Officer 2nd Class Grant Devuyst.

An aerial view of the ARM Facility site in Darwin, Australia, taken on a tour of the sites to be used during the Tropical Warm Pool – International Cloud Experiment conducted in January and February 2006.

Radar equipment from the second ARM Mobile Facility are prepared for the upcoming deployment in the harsh antarctic climate.

At ARM's Eastern North Atlantic facility on Graciosa Island in the Azores, researchers already have baseline data from low stratiform cloud systems common there. New radars will help determine what controls the amount of clouds, how aerosols affect precipitation, what causes them to break up, or how dry air enters to make them evaporate.

The new radars will help scientists get the best data to fill gaps in their fundamental understanding of cloud properties and determine how well numerical models benchmark against actual observations.

Data Advancements

Pilot Phase Begins for Routine Large-eddy Simulations

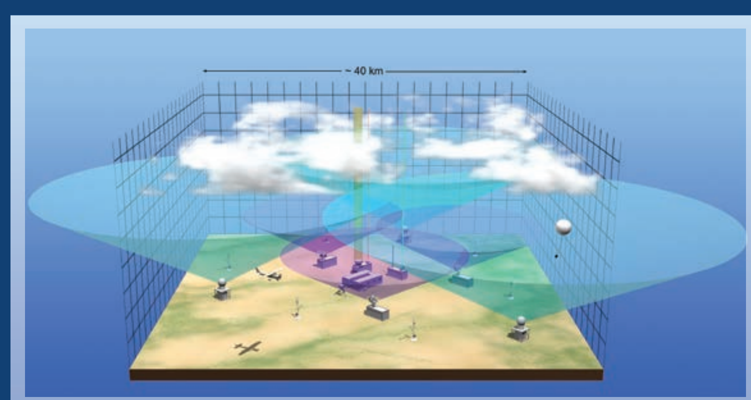
The next-generation ARM Facility is adding powerful new capabilities that will further its mission and provide more complete data sets to support process studies. A two-year pilot project was begun in 2015 to tie together the Facility's observational data and large-eddy simulation (LES) modeling to support the study of atmospheric processes, the improvement of observational retrievals, and parameterizations of clouds, aerosols, and radiation in climate models. These combined observational and modeling elements will enable a new level of scientific inquiry.

A team of DOE scientists, led by William Gustafson of Pacific Northwest National Laboratory in collaboration with Andrew Vogelmann at Brookhaven National Laboratory and Zhijin Li at University of California, Los Angeles, are developing the pilot project, called LASSO—the LES ARM Symbiotic Simulation and Observation workflow.

LASSO is laying the groundwork to produce routine LES modeling at the ARM Southern Great Plains megasite starting in 2017. The initial LASSO implementation will target shallow clouds and will later expand to other phenomena and ARM sites. The project will enhance ARM observations by using LES modeling to provide context and a self-consistent representation of the atmosphere surrounding the Southern Great Plains that will connect processes together and facilitate improved understanding. LASSO will result in a library of simulations that can be used to test the accuracy of climate model parameterizations, serve as a proxy for the atmosphere to develop remote retrievals, as well as many other applications.

A "data cube" for LASSO is being developed that will combine ARM observations and high-resolution model output to provide as complete as possible a description of the atmosphere in the vicinity of the megasite. By enhancing metadata search capabilities, presenting a full set of parameters on a common grid, and including metrics and diagnostics to evaluate each case, these data cubes will simplify data discovery, access, and analysis for climate researchers and modelers.

Left to right: William Gustafson, Pacific Northwest National Laboratory, and Andrew Vogelmann, Brookhaven National Laboratory, are leading the development of ARM's modeling capability.



This illustration depicts the new Southern Great Plains megasite, incorporating a network of instruments to support model development and evaluation.

To be included in LASSO project updates, sign up for the LASSO information emails at *http://eepurl.com/bCS8s5*.

Routine high-resolution model simulations combined with the detailed ARM observations will provide powerful new research capabilities. LASSO is being developed for the benefit of the atmospheric science and climate modeling communities. To ensure this DOE project meets researcher and modeler's needs, community input will regularly be sought through email communications and updates at highly attended conferences and meetings.

The LASSO Implementation Strategy is available at ***http://www.arm.gov/publications/programdocs/doe-sc-arm-15-039.pdf***.

A Smooth Move for ARM Metadata

In 2015, the ARM Facility migrated 20 years' worth of metadata, archived at the Oak Ridge National Laboratory in Tennessee, to an open-source database platform. The ARM Facility collects information from routine operations and field experiments using more than 500 instruments—ranging from rain gauges to Raman lidar—located at fixed and mobile sites around the world. The ARM Data Archive contains "metadata," the critical details about these measurements and the instruments. All that information is then made available to the public for free.

"The archive database is the 'brains' of ARM data systems, so you just can't shut it down," said Giri Palanisamy, the ARM Data Services and Operations Manager who led the transfer effort.

However, the amount of incoming data—and the accompanying metadata—is continually increasing as ARM deploys more instruments (such as the radar systems recently shipped to Alaska, Antarctica, and the Azores). From 2002 to 2011, ARM collected 300 terabytes of data. During the next four years, Palanisamy noted that number climbed to 750 terabytes. Looking ahead, he expects the ARM Data Archive to store metadata that describes about 1.5 petabytes of new ARM data each year.

Developing the next-generation ARM Facility will require more of these larger scale operations, which need a platform robust enough to handle the growth, without losing or corrupting data, hence, the need to move to a new platform called PostgreSQL (Postgres for short). Archive staff members are now helping their colleagues at the Brookhaven National Laboratory in New York move ARM's External Data Center to the Postgres platform. Ultimately, both Oak Ridge and Brookhaven will have reciprocal back-up of each other's databases.

Organizational Changes Bring Two New ARM Positions

The ARM Facility has added two professional positions to accelerate the application of ARM observations and data processing for model evaluation and development.

Giri Palanisamy, left, and Jennifer Comstock, right, assume new ARM roles.

Giri Palanisamy will manage both the Architecture and Services Strategy Team and Data Services Operations. First, he will facilitate teamwork and provide greater data analysis capacity for ARM's computational environment with a strategy and implementation plan called "ARM Adaptive Architecture." Second, he will focus on delivery from data collection to distribution.

As new Engineering and Process Manager, Jennifer Comstock will help integrate engineering and operations activities, assuring they are current and relevant, and make sure engineering workflow processes are consistent and refined, especially those related to product delivery. She is also leading the identification of engineering priorities for ARM development activities by collecting input from the ARM user community and working closely with ARM staff from around the facility.

ARM Data Developers Prepare for Next Generation of ARM

About 40 ARM staff members gathered at the National Weather Center in Norman, Oklahoma, from July 14 to 16 for the annual developers meeting to discuss current activities and help facilitate a reconfiguration to better streamline ARM operations and enhance its scientific impact.

Participants included representatives from ARM's External Data Center, Data Quality Office, Data Archive, and Data Management Facility who met with infrastructure management, operations staff, and scientists.

ARM Technical Director Jim Mather gave a program overview and talked about the Decadal Vision, which calls for a multiphase effort to consolidate ARM sites and instrumentation to provide more robust scientific data and the processes to more easily incorporate them into climate models. Highlighting the recent activities from the Architecture and Services Strategy Team was Tom Boden, Oak Ridge National Laboratory. This team is developing a strategy for the ARM computing environment to support the ARM reconfiguration, increased data volumes, and integration of observations and modeling. Introducing the LASSO modeling project was William Gustafson, Pacific Northwest National Laboratory. By increasing the density and spatial coverage of measurement capabilities, The ARM Facility is effectively moving from a vertical column of measurements to multidimensional measurements that give us a 4-dimensional view of the atmosphere in a defined space. These data will form the basis of the LES modeling, which will in turn be used to better understand gaps where measurements are not possible. These high-resolution model simulations will be run on a routine basis and will create a powerful new capability for furthering ARM's mission.

Possible ARM tools to support global climate model development were shared by Shaocheng Xie, Lawrence Livermore National Laboratory. Jimmy Voyles, Pacific Northwest National Laboratory, and Giri Palanisamy, Oak Ridge National Laboratory, discussed ways to improve ARM internal program communications.

Science Outreach

Students Explore the Skies at ARM Summer Training

Their heads were in the clouds, but the 26 graduate students and early career scientists who attended the first ARM Summer Training and Science Applications event weren't daydreaming. Instead, they spent eight days at the National Weather Center in Norman, Oklahoma, from July 15 to 24, attending lectures, doing group work using ARM data, and even spending a day at ARM's Southern Great Plains site.

About 40 ARM staff attended the 2015 Data Developer's Meeting to discuss current activities and the reconfiguration of ARM sites.

Learning practical and theoretical knowledge about observing and modeling aerosols, clouds, and precipitation processes, 26 students from around the world attended the ARM Summer Training and Science Applications event.

The U.S. and international students came from around the world representing the next generation of atmospheric researchers. Most were engaged in graduate work at U.S. institutions, while six others were studying at international locations in Brazil, Germany, Canada, and Korea. Each morning, they attended two lectures and discussion sessions before breaking into working groups to focus on different applications using data collected at the Southern Great Plains and other ARM sites that was applicable to their project work on observations and modeling of aerosols, clouds, and precipitation.

Dave Turner, NOAA/National Severe Storms Laboratory, worked with Pavlos Kollias, McGill University, and Susanne Crewell of the University of Cologne, Germany, to initiate the training, which featured a total of 12 instructors, including research scientists, professors, and engineers from agencies, universities, and national laboratories from around the world. The event leaders were inspired by Initial Training for Atmospheric Remote Sensing (ITaRS), a similar training session held in Europe under Crewell's leadership. The group plans to alternate future ARM training courses with the ITaRS.

"There's no graduate program in the United States that exposes students to hands-on training and scientific applications with even the core sensors of the ARM Facility," Kollias said. "The ARM training provides an experience you won't get in a classroom or from a textbook. We need to expose young, upcoming scientists to the ARM Facility to broaden the user community that can collaborate and use ARM data."

ARM Radar Scientists Lead Courses on Radar Meteorology

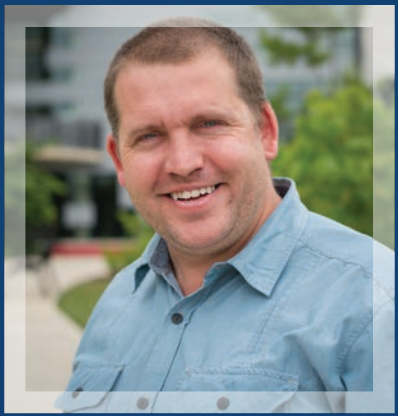
In September 2015, radar scientists from the ARM Facility led short courses at the 37th Conference on Radar Meteorology, sponsored by the American Meteorological Society (AMS). As a world leader in the synergistic use of centimeter- and millimeter-wavelength radars that breaks barriers between the weather and climate radar communities, ARM radar scientists share their knowledge by providing short courses and tutorials during society meetings like this one.

At this year's radar conference, Scott Collis and Jonathan Helmus, Argonne National Laboratory, led a short course, with assistance from their Py-ART colleagues, on open source radar software, the Python programming language, Python-ARM Radar Toolkit, and several applications for ARM and other radar systems.

Pavlos Kollias, McGill University, led a course on centimeter- and millimeter-wavelength radar applications, synergistic use of centimeter- and millimeter-wavelength radars, and holistic radar-views of the water cycle available at ARM sites.

"There's no graduate program in the United States that exposes students to hands-on training and scientific applications with even the core sensors of the ARM Facility."

—Pavlos Kollias, professor at McGill University



Scott Collis, left, Jonathan Helmus, middle, and Pavlos Kollias, right, are ARM radar scientists, who presented at the radar conference.

Joint Meeting of ARM Facility and Atmospheric System Research Yields Large Body of Information

After a joint meeting in March 2015, staff members and users of the ARM Facility and principal investigators from the Atmospheric System Research program shared more than 150 abstracts, 50 presentations, and 29 breakout session reports during a week-long meeting. Some abstracts include posters, all of which are available on the Atmospheric System Research website meeting page, ***http://asr.science.energy.gov/meetings/stm/2015-march***.

More than 300 researchers attended the four-day event, providing input on scientific priorities, needs, and gaps at the ARM Facility, and insights into Atmospheric System Research research and scientific progress. ARM staff reported on plans to develop "megasites" for providing an integrated approach to climate observations and the processes and tools to facilitate them. Principal investigators and facility users presented their work and tutorials demonstrated how to use the ARM Data Integrator to work with ARM NetCDF data and interact with or use the Facility.

Status of Value-added Products for FY2015

Many of the scientific needs of the ARM Facility are met through the analysis and processing of existing data into value-added products (VAPs). These products provide an important translation between the instrumental measurements and the geophysical quantities needed for scientific analysis, particularly model parameterization and development. ARM VAPs pass through the stages of initiation, development, evaluation, and release.

At the evaluation stage, a VAP is provided to the larger scientific community for evaluation and feedback. After the evaluation period is complete, ARM quality control and data standards are applied, and the VAP data are moved to production status in the ARM Data Archive.

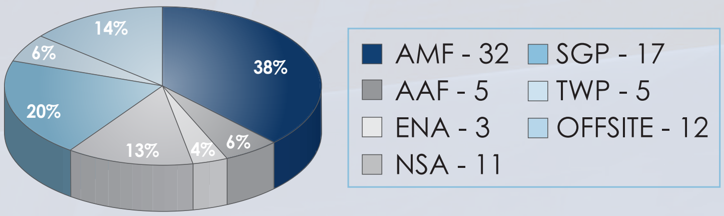
In FY2015, 2 new VAPs and 2 new tools were initiated, 12 VAPs were released to production, and data for 9 VAPs were released to evaluation. VAP processes and data are released to production when algorithms are updated, additional sites are added, or VAP processing code is moved to the ARM Data Integrator Library or a new operating system. See the Value-Added Product section, located on page 43, for a list of VAPs that were initiated and released in 2015.

Field Campaign **SUMMARY**

Field Campaign Activities

The ARM 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 pie chart here shows the total number of field campaigns, including Tropical Western Pacific studies and ongoing efforts that occurred in FY2015. The subsequent table summarizes just those campaigns that began in FY2015. For more information, visit the field campaign web page at ***http://www.arm.gov/campaigns.***

Field Campaign Total for FY2015



Dates	Campaign Name	Status	Description
ARM Aerial Facility			
January – March 2015	ARM Cloud Aerosol Precipitation Experiment (ACAPEX): Aerial Observations	Completed	The second ARM Mobile Facility and ARM Aerial Facility Gulfstream-1 (G-1) were deployed in a joint effort with the National Oceanic and Atmospheric Administration (NOAA) CalWater 2015 campaign. The goals of the joint campaign were to improve understanding and modeling of large-scale dynamics and cloud and precipitation processes associated with atmospheric rivers and aerosol-cloud interactions that influence precipitation variability and extremes in the western United States. The G-1 aircraft probed the clouds that form over the ocean and their transformations upon landfall as well as the orographic effects over the coastal range and the Sierra Nevada.
September – December 2015	Use of ARM Aerial Facility Cloud Spectrometer and Impactor (CSI) Probe in Olympic Mountain Experiment (OLYMPEX)	In Progress	This campaign is involved in improving remote-sensing retrievals of cloud and precipitation properties in winter storms from over the ocean to over complex terrain. Data obtained will support the National Aeronautics and Space Administration (NASA) Global Precipitation Measurement mission. This work is a continuation of University of North Dakota Citation flights, supported by the ARM Aerial Facility, during the spring 2014 season over North Carolina and adjacent coastal waters.
June – September 2015	Arctic Black Carbon Loading and Profile Using the Single Particle Soot Photometer (SP2)	Completed	This work addressed a significant deficiency that currently limits improved quantification of the impact of black carbon (BC) radiative forcing in the cryosphere—the scarcity of data on the vertical and spatial distributions of BC. The primary scientific objective was to provide a data set of refractory BC particle distributions to better understand and constrain the impact of BC radiative forcing in the cryosphere.
June – September 2015	ARM Airborne Carbon Measurements (ARM-ACME V)	Completed	This research was built upon the results from the NASA Carbon in Arctic Reservoirs Vulnerability Experiment missions and the DOE Next-Generation Ecosystem Experiment Arctic project. The G-1 research aircraft flew over the North Slope of Alaska site, with occasional vertical profiling to measure trace-gas concentrations at points between Prudhoe Bay and Toolik Lake. Measurements were made of carbon dioxide, methane, water, carbon monoxide, and nitrous oxide, carbonyl sulfide, trace hydrocarbon species including ethane, and the properties of aerosols and clouds, atmospheric thermodynamic state, and solar/infrared radiation.

Dates	Campaign Name	Status	Description
ARM Mobile Facility			
January – December 2015	Observations and Modeling of the Green Ocean Amazon: Year-to-Year Differences (GoAmazon 2015)	In Progress	This campaign seeks to understand aerosol and cloud life cycles, particularly the susceptibility to cloud-aerosol-precipitation interactions, within the Amazon Basin. The locations for the GoAmazon field campaigns are at T1 (National Institute for Amazonian Research in Manaus, Brazil), T2 (Iranduba, Brazil), T3 (Manacapuru, Brazil), and ZF2 (DOE's Terrestrial Ecosystem Science Measurement Sites north of Manaus and Manacapuru, Brazil). A second year of measurements began in January 2015 as part of GoAmazon campaign to enable comparative year-to-year variability in the measurements.
October 2014	Observations and Modeling of the Green Ocean Amazon: Lidar Comparison	Completed	Three lidar systems were operated simultaneously at different experimental sites, and an instrument comparison campaign was performed in which the mobile lidar system from Brazil's Nuclear and Energy Research Institute was moved from the T2 site to the T3 and then to Toe-Embrapa. Data collected by the mobile lidar system at Manacapuru and Toe-Embrapa were used for side-by-side comparison of the systems at these sites.
March – December 2015	Observations and Modeling of the Green Ocean Amazon: Hi-Vol Filter Sampling	In Progress	In this campaign, fine particles with diameters of 2.5 microns or less (PM2.5) are being studied because they present a health hazard. The atmospheric plume at Manaus, Brazil, contains substances of PM2.5 size, emitted mainly from burning fossil fuels, industrial activity, and soil dust. This campaign is intended to develop an understanding of the impact of climate change in the levels of air pollution and its relation to human health in a region of the Amazon and contribute the technical and scientific development of the region and to improve the quality of life and the environment.
January – February 2015	ARM Cloud Aerosol Precipitation Experiment (ACAPEX)	Completed	Deployed on the NOAA research vessel *Ronald H. Brown*, the second ARM Mobile Facility, along with the ARM Aerial Facility G-1, participated in a joint field effort with the NOAA CalWater 2015 campaign. The goal was to advance understanding and modeling of large-scale dynamics and cloud and precipitation processes associated with atmospheric rivers and aerosol-cloud interactions that influence precipitation variability and extremes in the western United States. Land and offshore assets were used to monitor 1) evolution and structure of atmospheric rivers from near the regions in which they develop, 2) long-range transport of aerosols in the eastern North Pacific and potential interactions with atmospheric rivers, and 3) how aerosols from long-range transport and local sources influence cloud formation and precipitation in the U.S. West Coast where atmospheric rivers make landfall and post-frontal clouds are frequent.

Dates	Campaign Name	Status	Description
ARM Mobile Facility			
January – February 2015	ARM Cloud Aerosol Precipitation Experiment (ACAPEX): Aerosols and Ocean Science Expedition (AEROSE)	Completed	The NOAA AEROSE campaign was a comprehensive measurement-based approach for gaining understanding of the impacts of long-range transport of aerosols over the tropical ocean. ACAPEX and NOAA AEROSE campaigns provided a set of in situ measurements that have been used to characterize the impacts and microphysical evolution of continental aerosol outflows (including both dust and smoke) across the Atlantic Ocean.
January – February 2015	ARM Cloud Aerosol Precipitation Experiment (ACAPEX): Ship-based Ice Nuclei Collections	Completed	Measurements were taken to evaluate hypotheses that 1) sea spray-sourced ice nucleating particles (INPs) are of biological origin and represent a distinctly different INP population compared to long-range transported desert or urban and regional land-sourced INPs, and 2) layering of marine INPs within other aerosol layers feed orographic storms over the mountains of California and the western United States. Proving these hypotheses would lead to common and quantifiable scenarios that influence precipitation over the region.
August 2015 – September 2016	Summertime Aerosol Across North Slope of Alaska	In Progress	In collaboration with the University of Michigan and Baylor University, the concentration, chemistry, and source of summertime aerosols impacting the Oliktok Point and Barrow ARM sites during the summers of 2015 and 2016 are being characterized. Measurements from the campaign will leverage the ARM extended mobile facility deployment that started in the fall of 2013. The resulting data will improve characterization and differentiation of local, regional, and long-range transported summertime aerosols on the North Slope of Alaska.
July 2015	U.S. Coast Guard Operation Arctic Shield 2015	Completed	The U.S. Coast Guard Research and Development Center partnered with Conoco Phillips to conduct a Search and Rescue exercise off of Oliktok Point, Alaska. The goal was to explore how unmanned aerial systems could be used to enhance rescue operations and gain a better understanding of how the Coast Guard could work with private industry during emergency response operations in remote regions. The exercise scenario involved survivors of a small aircraft crash offshore who took refuge in a life raft. Lessons learned will help the Coast Guard understand how to best collaborate with private industry during response operations and develop requirements for unmanned aerial systems performing Coast Guard missions in the arctic environment.
August 2015 – April 2016	Evaluation of Routine Atmospheric Sounding Measurements Using Unmanned Systems (ERASMUS)	In Progress	The ERASMUS campaign will operate several instrumented unmanned aerial systems at Oliktok Point during the summer of 2015 and spring of 2016. The campaign will serve two main purposes. First, it will support collection of a set of atmospheric measurements designed to complement those concurrently obtained by the third ARM Mobile Facility. Second, it will evaluate the potential for future routine atmospheric measurements using unmanned aerial systems at Oliktok Point.

Dates	Campaign Name	Status	Description
Eastern North Atlantic			
February – December 2015	ARM Radiosondes for National Polar-Orbiting Operational Environmental Satellite System (NPOESS)/National Polar-Orbiting Partnership (NPP) Validation – Eastern North Atlantic	In Progress	Satellite overpass is being timed with radiosonde launches from the Eastern North Atlantic site, similar to previous efforts performed for the Atmospheric Infrared Sounder (AIRS) instrument aboard NASA's Aqua satellite and the Infrared Atmospheric Sounding Interferometer (IASI) on the Meteorological Operational Satellite Program of Europe (MetOp). This campaign will explore the same data collection concepts and analysis techniques used for validation of Cross-track Infrared Microwave Sounding Suite (CrIMSS) and Visible Infrared Imaging Radiometer Suite (VIIRS) products from the upcoming NPP and NPOESS satellite platforms.
April 2015 – March 2018	Gamma Radiation Monitoring	In Progress	This campaign focuses on studying the temporal variability of noble gas radon (222Rn) concentrations, examining how it is influenced by meteorological conditions, how it impacts the local atmospheric electric field, and its association with the atmosphere's ionization and aerosol's concentration.
North Slope of Alaska			
June 2015	Micro-climate Influences on Bird Arrival Behavior	Completed	Radford University researchers deployed a microcontroller-based, micro-environmental sensor package near the Naval Arctic Research Laboratory grounds in Barrow, Alaska. Results from this campaign will lead to a longer study on how micro-environmental factors influence arrival behaviors of migrating birds in the area.
Off-Site Campaigns			
October 2014 – July 2015	Micropulse Lidar (MPL) Measurements, Norwegian Young Sea Ice cruise	Completed	A comprehensive instrument suite was deployed aboard the research vessel *Lance* to measure properties of the atmosphere, sea ice, ocean, and associated ecosystems. The main objective was to provide data about the dynamics of thin, first-year sea ice over three seasons.
January 2015 – August 2016	Dynamics-aerosol-chemistry-Cloud Interactions in West Africa (DACCIWA) Cloud-Aerosol Observations in West Africa	In Progress	This campaign seeks to improve capabilities for monitoring and modeling cloud-aerosol interactions in southern West Africa. This region is ideal for studying cloud-aerosol interactions because of its rich mix of natural and anthropogenic aerosols and diverse clouds, and its strong dependence of the regional and global climate to the sensitive West African monsoon.
March – April 2015	Experimental Measurement Campaign: Planetary Boundary-layer Instrument Assessment Experiment (XPIA)	Completed	Conducted at the Boulder Atmospheric Observatory, this campaign focused on quantifying uncertainties in Doppler lidar measurements of wind and turbulence. This offsite campaign was a unique opportunity to assess performance of the Doppler lidar against a well-calibrated reference, and to compare its performance against other lidar systems.

Dates	Campaign Name	Status	Description
Off-Site Campaigns			
March – April 2015	Single Particle Soot Photometer (SP2) Deployment at Boston College-Aerodyne led Coated Black Carbon Study (BC4)	Completed	This campaign focused on measuring the optical properties of BC particles coated with secondary organic and inorganic material and achieving optical closure with model predictions. Measurements of single-particle BC mass and population mixing states were central to this study.
May – October 2015	Stratocumulus Drizzle and Entrainment Study	In Progress	Observations from this campaign are used to examine precipitation and entrainment processes in marine stratocumulus clouds at a coastal site in California. The entrainment studies focus on characterizing turbulence at cloud tops using Doppler cloud radar observations. The precipitation studies focus on characterizing precipitation and the macroscopic properties of clouds.
June – September 2015	Deployment of ARM Aerial Facility Scanning Mobility Particle Sizer (SMPS)	Completed	While deployed at the Pacific Northwest National Laboratory Environmental Simulation Chamber, the differential mobility analyzer in the SMPS was used to classify aerosol particles, and then the classified aerosol was characterized by a condensation particle counter and the cloud condensation nuclei counter.
July 2015 – February 2016	Improving Boundary Layer and Surface Layer Model Parameterizations in a Complex Terrain: Observations of Heterogeneity of Atmospheric Conditions	In Progress	The first ARM Mobile Facility 915-MHz radar wind profiler is being used to support the DOE-sponsored Second Wind Forecast Improvement Project (WFIP2) campaign, a multi-disciplinary project focused on improving the response of the wind energy community to the nation's energy needs. The project is studying physical phenomena and developing process-scale knowledge of atmospheric structure over complex terrain to improve wind forecasting in forecasting models.
Southern Great Plains			
March 2015 – February 2016	2015 Full-column Greenhouse Gas Sampling	In Progress	This collaborative campaign joins efforts of ARM and the NOAA Earth System Research Laboratory to quantify the vertically resolved distribution of atmospheric carbon-cycle gases throughout 99 percent of the atmospheric column. The expected outcome is column-resolved greenhouse gas data that support key ARM science objectives for evaluating the radiative balance of the Earth's climate.
June – September 2015	Stereo Cloud Imaging Using Sky Imagers	Completed	Supported by the DOE SunShot Initiative, Brookhaven National Laboratory developed a fully automated cloud stereo imaging software package that forecasts surface irradiance and power production at utility-scale solar farms with lead times of 1 to 15 minutes.
April 2015 – March 2016	Portable Flux Tower Deployments	In Progress	This campaign is measuring carbon, water, and energy fluxes in two fields in the Southern Great Plains area. The primary goal is to generate data sets that can be used to test land models and surface-forcing estimates for the Southern Great Plains region.

Dates	Campaign Name	Status	Description
Southern Great Plains			
June – July 2015	ARM Support for the Plains Elevated Convection at Night Experiment (AS-PECAN)	Completed	Supported by the National Science Foundation with contributions from NOAA, NASA, and DOE, the AS-PECAN experiment focused on improving understanding and simulation of processes that initiate and maintain nighttime convection and convective precipitation over the central portion of the U.S. Great Plains.
June – July 2015	ARM Support for the Plains Elevated Convection at Night Experiment: Doppler Lidar Operations	Completed	In support of the AS-PECAN experiment described above, ARM provided a Doppler lidar that was deployed with one of the mobile PECAN Integrated Sounding Array (PISA) stations.
July 2015 – July 2016	Chemical Imaging of Atmospheric Organic Particles	In Progress	The goal of this campaign—characterization of the chemical and physical properties of atmospheric particles—is to establish a quantitative relationship between the composition of aerosol particles and their atmospheric impacts. Specific efforts focus on in-depth microscopy studies of chemical and physical properties of atmospheric organic particles collected at the Southern Great Plains site.
June – August 2015	Enhanced Soundings for Local Coupling Studies	Completed	High temporal resolution measurements of surface turbulent heat fluxes and boundary layer properties are required when evaluating the daytime evolution of the boundary layer and its sensitivity to land-atmosphere coupling. To address this need, 12 one-day studies with enhanced radio sonde launches were carried out at the Southern Great Plains Central Facility. An overarching goal of this campaign involved addressing how ARM could better observe land-atmosphere coupling to support evaluation and refinement of coupled weather and climate models.
June – October 2015	Scintillometry and Soil Moisture Remote Sensing	In Progress	This campaign supports the Enhanced Soundings for Local Coupling Studies campaign by providing 1) temporally continuous sensible heat flux measurements over homogeneous scintillometer transects and 2) spatially continuous evapotranspiration and root zone soil moisture distributions with a spatial resolution of 30 meters on days that a clear Landsat image is available.
August – September 2015	Mobile-Fourier Transform Infrared (FT-IR) spectrometer (FTS) EM27/SUN to Total Carbon Column Observing Network (TCCON) Comparison	Completed	To ensure valid data collection by portable spectrometers, side-by-side measurements were collected with the well-characterized and aircraft-validated TCCON spectrometers. Validated and reliable column greenhouse gas measurements from these portable spectrometers will help characterize the global cycle and regional fluxes.

Value-Added **PRODUCTS**

Value-Added Product Updates

In FY2015, the following 2 new data products and 2 new software tools were initiated, 12 products were released to production, and 9 evaluation data products were released for evaluation.

New Products and Tools Initiated

Aerosol Chemical and Speciation Monitors (ACSM) Harmonization

A new effort was approved to modify the ACSM datastreams to include robust quality checks to expand the Organic Aerosol Component value-added product (VAP).

ARM Metrics and Diagnostic Tool

An ARM-oriented metrics and diagnostics package to facilitate the use of ARM data in climate model evaluation began the development cycle.

ARM Radar Cloud Simulator

Development began on an ARM cloud radar simulator for global climate models. Efforts this year included finalizing the algorithm that creates simulated cloud radar data from climate model output and applying a height-dependent minimum for detectable reflectivity to the simulated radar data. Contoured Frequency by Altitude Diagrams, or CFADs, derived from model output, which measured reflectivity from the Active Remote Sensing of Clouds (ARSCL) VAP have been compared to test the new radar simulator.

Multi-Angle Snowflake Camera VAP

Software that applies automated image processing in near real time to output data products from the multi-angle snowflake camera (MASC) began development. A new datastream will be created for a hydrometeor microphysics VAP derived from MASC image data.

Released to Production

AOD: Aerosol Optical Depth

AOD generates robust calibrations for the Multifilter Rotating Shadowband Radiometer and Normal Incidence Multifilter Radiometer from Langley analysis. Data from the Cape Cod, Massachusetts, deployment were released to production status in the ARM Data Archive.

ARMBE2DGRID: ARM Best-Estimate 2-Dimensional Gridded Surface

The ARMBE2DGRID data set merges together key surface measurements at the Southern Great Plains sites and interpolates the data to a regular 2-dimensional grid to facilitate data application. A year of data from the Southern Great Plains site was released to production.

ARMBE2DSTNS: ARM Best-Estimate 2-Dimensional Station-Based

ARMBE2DSTNS is an hourly station-based surface data set that contains the same variables, such as atmospheric state, heat fluxes, short and longwave broadband fluxes, and soil properties, as in ARMBE2DGRID. A year of data from the Southern Great Plains site was released to production.

CCNPROF: Cloud Condensation Nuclei Profile

A method was developed to remove the influence of humidification from the extinction profiles and tie the "dry extinction" retrieval to the surface CCN concentration, thus estimating the CCN profile. The VAP algorithm to run with the new aerosol observing system cloud condensation nuclei (AOSCCN) datastream was made to run autonomously and moved into production.

DLPROF VAD: Doppler Lidar Profile Velocity-Azimuth-Display

DLPROF VAD VAP takes the vertical profiles of horizontal wind speed and direction using the VAD algorithm from the Doppler lidar data. All historical data were processed and released to the ARM Data Archive, and the VAP algorithm was released to production status.

DLPROF – WSTATS: Cloud and Vertical Velocity Statistics from the Doppler Lidar

The purpose of the Doppler lidar vertical velocity and cloud statistics VAP is to produce height- and time-resolved estimates of vertical velocity variance, skewness, and kurtosis from raw measurements. All historical data were processed and released to the ARM Data Archive, and the VAP algorithm was released to production status.

MFRSRCIP: Multifilter Rotating Shadowband Radiometer-Column Intensive Properties

This algorithm was developed for estimating the microphysical (e.g., size distribution) and optical (e.g., single-scattering albedo and asymmetry factor) properties of aerosols. The VAP algorithm to retrieve aerosol column intensive properties from the Multifilter Rotating Shadowband Radiometer (MFRSR) was made to run autonomously and moved into production.

MICROBASEPI: Continuous Baseline Microphysical Retrieval Profile-Instantaneous

MICROBASE is a baseline retrieval of cloud microphysical properties. MICROBASEPI provides scientifically relevant measurements of ice- and liquid-water content. The VAP algorithm was made to run autonomously and moved into production using a different operating system.

MPLCMASK: Cloud-Mask from Micropulse Lidar

In addition to retrieving cloud boundaries above 500 meters, the Micropulse Lidar Cloud Mask (MPLCMASK) VAP applies lidar-specific corrections (i.e., range-square, background, dead time, and overlap) to the measured backscattered lidar. Data from the ARM Cloud Aerosol Precipitation Experiment (ACAPEX) field campaign were released to production status.

QCRAD: Data Quality Assessment for ARM Radiation Data

The QCRAD VAP was developed to assess the data quality—and to enhance data continuity—for the ARM radiation data collected at all ARM central and extended facilities. The algorithm for second-level processing was automated and released to production status. Data from the new algorithm were released to production.

RADFLUX: Radiation Flux

RADFLUX uses surface broadband radiation measurements to detect periods of clear skies and produce continuous clear-sky estimates. Historical data for the North Slope of Alaska, Tropical Western Pacific, and Southern Great Plains sites and the VAP algorithm were released to production.

SASHE AOD: Shortwave Array Spectroradiometer Hemispheric Aerosol Optical Depth

SASHE calibration AOD VAP processes the intermediate files created by the SASHE Langley VAP to yield a robust calibration time series of top-of-atmosphere irradiances suitable for retrieval of optical depth. The VAP algorithm to apply stray light correction to diffuse hemispheric data was made to run autonomously and moved into production.

Data Released to Evaluation

AREALAVEALB: Areal Average Albedo

This VAP yields areal averaged surface spectral albedo estimates from MFRSR measurements collected under fully overcast conditions via a simple one-line equation, which links cloud optical depth, normalized cloud transmittance, asymmetry parameter, and areal averaged surface albedo under fully overcast conditions. Data were released to the evaluation area. Four years of Southern Great Plains data were released to the evaluation area.

KAZRARSCL: Ka ARM Zenith Radar Active Remotely-Sensed Cloud Locations

The KAZRARSCL VAP provides cloud boundaries and best-estimate time-height fields of radar moments. A year of data from the Southern Great Plains, North Slope of Alaska, and two Tropical Western Pacific (Manus Island, Papua New Guinea, and Darwin Australia) sites were released to evaluation.

KAZRCOR: Ka ARM Zenith Radar Correction

For each of the Ka ARM Zenith Radar (KAZR) datastreams, the KAZRCOR VAP produces significant detection mask, corrects reflectivity for gaseous attenuation, and dealiases mean Doppler velocity. A year of data from the Southern Great Plains, North Slope of Alaska, and two Tropical Western Pacific (Manus Island, Papua New Guinea, and Darwin Australia) sites were released to evaluation.

MICROARSCL: Micro ARM Cloud Radar Active Remote Sensing of Clouds

MICROARSCL provides information about the Doppler characteristics of millimeter-wavelength cloud radars and helps identify radar clutter (e.g., insects). A year and a half of North Slope of Alaska data were released to the evaluation area.

MICROBASEEN: MICROBASE Ensemble Data Products for Cloud Retrievals

MICROBASEEN provides ensemble means, standard deviations, and probabilistic density distributions of the cloud microphysical properties retrieved by ARM's baseline cloud microphysical algorithm, known as MICROBASE, at the Southern Great Plains. A month of Southern Great Plains data were released to the evaluation area.

NAVBE: ARM Navigation Best Estimate VAPs for Ship Deployments

The motivation of this VAP is to consolidate many different sources into a single, continuous datastream to be used when information is required about ship location and orientation and to provide a more complete estimate than would be available from any one instrument. Data from the Marine ARM GPCI Investigation of Clouds (MAGIC) and ACAPEX field campaigns were released to the evaluation area.

SACRCOR: Scanning ARM Cloud Radar Correction

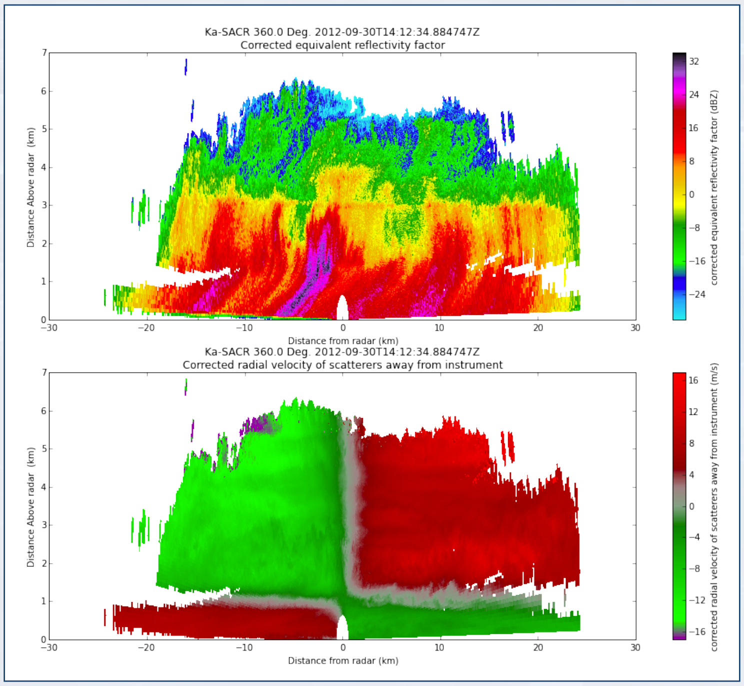
SACRCOR was proposed to develop a SACR corrections VAP to enhance the scientific value of data collected by the ARM Ka-, W- and X-band scanning cloud radars. Data from the Southern Great Plains, Cape Cod, Massachusetts, and Hyytiälä, Finland, were released to the evaluation area.

SHIPCOR: Ship Navigation Corrections for CEIL, HSRL, MPL

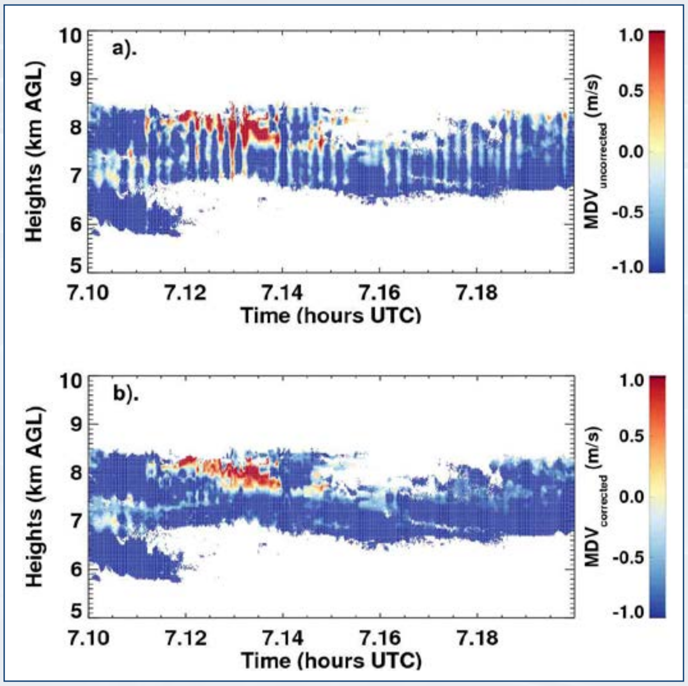
A new suite of evaluation VAPs is now available for the second ARM Mobile Facility to provide accurate ship location and orientation during ocean deployments and to correct for ship motion for the ceilometer, high-spectral resolution lidar, and micropulse lidar. Data from the MAGIC and ACAPEX field campaigns were released to the evaluation area.

WACRARSCL: W-band ARM Cloud Radar Active Remote Sensing of Clouds

WACRARSCL combines observations from the W-band cloud radar, micropulse lidar, and ceilometer to produce cloud boundaries and time-height profiles. Data from the Hyytiälä, Finland, Manacapuru, Brazil, and Gan Island, Maldives, field campaigns were released to the evaluation area. A year and a half of North Slope of Alaska data were also released the evaluation area.



Data from the Southern Great Plains, Cape Cod, Massachusetts, and Hyytiälä, Finland, were released to the ARM Data Archive evaluation area for the Scanning ARM Cloud Radar Correction value-added product.



All historical data were processed and released to the ARM Data Archive for the Doppler Lidar Profile value-added products for velocity azimuth-display and cloud and vertical velocity statistics. In addition, the algorithm was released to production status.

On the covers:

Front – Radar Row at the Southern Great Plains
In 2015, the road began to take shape to building the next-generation megasite at the Southern Great Plains site in Lamont, Oklahoma.

Inside – Main Barrow Platforms for North Slope of Alaska
Because the environment in the Arctic is changing rapidly, the North Slope of Alaska has become a focal point for atmospheric and ecological research and will be home to the second megasite of the ARM Facility.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