ARM

U.S. DEPARTMENT OF ENERGY

2017 ANNUAL REPORT

ATMOSPHERIC RADIATION MEASUREMENT

From the Technical Director

A Milestone Year Creating the Next-Generation ARM

2017 was a milestone year for the Atmospheric Radiation Measurement (ARM) Climate Research Facility. It marked the 25th anniversary of ARM collecting data at its first site in the Great Plains, 20 years of collecting data in the Arctic, and 10 years of collecting data with the ARM Aerial Facility. ARM successfully underwent its Triennial Review by a panel selected by the U.S. Department of Energy (DOE) and completed the development and testing of the Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) project's pilot phase, which adds modeling to ARM's suite of capabilities.

All of this exemplifies how ARM continues to support high-impact science—as it has throughout its history. Since a Decadal Vision was set forth in 2014, ARM has focused on helping ensure that the next generation of researchers would have the measurements they need of cloud and aerosol properties and their impacts on Earth's energy balance to continue to improve the scientific understanding of the atmosphere and the predictive capabilities of earth system models. Fiscal year 2017 was a year of seeing results from the Decadal Vision plan to combine observational and modeling elements.

This annual report showcases much of that progress, including:

- **Releasing LASSO's second set of results, made up of 544 simulations of shallow convection that span 13 days during May to August 2016 at ARM's Southern Great Plains atmospheric observatory.** This library of data bundles containing large-eddy simulations, accompanying observations, skill scores, and diagnostics can simplify users' needs for high-resolution data on shallow convective clouds. This is a landmark capability that is already attracting broad attention from diverse subject areas ranging from assessment of measurement strategies to model parameterization development.
- **Implementing a small and a moderate-size computer cluster at the ARM Data Center to support both the LASSO high-resolution model simulations and analyses associated with these simulations and large observation data sets.** These have greatly increased the Facility's computational capacity and will enable more effective use of the growing volume and complexity of ARM data.
- **Continuing regular sampling on the North Slope of Alaska using unmanned aerial systems (UAS) and tethered balloon systems (TBS) to obtain measurements of spatial heterogeneity.** These series of short deployments are meant to sample the varying conditions of the Arctic to support modeling and cloud process studies and also represent the continuing maturation of ARM UAS capabilities.
- **Procuring a mid-size UAS that will permit sampling over a much larger range, including flights over the Arctic Ocean.** Test flying is currently underway, with the UAS available to the scientific community for campaigns expected in 2019.

In addition, ARM continued to provide continuous data from its three fixed observatories and to sponsor field campaigns for scientists to obtain specific data sets or to test and validate instruments. There were a number of key campaigns in 2017 that collected data across the globe, including in Antarctica and on tiny Ascension Island in the South Atlantic Ocean. Also in this report, we examine the impactful scientific results from a few past campaigns and the significant research highlights from the year.

Throughout its history, ARM 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.

At ARM, we are proud of the Facility's past and current scientific impact, and we are excited about the progress we made in fiscal year 2017. The combined observational and modeling elements, and continued effective operations, will enable a new level of scientific inquiry.

Jim Mather
ARM Technical Director

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Facility **OVERVIEW**

The World's Premier Ground-Based Observations Facility to Advance Atmospheric Research

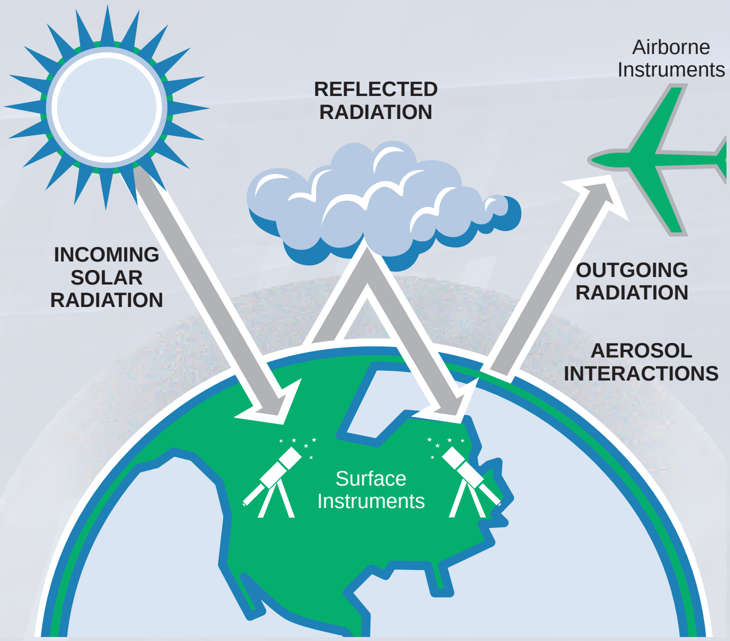
Data from the ARM Facility, a multilaboratory, U.S. Department of Energy (DOE) scientific user facility, are helping researchers answer basic science questions about clouds, aerosols, cloud formation, and Earth's energy balance.

In addition to advancing scientists' understanding of how the atmosphere works, over 25 years of data collected around the world by ARM are being used to improve the accuracy of how clouds, aerosols (small particles in the air), precipitation, and their interactions with Earth's radiant energy are represented in earth system models. Better models improve the accuracy of long-term weather forecasts and help our nation develop sustainable solutions to energy and environmental challenges.

ARM was the first atmospheric research program to deploy a comprehensive suite of cutting-edge instruments to continually measure cloud and aerosol properties and their impacts on Earth's energy balance. This strategy revolutionized scientists' ability to collect long-term statistics of detailed cloud properties and now serves as a model for similar programs around the world.

Since 1992, data collected by ARM in diverse climates have yielded insights into a range of scientific issues, including measuring absorption of radiation (energy) from the sun by clouds and water vapor, identifying factors that trigger cloud formation, and detailing the characteristics of aerosol and cloud properties, such as ice crystal sizes. Observations have led to greatly improved techniques for measuring cloud properties from the ground, which reveal ways to enhance the representation of clouds in earth system models.

This report provides an overview of the ARM Facility and a sample of achievements for fiscal year 2017 (FY17).



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.

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 Observatories

ARM operates three long-term, heavily instrumented fixed-location atmospheric observatories, three mobile facilities, and an aerial facility, and provides freely available data for use by scientists around the world. The long-term observatories were chosen to represent a broad range of atmospheric conditions and processes:

- **Southern Great Plains (SGP)**—The first observatory established by ARM in 1992 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)**—This includes a site at Utqiaġvik (formerly known as Barrow), near the edge of the Arctic Ocean, and a location in Oliktok Point, Alaska, where ARM has secured special-use arctic airspace.
- **Eastern North Atlantic (ENA)**—In operation since 2013, the newest ARM observatory is located on Graciosa Island in the Azores.

Each observatory operates a broad suite of advanced measurement systems to provide high-quality research data sets. The current generation of instruments includes three-dimensional cloud and precipitation radars, advanced lidars that provide information such as profiles of aerosol extinction and vertical air motion, infrared interferometers, in situ aerosol observing systems, microwave radiometers, and balloon-borne sounding systems among others.

Measurements obtained at the fixed atmospheric observatories are supplemented with data obtained from intensive field campaigns proposed by the scientific research community. Campaigns may use an ARM Mobile Facility (AMF), a collection of advanced measurement systems that can be deployed to locations around the world for six months to two years, or capabilities of the ARM Aerial Facility (AAF). Major campaigns in FY17 collected ground-based data from Antarctica and at Ascension Island in the South Atlantic Ocean, and aerial data at ARM's ENA observatory. In addition, about 70 smaller user-proposed intensive operational periods were conducted at either fixed or mobile facility locations. Once collected, the data from all of the ARM observatories are carefully reviewed for quality and stored in the ARM Data Center for use by the atmospheric science community.

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 Center to aid in further research.

ARM Data Center Reaches 1 Petabyte

In late December 2016, ARM reached a milestone of 1 petabyte (PB) of stored data archived in the ARM Data Center, beginning with the earliest data file from September 1992. To put that in context, 1 PB could hold approximately 20 million 4-drawer filing cabinets of text. Those file cabinets would fill 2 square miles.

At the end of FY17, the ARM Data Center held just shy of 10,000 continuous datastreams and 1,412 principal-investigator-contributed and field campaign data products. Data have been flooding into the ARM Facility with the increased types and amounts of instrumentation, much of it running continuously in the field. It took 20 years for ARM to reach the first petabyte, but the data collection rate is accelerating rapidly so ARM will hit its second petabyte much faster.

In late December 2016, ARM reached a milestone of 1 petabyte—picture approximately 20 million 4-drawer filing cabinets of text—of stored data archived in the ARM Data Center.

At Age 25, Southern Great Plains Observatory Gathers Critical Data

2017 was the 25th anniversary of data collected by the ARM Facility. The Southern Great Plains (SGP) site opened in 1992 and was the first ARM atmospheric observatory. Centered in Lamont, Oklahoma, it was chosen for its synergies with other programs and for its logistical advantages because of its mid-continental location. It remains ARM's flagship atmospheric observatory.

In those two and a half decades, ARM science and data have inspired more than 4,000 journal articles. Of that number, the Oklahoma site accounts for about 837—more than any other source of data, fixed, mobile, or airborne. There is a legacy of science that includes water vapor methodologies developed at SGP and the quality of radiometric calibrations, as well as multi-year, decadal studies that use SGP data.

Discover 20 Years of ARM Arctic Data

ARM's North Slope of Alaska (NSA) atmospheric observatory in Utqiaġvik (formerly Barrow), Alaska, celebrated its 20th year of continuous operation in 2017, marking another important data collection milestone.

An arctic observatory was planned for in ARM's original site identification report. The Utqiaġvik site began continuous operations in the summer of 1997, when the Surface Heat Budget of the Arctic Ocean (SHEBA) field campaign kicked things off by deploying a suite of basic instruments on an ice breaker in the Arctic Ocean. Following SHEBA, the North Slope of Alaska site was established in 1998.

ARM's NSA observatory has a wider array of instruments than any other arctic research site. It has accelerated the development of atmospheric system knowledge and improved models, especially about the critical surface energy budget.

Celebrating 10 Years of Aerial Data

October 2016 marked the 10th anniversary of the ARM Aerial Facility (AAF). ARM consolidated all its aircraft research efforts in 2006.

At the heart of the AAF is the 63-foot-long Gulfstream-159 (G-1) aircraft, which during campaigns is carefully stacked with instruments hooked to intakes that capture outside air, particulates, and liquids. Onboard instruments collect data on aerosol and cloud properties, trace gases, radiation, and other factors, depending on a particular campaign's research focus. During flights lasting up to five hours, the G-1 carries two pilots and two to five scientists on data-scouring missions below, through, and above the clouds. The AAF fleet expanded in 2016 to include unmanned aerial systems (UAS).

The SGP atmospheric observatory opened in 1992. Still the flagship of the ARM Facility, it was the first ARM site to begin continuous data collection that now spans 25 years.

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.

ARM is directed by DOE's Office of Biological and Environmental Research, part of the Office of Science. An Infrastructure Management Board coordinates the scientific, operational, data, financial, and administrative functions of the ARM Facility. The ARM Science Board, selected by the DOE ARM Program Manager, serves as an independent review body that reviews proposals for the ARM Mobile Facility and ARM Aerial Facility 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 atmospheric research program, as well as by scientists at other government, academic, and private organizations. The 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.

Triennial Review Finds ARM Enables High-Impact Science

Once every three years, ARM undergoes an extensive external review by a panel selected by DOE. The latest review was April 12 and 13, 2017, in Gaithersburg, Maryland. The reviewers found that "ARM has unique capabilities, enables high-impact science supporting DOE Climate and Environmental Sciences Division (CESD) strategic goals, has effective management and operations, effectively engages with the DOE Office of Biological and Environmental Research (BER) user community, and has addressed the recommendations from the 2014 review." These were the criteria against which ARM was being assessed.

"The review is quite positive," ARM Technical Director Jim Mather said. "While the review is very good, the reviewers have identified areas where we can improve—many of which are priorities that we are already working on and that we discussed during the review."

Newly Elected User Executive Committee Gets Down to Business

Elections for ARM's User Executive Committee (UEC), the official voice of the user community in its interactions with ARM management, were held in fall 2016 with new terms beginning January 1, 2017. The 12-member UEC provides objective, timely feedback to ARM leadership with respect to the user experience and represents ARM's various science domains. Members serve four-year terms with a staggered election cycle.

During FY17, the UEC focused on four goals under the leadership of new chair Larry Berg, Pacific Northwest National Laboratory.

1. Actively engage with users beyond the Atmospheric System Research (ASR) program, which still provides ARM's largest single constituent group.
2. Spread the word about ARM data among early career scientists.
3. Represent user interactions in infrastructure planning.
4. Encourage users to talk more with the committee.

2017 Joint Meeting Well Attended Despite Spring Nor'easter

About 285 ARM staff members and ASR scientists met March 13 to 16—in the middle of a major snow storm—at the 2017 Joint User Facility/Principal Investigator Meeting in Tysons Corner, Virginia, to review progress from the past year and plan future research directions. With more than 30 plenary presentations, 36 breakout sessions, and 200 science and facility posters in four poster sessions, the meeting shared a wealth of information in a very short time frame.

The opening plenary included updates from DOE program managers, a tutorial on scientific product development led by ARM, and a chance for the four new ASR working groups—Aerosol Processes, Warm Boundary Layer Processes, High Latitude Processes, and Convective Processes—to meet for the first time.

Key **ACCOMPLISHMENTS**

Featured Field Campaigns

More AWARE: ARM Completes Challenging Antarctic Atmospheric Study

In a science campaign of unprecedented challenge, researchers in FY17 completed the first substantial atmospheric measurements on the West Antarctic Ice Sheet in 50 years. During the ARM West Antarctic Radiation Experiment (AWARE), sophisticated instruments collected data that may help explain changes on this remote continent that could have global implications.

"Ice mass loss from West Antarctica is now the second-largest polar contribution to global sea level rise, after Greenland, and this contribution is expected to increase," said Dan Lubin, AWARE's lead scientist and a researcher at Scripps Institution of Oceanography, one of several research organizations working on the campaign.

Papers have already been published about events during the campaign. For the first time, experts and instrumentation were on hand for an extensive summer surface melt that affected an area more than twice the size of California (Nicolas et al. 2017). Researchers used satellite data to measure the extent and duration of the melt, as well as ARM data to examine the atmospheric physics that led to it. Understanding these physics will provide insight into its future likelihood. Ryan C. Scott at Scripps and colleagues (2017) also used AWARE data to help quantify how clouds affect warming in the area.

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Scott RC, D Lubin, AM Vogelmann, and S Kato. 2017. "West Antarctic ice sheet cloud cover and surface radiation budget from NASA A-Train satellites." *Journal of Climate,* 30:6151-6170, doi:10.1175/JCLI-D-16-0644.1.

The 14-month AWARE campaign continues to shine the light on atmospheric conditions in the Antarctic region. *Image courtesy of Joshua Swanson, National Science Foundation – United States Antarctic Program.*

LASIC: When Smoke Gets in Your Eyes

The United States may have just finished one of the worst wildfire seasons in recent history, but dealing with smoke is commonplace now for Paquita Zuidema, an atmospheric scientist from the University of Miami. In October 2017, Zuidema and her colleagues finished 17 months of studying smoke in the Layered Atlantic Smoke Interactions with Clouds (LASIC) field campaign.

Located on Ascension Island, more than 1,000 miles west of Africa, the campaign used the first ARM Mobile Facility to measure smoke after it had been blown across the ocean. Africa is a large producer of smoke from burning vegetation, and this smoke is carried routinely across one of the largest low cloud decks on Earth. The interaction of this smoke with this cloud deck in the equatorial Atlantic is currently not well understood, but is an important part of the climate system. A better understanding of this phenomena can improve predictions of cloud-aerosol interactions.

"Early LASIC measurements surprised us," said Zuidema, LASIC's lead scientist. "Smoke is present on Ascension Island nearly all the time. The extremely high concentrations at times were comparable to being downwind of wildfires in the United States."

Before LASIC, only one anecdotal aircraft profile—taken in 2000—hinted that smoke might be present in boundary layer clouds.

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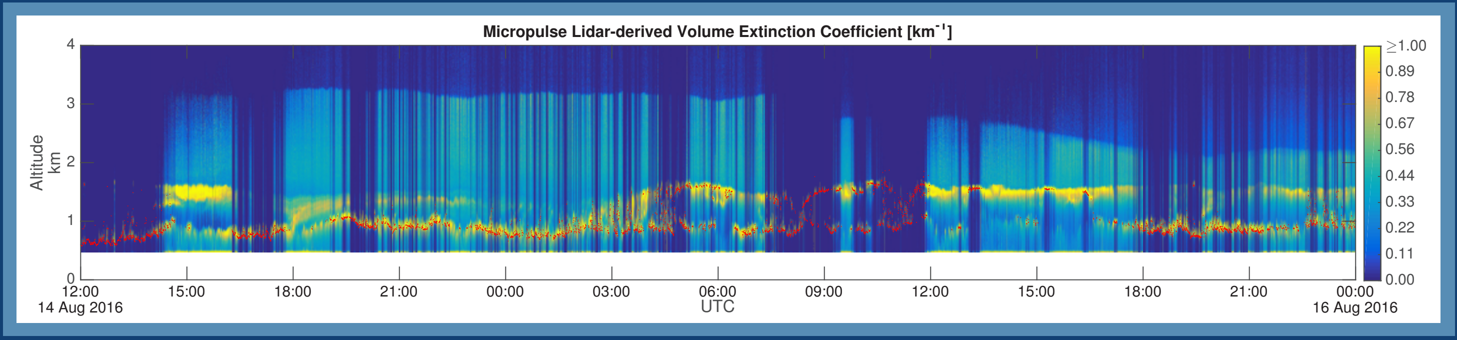
>
> *—Paquita Zuidema, LASIC lead scientist from the University of Miami*

But that isn't the only new ground broken by the campaign. LASIC was the first study to gather comprehensive data with ground-based instruments on changes to the radiative properties of smoke-related aerosols after long-range transport. It was also the first time that such data were gathered on a diurnal cycle.

The field campaign will provide an amazing amount of data to help scientists understand the effects of smoke and to improve global aerosol and earth system models.

Reference

Zuidema P, J Redemann, J Haywood, R Wood, S Piketh, M Hipondoka, and P Formenti. 2016. "Smoke and clouds above the Southeast Atlantic: upcoming field campaigns probe absorbing aerosol's impact on climate." *Bulletin of the American Meteorological Society,* 97:1131-1135, doi:10.1175/BAMS-D-15-00082.1.



Yellow on this set of measurements from the ARM Mobile Facility shows the amount of smoke from the surface up to 2 kilometers (1.24 miles) above Ascension Island (red dots indicate the cloud base).

In the Air and On the Ground, ACE-ENA Searches for Better Data

It is no surprise to most atmospheric scientists that low clouds are poorly represented in earth system models, and gaps in observational data are largely to blame. The Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign, which began in June 2017, is filling some of these observational gaps. Centered at ARM's atmospheric observatory on Graciosa Island in the Azores, the campaign has two 40-day phases, including one in January and February 2018.

"Combining ground and aircraft observations is at the heart of ACE-ENA," said Jian Wang, ACE-ENA lead scientist and an atmospheric scientist at Brookhaven National Laboratory.

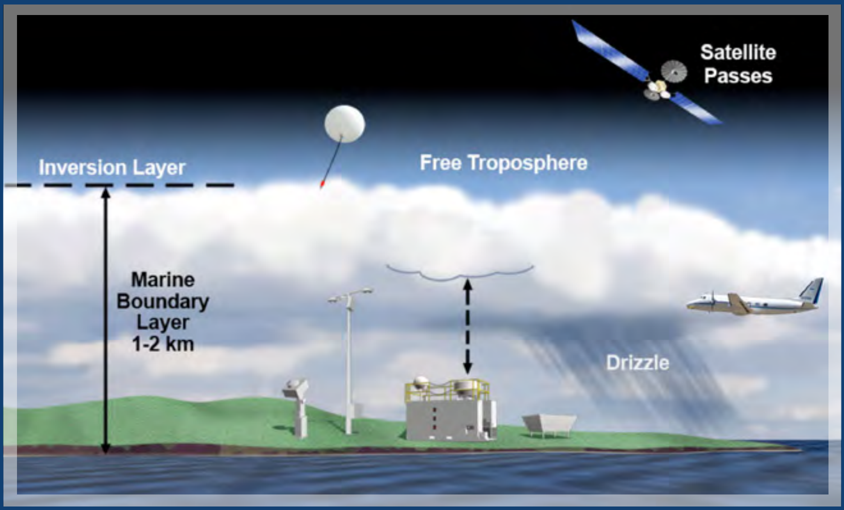
Air measurements are largely covered by ARM's Gulfstream-159 (G-1) research aircraft, for the first time carrying a Holographic Detector for Clouds. Developed by Michigan Technological University in part through support from the ARM Facility, this wing-mounted device takes detailed pictures of cloud droplets so scientists can understand how populations of the microscopic droplets evolve. The results will shed light, for example, on how different-sized drops behave during mixing of wet and dry air. These changes heavily affect weather patterns.

Aerosol samples collected on the G-1 aircraft will also be brought back to the Environmental Molecular Sciences Laboratory at Pacific Northwest National Laboratory and the Advanced Light Source at Lawrence Berkeley National Laboratory for subsequent laboratory analyses.

Already the campaign is bearing fruit. This summer, team members led an earth system processes workshop for postgraduate students. Participants discussed aerosol processes over the ENA, the importance of marine boundary clouds, and cloud and aerosol interactions. Other lecturers came from the University of the Azores; University of Lisbon; Portuguese Institute for Sea and Atmosphere; Institute for Systems and Computer Engineering, Technology, and Science; Duke University; Stevens Institute of Technology; Rutgers University; Michigan Technological University; and Oceanic Observatory of Madeira.

When the Land Affects the Sky: LAFE Uses Remote Sensing to Study Land-Atmosphere Feedback

The sky may seem far above us, but interactions between the land surface and the atmosphere are affecting both. The atmospheric boundary layer—the lowest part of the atmosphere—controls the exchange of heat and water between the Earth's surface and the atmospheric column. Understanding these interactions and representing them accurately in models are fundamental for accurate predictions of boundary layer clouds, which can further lead to the development of more vigorous deep convective cloud systems.



The measurements taken in ACE-ENA detail processes in the marine boundary layer.

The Land-Atmosphere Feedback Experiment (LAFE; pronounced “la-fey”) at ARM’s Southern Great Plains (SGP) atmospheric observatory looked at the relationships between soil, vegetation, and atmospheric properties. By observing atmospheric boundary layer structure over areas with varying vegetation—for example, native grasslands, wheat fields, and bare soil—researchers learned more about land-atmosphere interactions.

“The simultaneous measurements of surface and entrainment fluxes, as well as the daily cycle of the boundary layer thermodynamic state, provided a unique data set,” said Volker Wulfmeyer, LAFE lead scientist and chair of physics and meteorology at Germany’s University of Hohenheim. “We applied probably the most sophisticated scanning active remote-sensing approach so far in a field campaign.”

Despite their challenging operation and coordination, all instruments performed extremely well with almost no data gaps during all intensive and special observational periods, significantly exceeding expectations. The data will allow scientists to characterize land surface-atmospheric interactions that depend on large-scale meteorology and local variables such as soil moisture and vegetation. The solar eclipse on August 21, 2017, provided a unique look at land-atmosphere feedback.

Though the experiment ran for only one month (August 2017), it took nearly a dozen scientific organizations and more than 60 instruments, including several highly advanced lidar systems, to obtain measurements of temperature, moisture, wind fields, and cloud evolution. These systems came from Germany, the National Oceanic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research, and a number of universities to complement the measurements routinely taken at the ARM SGP observatory. Scientists chose August because of the large differences in surface temperatures between different fields and bare soil—for example, pastures versus fields where the wheat had already been harvested.

Initial results of the effort were presented at the American Geophysical Union Fall Meeting in 2017. More insights will come out of LAFE in the months to come.

“The results can help verify large-eddy simulation and mesoscale models, which are planned for the SGP site,” said Wulfmeyer. “Thus, this new generation of experiments can drive the development of improved parameterizations of key processes in weather and earth system models.”

“The simultaneous measurements of surface and entrainment fluxes, as well as the daily cycle of the boundary layer thermodynamic state, provided a unique data set. We applied probably the most sophisticated scanning active remote-sensing approach so far in a field campaign.”

—Volker Wulfmeyer, LAFE lead scientist from Germany’s University of Hohenheim

LAFE benefited from a variety of specialized scanning equipment, including the NOAA Doppler lidar DALEK (on the blue container), University of Hohenheim scanning temperature lidar (central white trailer), and University of Hohenheim scanning water vapor differential absorption lidar (trailer on the right).
Image courtesy of Volker Wulfmeyer, University of Hohenheim.

CLOUD-MAP: The Future is Now

In July 2017, a dozen unmanned aerial systems (UAS) took to the skies at ARM's Southern Great Plains (SGP) atmospheric observatory in Oklahoma for the second year of the four-year CLOUD-MAP field campaign.

CLOUD-MAP stands for the project's formal name—Collaboration Leading Operational UAS Development for Meteorology and Atmospheric Physics.

"As far as we know, this experiment is the largest research effort yet attempted to use UAS to study the weather," noted Jamey Jacob, CLOUD-MAP lead scientist and a professor of mechanical and aerospace engineering at Oklahoma State University.

CLOUD-MAP's overall goal is to develop small, affordable unmanned systems and a knowledge base about their use. Jacob is convinced that UAS will become a common tool for researchers because they make aerial data acquisition much easier and cheaper than using conventional aircraft, which cannot fly as low or slow.

While CLOUD-MAP only arrives in force at the SGP once a year to test systems, the developers use the site year-round to calibrate instruments.

"No one else has the SGP's breadth and depth of instrumentation, including tower-mounted and balloon-borne, to calibrate and validate our measurements," said Jacob.

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>
> ***—Jamey Jacob, CLOUD-MAP lead scientist from Oklahoma State University***

Mike Ritsche, SGP assistant facility manager and a meteorological specialist at Argonne National Laboratory, knows the future when he sees it. "This is definitely the way aerial atmospheric measurement is headed, especially for the lower boundary layer," he said, "and we want to be part of it."

"Our goal is to determine best practices," said Jacob. "We're breaking new ground with technology and processes, and we're collecting good, usable data. In the end, we want to provide out-of-the-box data collection tools for scientists to use without worrying about the technical aspects."

Laughing, he added, "I have to keep reminding our engineers: It's all about the data, not the enabling tools."

With flying finished for now, the CLOUD-MAP team is absorbing the data and tweaking future plans. For example, a new component has been added that will compare UAS-gathered measurements with those collected by the SGP's tower instruments. With campaign plans to continue over the next two years, expect to see more UAS activity in the Oklahoma sky.

Some CLOUD-MAP participants stop at the entrance to ARM's SGP atmospheric observatory with their UAS. *Image courtesy of Jamey Jacob, Oklahoma State University.*

Past Campaign Results

STORMVEX Continues to Yield a Storm of Data

It is rarely a good idea to tell a scientist she has her head in the clouds. But Anna Gannet Hallar, an atmospheric scientist who specializes in aerosol and cloud microphysics, thinks it is a lovely idea.

Hallar directs the Storm Peak Laboratory, a Rocky Mountain satellite facility of the Nevada-based Desert Research Institute. She joined with dozens of scientists, students, and citizen-science volunteers as part of a five-month study of mountaintop clouds in Colorado's Park Range. The Storm Peak Lab Cloud Property Validation Experiment (STORMVEX) provided an unprecedented amount of information on the properties of liquid, mixed-phase, and precipitation clouds. The storm of data will be powering analyses for decades to come.

"We're still learning, and a lot of the analysis we had planned is still emerging," said Gerald "Jay" Mace, STORMVEX lead scientist and a University of Utah atmospheric scientist. "We're on the verge of really amazing science."

Studying Up a Storm

STORMVEX data are linked to at least 11 journal articles, four reports, and three theses so far. Pacific Northwest National Laboratory atmospheric researcher Evgueni Kassianov and colleagues at other institutions (2017) used STORMVEX data to track how trans-Pacific transport of African and Asian dust influences North American aerosol properties.

Matthew Shupe (2016), atmospheric professor at the University of Colorado, Boulder, investigated the composition and size of cloud condensation nuclei, the tiny particles around which clouds form. He took advantage of the information from the high-elevation STORMVEX research sites to investigate the properties of particles that form ice and mixed-phase clouds. They are less studied than warm clouds, even though they dominate precipitation formation globally.

David Kingsmill at the Cooperative Institute for Research in Environmental Sciences in Boulder and colleagues (2016) looked at the possible correlation between mountain structure and precipitation. Their results found a weaker correlation than expected, but shorter-term, transient processes may mask the true correlation.

Researchers from the University of Wyoming and the University of Illinois at Urbana-Champaign (2015) studied the impact of blowing snow on precipitation, a phenomenon that has not been researched extensively. Small, fractured snow particles, they found, may act as a cloud-seeding mechanism that enhances snow growth.

Sunlight gilds the mountains overlooking the valley instrumentation in STORMVEX.

Data from STORMVEX fueled recent research on ice cloud formation, the correlation between mountain structure and precipitation, and the impact of blowing snow on precipitation.

Many Heights, Many Data

By design, STORMVEX gathered multiple layers of data from multiple altitudes. The second ARM Mobile Facility (AMF2) was located at 2,760 meters (9,055 feet). The portable instrument cluster included devices for measuring aerosols, profiling the atmosphere, and characterizing clouds. More AMF2 gear was stacked on snow-white ARM shipping containers at Christie Peak at 2,103 meters (6,900 feet), while Storm Peak Lab gathered data from the top of Mount Werner (3,200 meters, or 10,500 feet).

“Collecting such a wealth of data from multiple levels in a region of complex terrain was a longstanding goal of ARM,” said Mace. “STORMVEX presented a unique challenge, and the results will continue to provide outstanding opportunities for modeling.”

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Sixteen Years of Routine Aerial Measurements Provide Powerful Data

One day in March 2000, a Cessna 172 took off from a little airstrip in Ponca City, Oklahoma. The intent: Measure air samples of dried aerosols at nine different altitudes to determine their light-scattering and absorption properties.

The data were collected on behalf of ARM’s In Situ Aerosol Profiles (IAP) campaign, an investigation of atmospheric composition. This humble beginning—one pilot, two instruments, and a plane the size of a family sedan—turned into 16 years of data-gathering flights that ended in the fall of 2016. Recorded in that long interval were the vertical profiles of aerosols (and later trace gases) in the atmosphere over ARM’s Southern Great Plains (SGP) atmospheric observatory, and how they change with time.

“I’m not aware of a greater set of profiles for aerosols and trace gases,” said Beat Schmid, ARM Aerial Facility manager at Pacific Northwest National Laboratory.

Over the years, instrumentation advanced, and planes were replaced with bigger, faster ones. In 2007, after 600 research flights, the IAP campaign transitioned to the first ARM-ACME (Airborne Carbon Measurements) field campaign.

Week In, Week Out, Always Flying

By the time that first Cessna lifted off the ground, the broad outline of the way measurements were gathered above the SGP was established: Twice a week, fly in daisy-like vertical flight patterns at different altitudes, from 152.4 meters (500 feet)

Thanks to the ARM-ACME campaigns, more than a decade of air samples taken over ARM’s SGP atmospheric observatory are available.

This Cessna 206 became the air-sampling workhorse of ARM-ACME.

to, later, 5,334 meters (17,500 feet). Fly these 5- to 10-minute horizontal legs only in good weather, and never into clouds. (DOE safety rules forbade a single-pilot aircraft from flying into clouds.)

Data from lower elevations allowed scientists a look at fine details and the role of the land surface. Measurements from higher altitudes are helping scientists understand how constituents are transported at the scale of continents and has improved the way they are represented in earth system models.

Next Step, But Not the Last

Over time, ARM-ACME had six iterations. One of these campaigns, ARM-ACME V, focused on the North Slope of Alaska. The other five inventoried trace gases in weather-charged terrain spanning Oklahoma and Kansas. Ground-based instruments at the SGP complemented ARM-ACME's aerial record of changes in trace gases in the column of air directly overhead.

A few basic imperatives informed ARM-ACME: Establish a long-term baseline of measurements from vertical profile flights. Add in data from land-atmosphere interactions. Combine data with that from national observing networks, such as the National Oceanic and Atmospheric Administration's Cooperative Air Sampling Network and NASA's Orbital Carbon Observatory, to capture long-term trends.

In 2007, with the addition of a specialized analyzer aboard the Cessna, the plane became the only airborne U.S. platform for systematic continuous measurements of certain trace gas concentrations in the atmosphere.

In 2010, for cross-validation purposes, ARM-ACME added a second trace gas analyzer on the platform. That brought the campaign closer to the precision of the 0.1 parts per million (ppm) standard achieved in laboratories and at ground-based observation sites for trace gases. It is notoriously difficult to measure minute changes in gas levels, some of which hover near 400 ppm.

"We're looking for a very small change in that number, smaller than about a tenth of a percent," said Sébastien Biraud, lead scientist for the ARM-ACME campaigns and an atmospheric scientist at Lawrence Berkeley National Laboratory. But in the end, he added, ARM-ACME "achieved unprecedented accuracy."

ARM-ACME VI started in October 2015 and closed out a year later. The measurements helped close a trace gas data gap in the south-central United States, where some trace gas estimates may be a mere third of real totals.

So far, the publications related to ARM-ACME have reached more than 30. Additional published work is on the way, thanks to a data set so large, novel, and robust, said Schmid. "It will be used heavily."

"We're looking for a very small change in that number, smaller than about a tenth of a percent. ARM-ACME achieved unprecedented accuracy."

—Sébastien Biraud, ARM-ACME lead scientist from Lawrence Berkeley National Laboratory

ERASMUS Teaches Scientists How to Fly in the Cold

The Arctic is experiencing rapid changes and is consequently the object of intense research. It is also an ideal place to test the use of unmanned aerial systems (UAS) for data gathering. At Alaska's Oliktok Point, ARM hosted the Evaluation of Routine Atmospheric Sounding Measurements Using Unmanned Systems (ERASMUS) campaign. ERASMUS taught scientists to use small, low-cost UAS to collect hard-to-gather data that will improve earth system models.

"These unmanned systems can provide revolutionary scientific information through the routine measurement of atmospheric conditions, particularly properties related to clouds, aerosols, and radiation," said Gijs de Boer, ERASMUS lead scientist and a researcher with the Cooperative Institute for Research in Environmental Sciences at the University of Colorado, Boulder.

These flights demonstrated that, despite some challenges, small UAS are capable of providing research-grade measurements in the lower portion of the arctic atmosphere. The team recorded 17.3 hours of flying time over 11 days.

Gijs de Boer, lead scientist for ERASMUS, works on one of the UAS used to collect atmospheric data in Alaska.

Research Highlights

NASA, We Have a Problem: New Research Improves Modeling of Ice Particles in NASA Models

The NASA Goddard Institute for Space Studies (GISS) maintains and advances one of the most respected earth system models for simulating sensitivity to a variety of factors such as volcanic eruptions and solar activity. But studies showed that the model overestimated upper tropospheric ice water contents by twice as much as was possible in the real world.

NASA scientists traced the issue back to how the model partitioned ice into snow and cloud components, particularly in areas with a lot of rain.

"Depending on their altitude and thickness, ice clouds have the potential to warm or cool Earth's surface," said Gregory Elsaesser, Columbia University/NASA GISS and lead author of the paper describing the effort. "Our improved simulation of cloud ice in the upper troposphere is an important step toward increasing the accuracy of model projections."

To fix the problem, Elsaesser and his colleagues at NASA and NASA's Jet Propulsion Laboratory turned to years of aircraft measurements from multiple ARM field campaigns and NASA missions. Among them were data on ice clouds from the Small Particles in Cirrus (SPARTICUS) campaign in 2010 and the Midlatitude Continental Convective Clouds Experiment (MC3E) in 2011. The researchers discovered that ice particles falling from deep clouds were smaller than expected and fell faster.

"The results were new observational benchmarks for ice particle sizes and fall speeds," said Elsaesser.

Once input into the model, the new cloud ice parameters decreased estimated upper troposphere ice from deep clouds by 30 to 50 percent. More important, the numbers aligned with real-world satellite data.

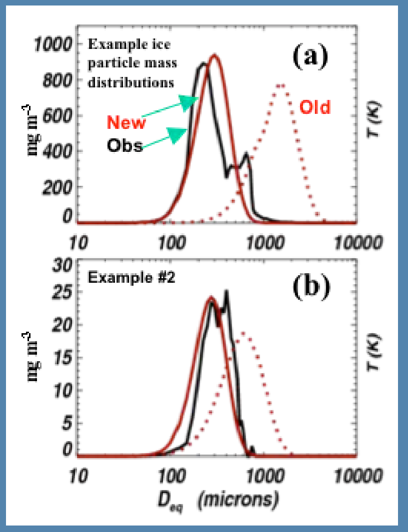
"Our study highlights the value of using multiple field campaign and satellite observations in both the development step and evaluation step of creating earth system models," said Elsaesser.

Reference

Elsaesser GS, AD Del Genio, JH Jiang, and M van Lier-Walqui. 2017. "An improved convective ice parameterization for the NASA GISS global climate model and impacts on cloud ice simulation." *Journal of Climate,* 30:317-336, doi:10.1175/JCLI-D-16-0346.1.

Autoconversion Does Not Mean Auto-correct: Researchers Identify Deficiency in Aerosol-Cloud Lifetimes in Models

One of the largest sources of uncertainty in current earth system models is how cloud properties will change with the number of aerosols in the atmosphere. Traditionally, aerosols



Before the new ice parameters were built from campaign data, model results varied widely from measurements [dotted red lines in (a) and (b) were the old model results; black lines are from the measurements]. Afterward, results (solid red lines) are more closely aligned with measurements (black lines), changing results by as much as 50 percent in certain areas.

have been thought to lengthen cloud lifetime by increasing the number of droplets in a cloud and reducing their size. These changes delay and reduce the formation of rain, which would otherwise cause clouds to dissipate. Longer-lived clouds increase cloud cover and reflect more sunlight.

Unfortunately, measurements of such effects are limited and sometimes contradictory. Most earth system models opt for increasing the amount of liquid water as aerosol concentrations increase, which may not be correct.

"We know those results don't match observations," said Joyce Penner, Distinguished Professor of Atmospheric Science at the University of Michigan. "Previous studies attempted to fix the problem by tuning autoconversion rates, but the results still overestimated the amount of liquid water in the atmosphere."

Autoconversion rates control how fast cloud droplets collide and combine to form precipitation in models. To determine the source of error in these rates, Penner and her colleague Cheng Zhou used observational data from ARM's Southern Great Plains atmospheric observatory to compare results from two widely used models. One was a more detailed cloud-resolving model. The other was a simplified version of an earth system model.

They quickly saw that the autoconversion rates were not the problem, because even with the same rates and data, the models returned opposite results. The issue lay deeper.

The cloud-resolving model balanced the amount of water in the top of a cloud, which increased liquid water, with the autoconversion rates, which decreased the water. The end result was that liquid water stayed relatively constant with aerosol concentrations. The earth system model, on the other hand, failed to take into account increased mixing of dry air from above the cloud with increases in aerosols.

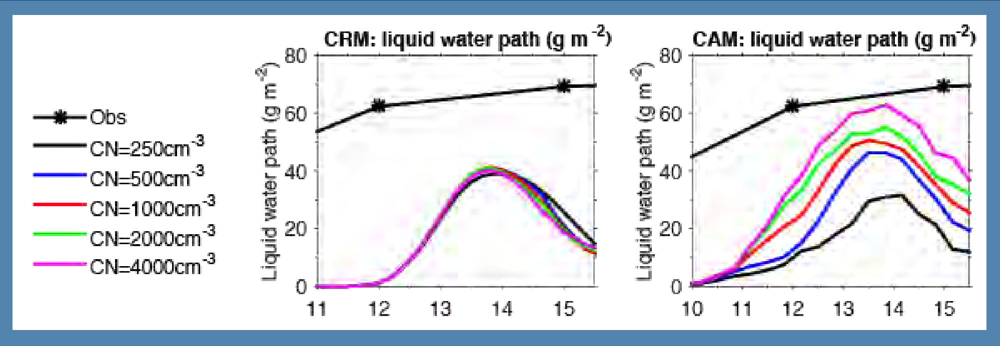
"The earth system model couldn't simulate the growth of the cloud top because of its coarse vertical resolution," said Penner. "But even if that is corrected, key parameters are not linked to the cloud droplet number. That means that any changes in the number of aerosols will have no direct impact on mixing or liquid water."

And that means the model will always come up short.

"The results suggest that earth system models need to include the dependence of cloud-top growth and the evaporation/condensation process on cloud droplet number concentrations to more accurately simulate clouds and their interactions with aerosols," said Penner.

Reference

Zhou C and JE Penner. 2017. "Why do general circulation models overestimate the aerosol cloud lifetime effect? A case study comparing CAM5 and a CRM." *Atmospheric Chemistry and Physics,* 17(1):21-29, doi:10.5194/acp-17-21-2017.



No matter the aerosol number concentration (CN in the legend), results from the cloud-resolving model (CRM) and earth system model (CAM) could not match real-world observations for how clouds and aerosols react to influence cloud lifetimes.

How Low Can We Go? Researchers Study Low-Aerosol Conditions for Insights

Tiny aerosols in the atmosphere form the nuclei around which clouds condense and grow. Understanding exactly how is key to improved understanding of these critical components of the earth system, but finding a location and time in the Northern Hemisphere to study cloud condensation nuclei can be difficult because of atmospheric conditions and high aerosol concentrations.

Enter ARM's Eastern North Atlantic (ENA) atmospheric observatory on Graciosa Island in the Azores. The remote site was perfect for the study envisioned by University of Washington researchers to provide new insights into processes controlling aerosol concentrations.

"The site is far from continental sources of aerosols," said Robert Wood, University of Washington professor in atmospheric sciences and lead author of the paper describing the effort. "Yet there is clear evidence of continental aerosols reaching there from North America."

Graciosa Island experiences concentrations of cloud-forming aerosols that vary by two orders of magnitude, from 10 particles per cubic centimeter to more than 1,000 per cubic centimeter. Few observational sites experience such clean conditions, and so very few studies have examined the low end of this wide range, which is more representative of past (pre-industrial) conditions when low concentrations of aerosols were more common.

Digging through 20 months of surface, satellite, and weather model data, Wood and his colleagues looked for cases in which the island experienced very low concentrations of aerosols. Their hope was to find clues to the processes that remove particles from the atmosphere and ultimately to understand what past conditions were like. Understanding these past conditions is important because the effects of aerosols on clouds inherently depend on the nature of the clouds before pollutants were added.

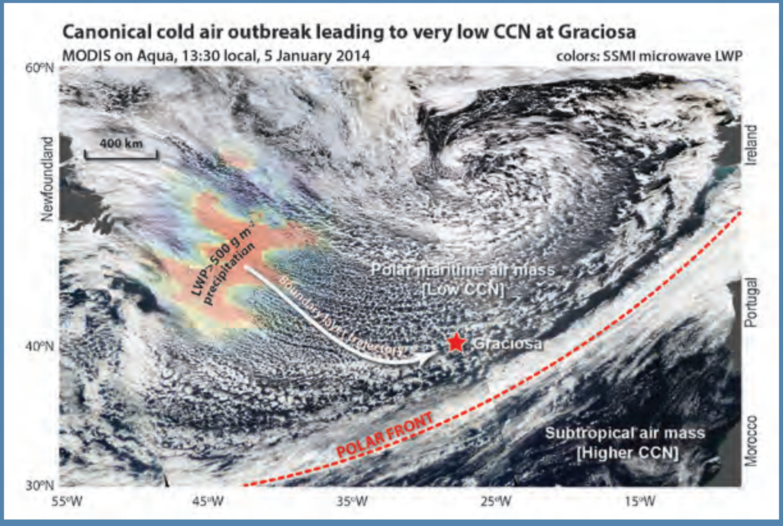
"These events occur in all seasons," said Wood, "but their frequency was three times higher in December-May than during June-November, and many of the low-aerosol events had a common meteorological basis."

This common meteorological basis involved the transport of cold air from the north and west of Graciosa, a weather phenomenon known as a marine cold-air outbreak. Researchers found evidence that such outbreaks removed aerosols by precipitation, resulting in very clean conditions.

"We found one more clue to the puzzle," said Wood. "But there's always more to learn."

Reference

Wood R, JD Stemmler, J Rémillard, and A Jefferson. 2017. "Low-CCN concentration air masses over the Eastern North Atlantic: seasonality, meteorology, and drivers." *Journal of Geophysical Research: Atmospheres,* 122:1203-1223, doi:10.1002/2016JD025557.



Low clouds associated with a cold-air outbreak sweep over the Azores. Using data from the ARM ENA atmospheric observatory on Graciosa Island, researchers discovered that these conditions are associated with very low aerosol concentrations at the island.

Thirteen Years of Data Yield Better Day for Modeling Shallow Cumulus

June 21, 1997, might not sound like a particularly memorable day, but the cloud formation over ARM's Southern Great Plains (SGP) atmospheric observatory on that day has served as a benchmark for decades. The observational data available created a so-called golden day for testing large-eddy and cloud-resolving simulations and developing convection parameterizations, key components of earth system models. Almost every newly developed convection scheme related to shallow cumulus clouds has been tested using that golden-day case. But with so many more data now available, from even more advanced instrumentation, scientists wanted to build a better case.

So, they built a better day.

Using 13 years of SGP observations, a team of scientists led by Lawrence Livermore National Laboratory (LLNL) developed a composite case. Their example represents the typical daytime evolution of non-precipitating shallow cumulus clouds whose formation and dissipation are driven by the local atmospheric conditions and land surface, and not influenced by weather events such as storms.

Correctly simulating the development of clouds and rain over land has always been a challenge for conventional large-scale models, such as those used to predict the weather and long-term change. Testing improvements within these models generally requires golden-day simulations, representing stereotypical environmental conditions and cloud formation.

"It is only by constructing a new case that we can get one typical of surface-driven shallow cumulus and for which we can use the observations from the advanced instrumentation that ARM has installed in the 20 years since the date of the ARM97 case," said Yunyan Zhang, LLNL atmospheric scientist and lead author.

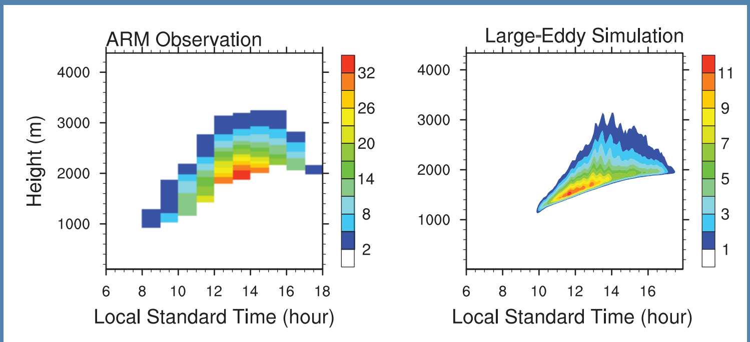
The new composite case integrates the advanced ARM cloud retrieval data gathered since 1997. It also takes advantage of vertically pointing instruments, such as cloud radars, lidars, and ceilometers, to create reliable statistics for testing models. These retrievals provide valuable information about the cloud size distribution, cloud vertical extent, and cloud vertical velocity.

"We took these steps to make the best use of the measurements," said Zhang, who worked with LLNL colleagues and scientists at Pacific Northwest National Laboratory, the University of Miami, and Stony Brook University. "We also kept the case as simple as possible to represent the most important features in local atmospheric and surface conditions on a typical surface-forced shallow cumulus day."

The composite will serve as a new test case—Continental Active Surface-forced Shallow cumulus (CASS)—for cloud-scale large-eddy simulation studies and the development of convection and cloud parameterizations in large-scale models.

Reference

Zhang Y and et al. 2017. "Large-eddy simulation of shallow cumulus over land: a composite case based on ARM long-term observations at its Southern Great Plains site." *Journal of the Atmospheric Sciences,* 74:3229-3251, doi:10.1175/JAS-D-16-0317.1.



Daily variation of cloud fraction from ARM measurements (left) and a large-eddy simulation (right) shows that the new composite case can help models more closely match real life.

The Dry Side of the Amazon: New Studies Show Effects on Weather

When we think of the Amazon, we think of water—the world's longest river, the Earth's largest river basin, millions of square miles of steaming rainforest. Yet recent research using data from the Green Ocean Amazon (GoAmazon2014/15) field campaign focuses attention on the dry side: the surprising influences of the Amazon's dry season on weather.

Scott Giangrande, atmospheric scientist at Brookhaven National Laboratory, and an international team of scientists were interested in how air rose and fell during the dry season, particularly as its movement affected storms rolling through the area. Using data from ARM radar wind profilers, they developed a vertical motion climatology of Amazon clouds for the first time. They also investigated the role of the environment on the coverage and intensity of major storms. The work confirmed that the most intense air movement in Amazonian storms is found within the dry season.

"Understanding vertical air motions in clouds and how those air motions impact cloud life cycle and precipitation is invaluable for unlocking uncertainties in current earth system models," said Giangrande.

Virendra Ghate, an atmospheric scientist at Argonne National Laboratory, worked with Pavlos Kollias, an expert in cloud microphysics at Brookhaven National Laboratory and Stony Brook University, to determine the factors controlling precipitation during the Amazonian dry season. With variability, most of the earth system models forecast the dry season to get longer and drier in the future. Ghate and Kollias studied data from instruments that are part of the first ARM Mobile Facility, which was deployed to Manacapuru, Brazil, during the GoAmazon campaign. They found that large-scale moisture in the rainforest controlled daytime precipitation, while storms rolling through the area controlled overall precipitation. The results of their work can help inform both weather research and land management approaches.

"Understanding vertical air motions in clouds and how those air motions impact cloud life cycle and precipitation is invaluable for unlocking uncertainties in current earth system models."

—Scott Giangrande, scientist at Brookhaven National Laboratory

Data from the GoAmazon2014/15 campaign are shedding light on how the dry season of the wet river basin affects weather.

"The health and extent of the Amazon rainforest critically depends on the precipitation received during the dry season," said Ghate.

References

Giangrande SE, T Toto, MP Jensen, MJ Bartholomew, Z Feng, A Protat, CR Williams, C Schumacher, and L Machado. 2016. "Convective cloud vertical velocity and mass-flux characteristics from radar wind profiler observations during GoAmazon2014/5." *Journal of Geophysical Research: Atmospheres,* 121:12891-12913, doi:10.1002/2016JD025303.

Giangrande S, Z Feng, M Jensen, JM Comstock, K Johnson, T Toto, M Wang, CD Burleyson, N Bharadwaj, F Mei, L Machado, A Manzi, S Xie, S Tang, MAF Silva Dias, RA de Souza, C Schumacher, and ST Martin. 2017. "Cloud characteristics, thermodynamic controls and radiative impacts during the observations and modeling of the Green Ocean Amazon (GoAmazon2014/5) Experiment." *Atmospheric Chemistry and Physics,* 17(23):14519-14541, doi:10.5194/acp-17-14519-2017.

Ghate VP and P Kollias. 2016. "On the controls of daytime precipitation in the Amazonian dry season." *Journal of Hydrometeorology,* 17:3079-3097, doi:10.1175/JHM-D-16-0101.1.

Researchers Discover Key Factor Governing Variability of Isoprene Emissions in the Amazon

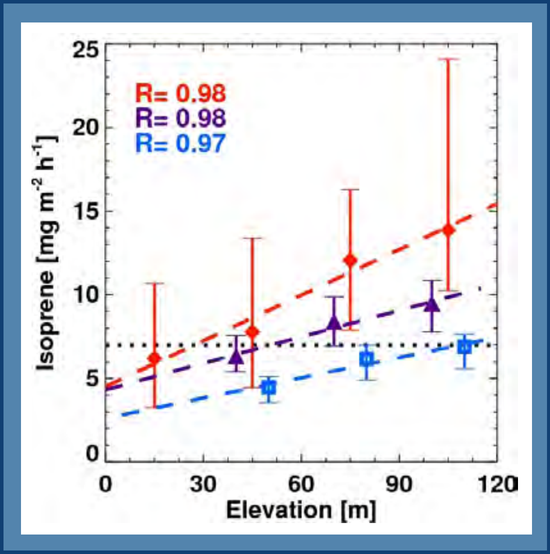
During the Green Ocean Amazon (GoAmazon2014/15) field campaign, scientists studied the atmosphere above and around Manaus in central Brazil during both the wet and dry seasons. This unique research landscape allowed them to investigate a polluted urban environment set in the near pristine vastness of the Amazon rainforest, which spans 1,500 kilometers (932 miles) in any direction.

In research bursts of one month each, scientists from Brazil, the United States, and several European countries measured three atmospheric worlds: that of the urban plume; the hybrid world created by the clash of urban and pristine air; and that of the forest alone, as it was—perhaps—eons ago.

The forest-only view provides a unique opportunity for some researchers. In a *Nature Communications* paper, 22 authors used ARM GoAmazon data to report some startling conclusions about isoprene. That's the non-methane biogenic volatile organic compound from plant matter that influences atmospheric oxidants and aerosols.

Analyzing aircraft eddy covariance measurements during the GoAmazon campaign, researchers discovered that isoprene emissions strongly correlated with terrain elevations, most likely a result of varying plant species at different elevations.

"Most isoprene in the world is from the Amazon rainforest, but unfortunately, previous data were very limited," said Dasa Gu, a postdoctoral researcher at the University of California, Irvine, and lead author of the paper.



As this data plot shows, at higher elevations, levels of isoprene were higher too.

This work demonstrates the value of aircraft-derived measurements during the GoAmazon2014/15 field campaign and produces new insights on the isoprene emissions rate. The findings provide key clues to improve the representation of isoprene emissions within regional and global earth system models.

Isoprene emissions, the paper concluded, could be as much as three times higher than reported by satellite observations (the usual method for getting such data). The authors also concluded that a previously unexamined "elevational gradient" in the Amazonian forest may substantially explain the variability of isoprene emissions in tropical forests.

Reference

Gu D, AB Guenther, JE Shilling, H Yu, M Huang, C Zhao, Q Yang, ST Martin, P Artaxo, S Kim, R Seco, T Stavrakou, KM Longo, J Tóta, RAF de Souza, O Vega, Y Liu, M Shrivastava, EG Alves, FC Santos, G Leng, and Z Hu. 2017. "Airborne observations reveal elevational gradient in tropical forest isoprene emissions." *Nature Communications,* 8:15541, doi:10.1038/ncomms15541.

Winter Wheat on the Southern Great Plains: Bounty of Research Opportunities

ARM's Southern Great Plains (SGP) atmospheric observatory is playing a key role in the quest to accurately represent winter wheat in land-surface models. Winter wheat accounts for more than 70 percent of total U.S. wheat production and is a prominent crop in the Great Plains region.

Winter wheat is planted in the fall and harvested in May or June—a very different growing cycle than summer crops or grasses. Near-surface air is cooler and moister over Oklahoma's winter wheat belt than over nearby grassland.

"Winter wheat's growing cycle makes it particularly interesting and unsuitable for the generic crop types that are used in many land-surface models," said researcher Justin Bagley, who has studied winter wheat at Lawrence Berkeley National Laboratory (LBNL).

An LBNL team modified the winter wheat portion of the Community Land Model to improve simulations. The modified model—validated at eight other North American sites—accurately simulated the year-to-year change in yield at the SGP site. The effort improved the prediction of monthly variation in certain aspects of winter wheat by as much as 41 percent during the spring growing season. These improvements are important for accurately predicting the energy and water cycles in earth system models.

Said Yaqiong Lu, lead author of the paper describing the LBNL team's work: "At other agronomic sites, they measure other crop observations, but they don't have the flux measurements included in our model. They can't tell how the crop influences the atmosphere."

Other research looked at how land cover influences surface energy balance, particularly as winter wheat locations are bare fields while other grassland is covered during the summer. To understand these influences, LBNL and University of Nebraska-Lincoln scientists pored over measurements from the SGP observatory, some of which have existed for more than a decade.

Said Bagley, lead author of the paper describing that effort: "The long period that these observations were available and the spatial distribution of the sites enabled us to make confident conclusions about the impacts of land cover in the SGP on the partitioning of surface energy, and be confident that the winter wheat model we developed was accurate under a variety of conditions."

References

Lu Y, IN Williams, JE Bagley, MS Torn, and LM Kueppers. 2017. "Representing winter wheat in the Community Land Model (version 4.5)." *Geoscientific Model Development,* 10:1873-1888, doi:10.5194/gmd-10-1873-2017.

Bagley JE, LM Kueppers, DP Billesbach, IN Williams, SC Biraud, and MS Torn. 2017. "The influence of land cover on surface energy partitioning and evaporative fraction regimes in the U.S. Southern Great Plains." *Journal of Geophysical Research: Atmospheres,* 122:5793-5807, doi:10.1002/2017JD026740.

Winter wheat turns green as other plants die off, making it difficult to account for in earth system models.

Advancing **Capabilities**

Infrastructure Achievements

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

ArcticShark Joins AAF, Flies its First Instruments

During a series of test flights at the Eastern Oregon Regional Airport on September 21 and 22, 2017, in Pendleton, Oregon, the ArcticShark unmanned aerial system (UAS) carried aloft its first instrument payload. Though the payload was modest (18 pounds), it was a landmark moment for ARM's latest and biggest UAS, which the ARM Aerial Facility (AAF) took possession of in March 2017.

Over two days, in three patterned runs up to about 2,500 feet, the ArcticShark pulled in data on down-looking infrared temperature, ambient temperature, wind velocities, and ambient relative humidity.

"We think it's highly successful and right on schedule," said Beat Schmid, AAF manager at Pacific Northwest National Laboratory.

Owned by the U.S. Department of Energy and managed by the AAF, the ArcticShark is a midsize UAS that weighs 650 pounds, is 14 feet long, and has a 22-foot wingspan. UAS aircraft have some advantages over large, conventional aerial research platforms that require an onboard pilot. Although they carry smaller payloads, they are lighter, smaller, and less expensive to buy and fly. They also fly low and slow enough to capture a small area of atmospheric data in greater detail—desirable for experiments and models in which grid scales are getting increasingly fine.

The ArcticShark will undergo additional testing and make trial flights for a year before ARM begins accepting research proposals to use the aircraft.

Cloud Radar Simulator Bridges Gap Between Earth System Models and Field Data

A new value-added product made it more feasible to compare clouds simulated in earth system models to ARM cloud observations.

In a paper published by the *Bulletin of the American Meteorological Society (BAMS),* researchers described the development of a ground-based ARM radar simulator that converts model data into parameters that a cloud radar can more directly observe.

The ArcticShark is ready for takeoff on an airstrip in Pendleton, Oregon.
Image courtesy of The Duke Joseph Agency.

A new ground-based simulator bridges the gap between cloud radar observations and the clouds simulated by earth system models.

"The creation of the ground-based cloud radar simulator represents an important step that ARM has taken to address the gap between field data and models, and make the data-model comparison more meaningful," said principal investigator Shaocheng Xie of Lawrence Livermore National Laboratory.

The simulator bridged differences between model-simulated clouds and ARM radar observations in addressing the spatial scale and properties of liquid and solid water in the atmosphere.

The new tool was incorporated into the Cloud Feedback Model Intercomparison Project Observation Simulator Package (COSP), a community satellite simulator package. This work enhanced the COSP's capability so that it can simulate cloud radar reflectivities from ground-based radars that ARM operates at its fixed and mobile atmospheric observatories. Users can find the simulator and COSP on Github.

Transitioning LASSO from Pilot to Operations

The Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) pilot phase wound down in 2017 after two years of development and testing. LASSO ties together ARM observational data and LES modeling to support the study of atmospheric processes, improvement of observational retrievals, and simplified representations of clouds, aerosols, and radiation in earth system models.

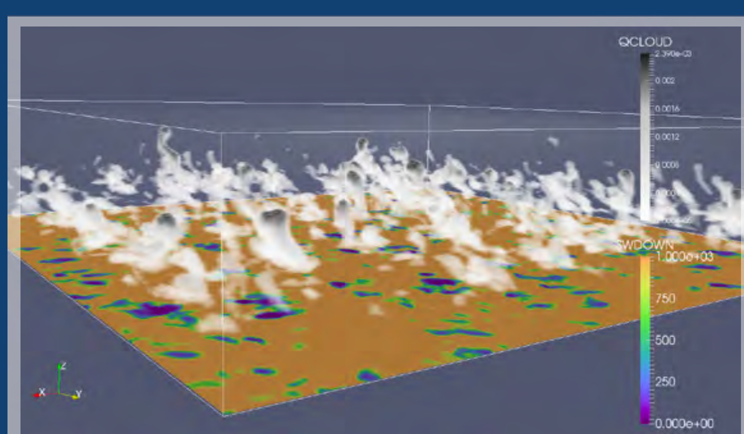
In summer 2017, the second and final early data release for the LASSO pilot phase (Alpha 2) became available via the ARM Data Center. Alpha 2 consisted of 544 simulations of shallow convection that spanned 13 days during May to August 2016 at ARM's Southern Great Plains (SGP) atmospheric observatory. This library of data bundles contains large-eddy simulations, accompanying observations, skill scores, and diagnostics simplified for users' needs for high-resolution data on shallow convective clouds.

Alpha 2 built upon the first LASSO data release (Alpha 1) through improved LES models, increased use of observations for evaluating the model, and testing of incorporation of ARM wind profiles in the data assimilation process.

To support both the LASSO high-resolution model simulations and analyses associated with these simulations and large observation data sets, the ARM Data Center implemented a small and a moderate-size computer cluster. These clusters have greatly increased ARM's computational capacity and enabled more effective use of the growing volume and complexity of ARM data.

The successful completion of the LASSO pilot project has laid the groundwork to produce routine LES modeling at the SGP observatory, beginning in 2018. Long term, the team aims to expand coverage to other sites and other atmospheric phenomena.

"Stay tuned," said William Gustafson, LASSO's principal investigator and a scientist at Pacific Northwest National Laboratory. "We're just getting started."



"Data bundles" combine observations, model output, and metrics into a unified package.

New Radar Plan Delivers for Users

In 2016, ARM implemented a radar maintenance plan to maximize the production of reliable high-quality data from the sophisticated research radars at its three fixed and three mobile atmospheric observatories. Radar engineers began tuning up five radars at a time and creating a program to convert raw radar output data into a user-friendly, common format. The first phase wrapped up in 2017.

For users, the effort means cleaner data that are ready to analyze and are available as usual from the ARM Data Center. Calibrated data helps in quantitative analysis, speeding the production of scientific results, thereby increasing ARM's impact and value.

The improved data quality represents a big change from ARM's pioneering phase when the radars operated near continuously. Radars were being moved so often and so far—typically from one weather extreme to another—that there was little time for routine calibration and characterization before the next deployment.

The "unprecedented" radar plan is going well, said Nitin Bharadwaj, ARM's radar engineering group lead at Pacific Northwest National Laboratory. For example, the radars at ARM's Eastern North Atlantic atmospheric observatory and those in the third ARM Mobile Facility were calibrated so that they would be consistent with one another.

ARM maintains a network of almost 30 radars, the most comprehensive research radar network in the world.

New Aerosol Observing System Deployed to Southern Great Plains

In November 2016, a brand-new Aerosol Observing System (AOS) was trucked from Long Island, New York, to ARM's Southern Great Plains (SGP) atmospheric observatory in Oklahoma. The new AOS represents an upgrade for aerosol observational capability at the SGP. The AOS instruments measure the composition, size distribution, and ability to scatter and absorb light of aerosol particles. These detailed data are essential to understanding more about aerosol effects on the Earth's energy budget and their role in the formation of clouds.

An AOS design team led by Brookhaven National Laboratory project engineer Scott Smith specified, built, and field-tested two of these sophisticated atmospheric measurement systems for ARM in a year.

The new AOS differs from its predecessor in several ways. First, it was ordered with many basic design features already built in, whereas the previous one was an off-the-shelf steel shipping container that BNL had to modify for every requirement. Second, the "stack"—a 20-foot-tall pipe on top of the container used to pull in sample air—was moved from the end to the middle, which equalizes the strain on the eight corner-mounted guy wires and eliminates wind loading issues.

The new unit has a larger instrument suite to make more measurements. Finally, the AOS has uninterrupted power

Radar engineer Nitin Bharadwaj, Pacific Northwest National Laboratory, stands on top of the X-band precipitation radar at ARM's SGP atmospheric observatory, a crucial component in the next-generation ARM strategy.

ARM installed the next-generation Aerosol Observing System at the SGP atmospheric observatory in November 2016.

supply backup on all instruments, not just critical ones, so intermittent power outages or surges do not affect measurement continuity. This is crucial to recording an unbroken—and therefore far more valuable—data set.

New Computing Capability Offered as Part of Next-Generation ARM

Starting May 15, 2017, ARM data users needing more storage capacity and computational power could apply for direct access to ARM computing resources and data. This public software development space enabled users to work with large volumes of ARM data without having to download them.

"As our data volume grows," said ARM Technical Director Jim Mather, "we would like to provide the means to do intensive processing where the data are."

To that end, the ARM Data Center integrated two computational clusters it calls Stratus and Cumulus. The goal: Make it easy for users to migrate their computational scripts from single workstations to one of the new computing clusters.

The first call for use of the ARM computing clusters closed in June, making this resource available to ARM science users working with very high volumes of ARM data for the first time. The clusters can support model simulations, petascale data storage, and big-data analytics for successful ARM science research.

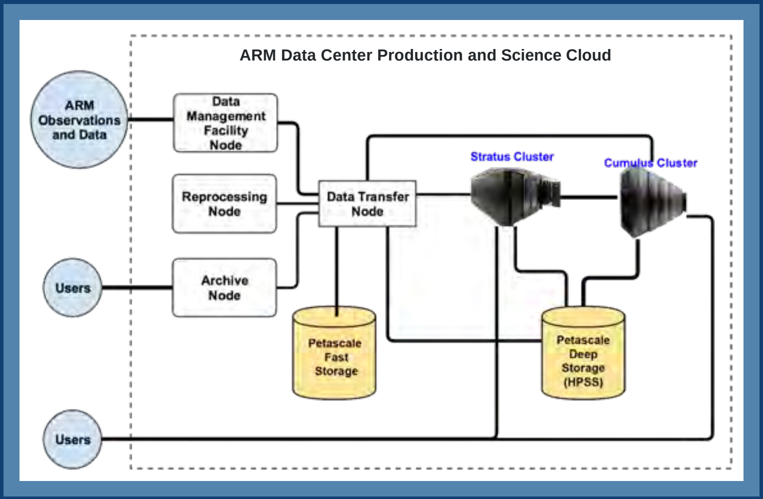
"As our data volume grows, we would like to provide the means to do intensive processing where the data are."

— Jim Mather, ARM Technical Director, Pacific Northwest National Laboratory

ARM Data Discovery Browser Provides New Data Delivery Methods

Hundreds of users every month download 20 to 25 terabytes of ARM data. The ARM Data Center responded to increased data requests through ARM's Data Discovery by offering three new ways to acquire data: Globus, Dropbox, and Unidata's Thematic Real-time Environmental Distributed Data Services (THREDDS).

"Over the years, our users have wanted a better way to download large quantities of ARM data," said Giri Prakash, ARM Data Services and Operations manager at Oak Ridge National Laboratory.



ARM's new high-performance computing facility integrates multiple levels of computing resources and storage systems.

From the Data Discovery order form, users can select one or more of the new data delivery options. Each method has its advantages, particularly over conventional FTP delivery.

Globus provides higher bulk data transfer speeds and automatically resumes downloads after any network interruption. Users preferring a commercial file-hosting service can use the Dropbox option. Users can link their personal Dropbox accounts—a 2-gigabyte account is free—to ARM's institutional-level account so they do not drain their space. Meanwhile, users looking for specific data in a large file can access THREDDS. It allows users to extract the measurements they need with a variety of remote data access protocols.

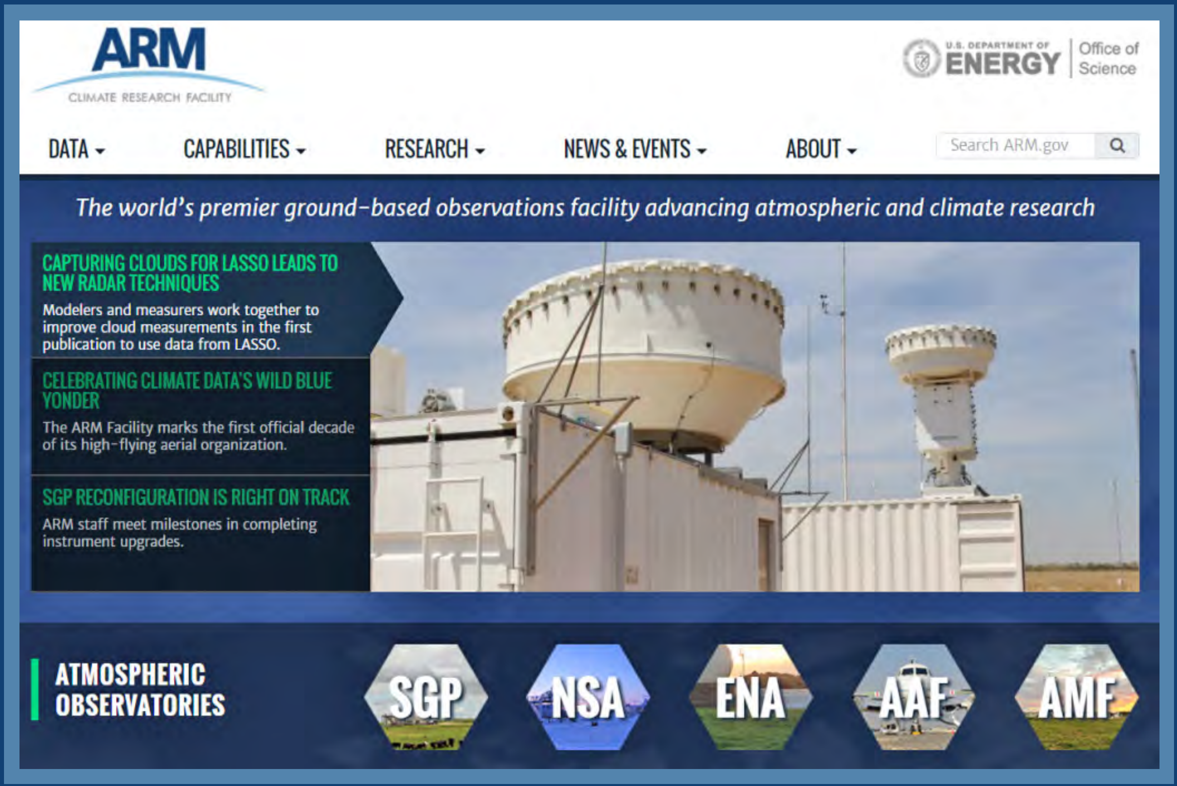
New Website for the Next-Generation ARM User

A new ARM website went live December 29, 2016. In response to user feedback, the website was redesigned to make:

- navigating easier by reducing the number of tabs at the top from 10 to five
- accessing data easy by listing it as the first navigation tab
- submitting campaign proposals faster with a new form
- searching for instruments and value-added products speedy and efficient
- searching the site more effective with a new search capability that sorts by relevance and latest content
- finding important information from any page simpler with a new footer navigation
- timely information accessible on the front page, with all articles searchable under News & Events
- getting help a snap with a new question form in the footer.

The redesign of the site was almost two years in the making. To ensure that the new website hit the mark, a two-day workshop was held in February 2015 with a multilab team to identify audiences and requirements for the site.

An extensive review process included numerous presentations to ARM leadership, the ARM User Executive Committee, and the multi-lab web team, as well as at two ARM Developers Meetings. A usability study of the new site conducted before the site launch showed an 89 percent success rate in potential new ARM users navigating the site to find pertinent tools, information, and support.



ARM redesigned its website based on user feedback.

New Data Products

Multi-Angle Snowflake Camera Value-Added Product Delivers First Data

First production data from the Multi-Angle Snowflake Camera (MASC) Particles value-added product (VAP) were delivered using the MASC instrument for the third ARM Mobile Facility deployment at Oliktok Point, Alaska. The MASC Particles VAP provides analysis of images and fall speed data from the MASC instrument to provide a range of attributes including hydrometeor size, fall speed, orientation, and shape. These measurements provide important information for understanding ice microphysical processes in ice and mixed-phase clouds.

Providing high-resolution multi-angle imaging of hydrometeors, such as snowflakes, the MASC instrument consists of three cameras, separated by 36 degrees and pointing at an identical focal point approximately 10 centimeters away within a 20-centimeter-wide ring through which hydrometeors fall. A relatively new instrument to ARM, the MASC uses an infrared system to both measure hydrometeor free fall and fall speed. It also triggers the cameras to capture an image of the hydrometeor.

This system relies on two sets of sensors arranged vertically (one set above the other) separated by 32 millimeters. Nearly 3,600 data files from the MASC Particles VAP were provided to 12 unique users in FY17 with 18 unique requests.

SACR ADVance Quasi-Vertical Profile Evaluation Product Released

A new evaluation data product—Scanning ARM Cloud Radar ADVance Quasi-Vertical Profile (SACR-ADV-QVP)—was developed based on the algorithm described in Ryzhkov, et al. (2016). The SACR-ADV-QVP value-added product provides a quasi-vertical representation of azimuthal averaged polarimetric variables to reveal important signatures in ice and mixed-phase clouds. These profiles are produced using a sequence of plan-position-indicator (PPI) scans from the second-generation SACR (SACR2).

A new value-added product for the Multi-Angle Snowflake Camera (MASC), which produces hydrometeor (like snowflakes) images, provides analysis of images and fall speed data for the MASC.

The SACR2 is a polarimetric radar capable of observing cloud/precipitation particle properties from lower-elevation-angle observations (e.g., PPI), which are more informative. However, it is difficult to directly compare the polarimetric variables observed at lower-elevation angles with other profiling measurements (e.g., Ka-band ARM zenith radar, microwave radiometer, and ceilometer). Therefore, the quasi-vertical profile approach provides a way to average the PPI scans into a time-versus-height format for comparison.

SACR-ADV-QVP provides a daily netCDF file containing quasi-vertical profiles of polarimetric variables every time the PPI scan strategy is performed (this could cause an irregular time stamp). This evaluation product is produced at a 10-meter height resolution at an elevation angle of 20 degrees. In fiscal year 2017, 148 data files were delivered to users for the SACR-ADV-QVP evaluation product.

Reference

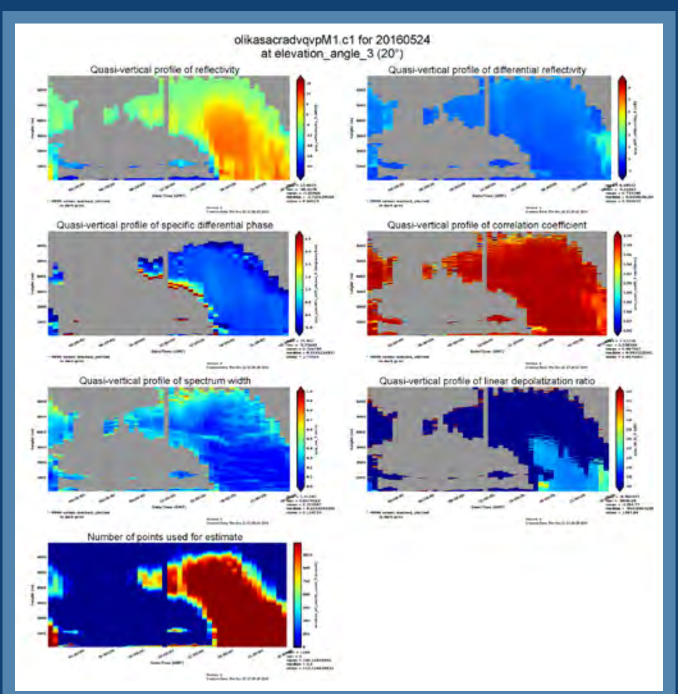
Ryzhkov A, P Zhang, H Reeves, M Kumjian, T Tschallener, S Trömel, and C Simmer. 2016. "Quasi-Vertical Profiles-A New Way to Look at Polarimetric Radar Data." *Journal of Atmospheric and Oceanic Technology,* 33(3), doi:10.1175/JTECH-D-15-0020.1.

Two New Datastreams Developed from the Radar Wind Profiler

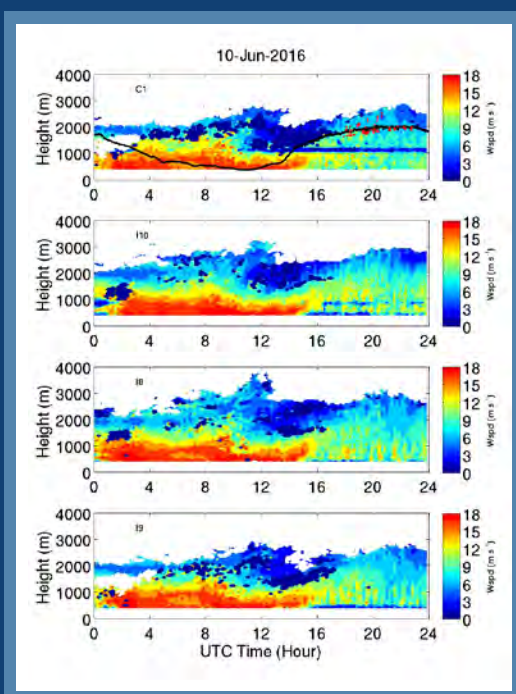
Two new radar wind profiler (RWP) datastreams were produced in 2017 to improve estimates of radar moments from the boundary layer mode and boundary layer winds at 10-minute resolution. The datastreams were part of a new evaluation value-added product (VAP), called RWPWIND.

RWPWIND was developed for all the observing facilities at the ARM Southern Great Plains (SGP) and Eastern North Atlantic (ENA) atmospheric observatories. Evaluation data are available for the summer months of 2015 and 2016. The RWP instruments record the full Doppler spectrum in a wind mode and a precipitation mode. Data from the wind mode were used to calculate the first three moments of the Doppler spectrum (reflectivity, mean Doppler velocity, and spectrum width) with the mean Doppler velocity further used to retrieve boundary layer winds.

Retrieved winds are useful for understanding interactions between turbulence and cloud properties as well as for forcing and evaluating model simulations. The raw Doppler spectrum data collected during the wind mode were used to recalculate the moments using an improved noise estimate.



The Scanning ARM Cloud Radar ADVance Quasi-Vertical Profile (SACR-ADV-QVP) provides a quasi-vertical representation of azimuthal averaged polarimetric variables.



Time-height images are shown here of the wind speed at a uniform 10-minute and 50-meter resolution from the radar wind profilers at the SGP atmospheric observatory.

Further, the profiles of boundary layer winds were retrieved at a uniform 10-minute resolution at all locations using the improved algorithm. For the RWPWIND VAP, 1,126 data files were delivered to users in 2017.

Soil Moisture Evaluation Data Product Created from Oklahoma Mesonet Data

Researchers supported by the U.S. Department of Energy's Atmospheric System Research (ASR) program are interested in studying land-atmosphere interactions at the mesoscale level around the ARM Southern Great Plains (SGP) atmospheric observatory. In order to help address these research needs, ARM staff at Brookhaven National Laboratory created a soil moisture value-added product (VAP) using the 30-minute-averaged product from the Oklahoma Mesonet.

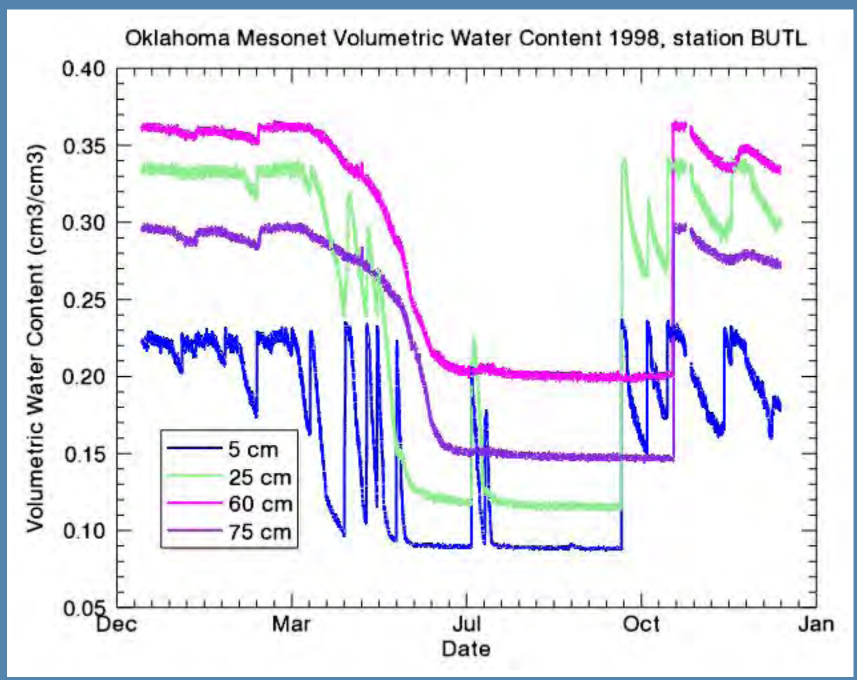
The Oklahoma Mesonet is a network of monitoring stations developed as a joint project between Oklahoma State University and the University of Oklahoma. Since its creation in the early 1990s, the Oklahoma Mesonet has created and maintained over 100 surface mesonet stations. The dense surface network of the mesonet provides a good representation of land surface/subsurface conditions over the region. However, the mesonet data alone do not provide the information necessary to calculate soil moisture across the network. Soil moisture is a key parameter for understanding fluxes of moisture and energy between the land and atmosphere.

Recently, a soil hydraulic parameter database (Meso-Soil Database) with extensive in situ validation was developed and published. Brookhaven staff created a soil moisture VAP from the current 30-minute-averaged product from the Oklahoma Mesonet network of monitoring stations, using parameters from the Meso-Soil Database and the equations developed by Oklahoma Mesonet scientists (Illston 2008).

Evaluation data were created for the Oklahoma Mesonet Soil Moisture product from October 2011 to July 2016. This fiscal year, 1,721 data files were delivered to users for the soil moisture VAP.

Reference

Illston R, J Basara, D Fisher, R Elliott, C Fiebrich, K Crawford, K Humes, and E Hunt. 2008. "Mesoscale monitoring of soil moisture across a statewide network." *Journal of Atmospheric and Oceanic Technology,* 25: 167-182, doi:10.1175/2007JTECHA993.1.



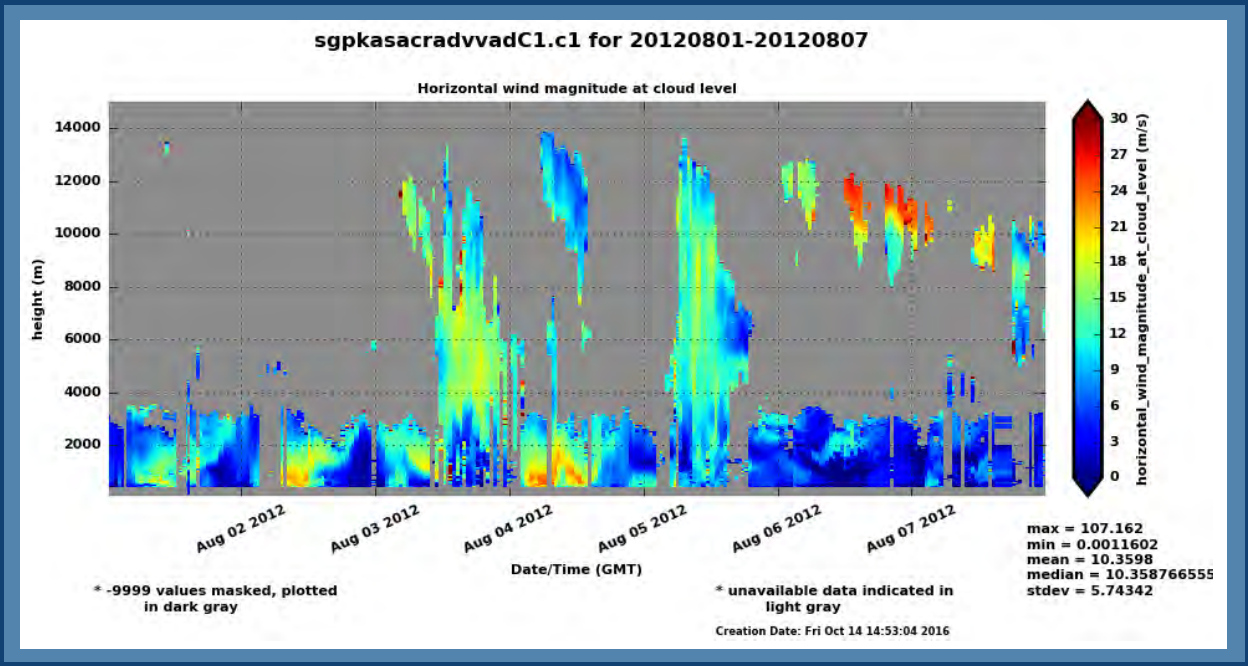
In this plot, 1998 volumetric water content for the station Butler (BUTL) in the Oklahoma Mesonet is used for comparison to the Illston 2008 paper.

New Scanning ARM Cloud Radar-Advanced-Velocity Azimuth Display (SACR-ADV-VAD) Product Released to Evaluation

The Scanning ARM Cloud Radar-Advanced-Velocity Azimuth Display (SACR-ADV-VAD) value-added product (VAP) provides profiles of horizontal wind estimates at cloud level, using observations from the Hemispherical Sky Range Height Indicator (HS-RHI) scan strategy of the Ka-Band Scanning ARM Cloud Radar (KASACR). In 2017, evaluation data using the SACR-ADV-VAD VAP were produced for August 2012 at the Southern Great Plains (SGP) observatory and for September 2012 in Cape Cod, Massachusetts, during the Two-Column Aerosol Project (TCAP).

The VAD technique historically was used to retrieve wind field properties using weather radars. SACR-ADV-VAD employs the technique using three horizon-to-horizon HS-RHI scans, typically repeated one to two times per hour, and spaced by 30 degrees in azimuth. The resultant product has a 30- to 60-minute time resolution and a 50-meter height resolution. It is intended to complement infrequent soundings, only two to four launches per day, depending upon the site.

The SACR-ADV-VAD evaluation product was released at the end of fiscal year 2017 and will be available to users in 2018.



In 2017, evaluation data using the SACR-ADV-VAD VAP were produced for August 2012 at the SGP observatory. The first seven days of horizontal wind speed and direction at cloud level are shown here.

Science Outreach

ARM Staff, Users Teach Instrumentation Course

In September 2017, the University of Washington (UW) Department of Atmospheric Sciences sent 10 students to Pacific Northwest National Laboratory (PNNL) for a two-week instrumentation short course. The teachers were PNNL scientists and engineers, most of whom are or have been connected to ARM.

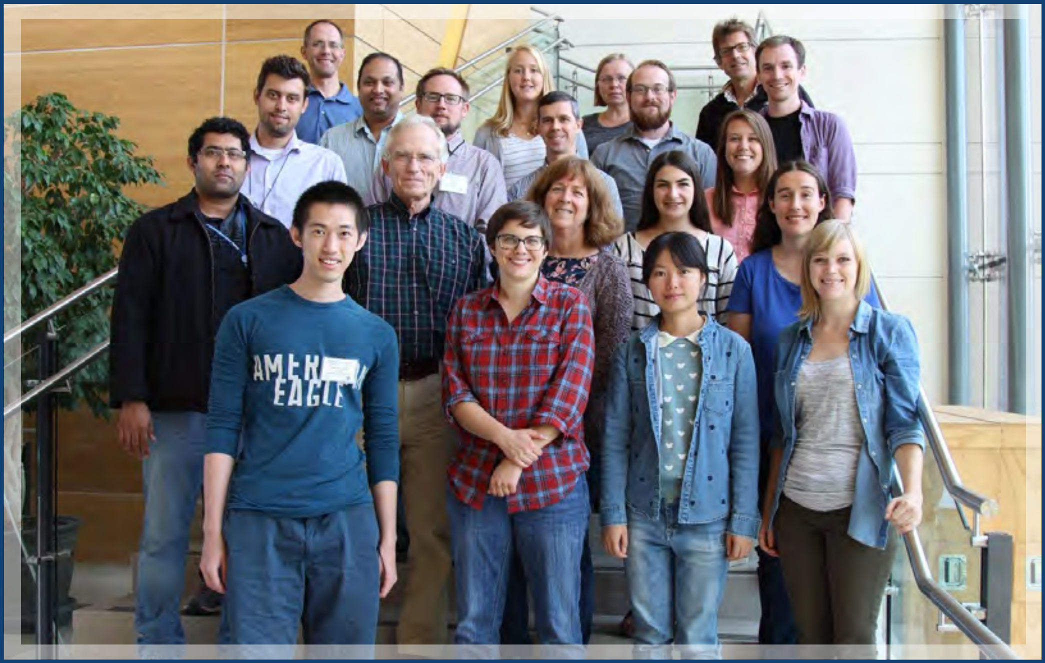
Focusing on themes such as calibration and accuracy, instructors developed lectures on ground and airborne instrumentation and measurements, data management, and atmospheric chemistry and cloud microphysics. They reinforced their lessons through experiments, demonstrations, computer analyses, mock field campaign designs, and field trips, including a tour of ARM's Gulfstream-159 (G-1) research aircraft that PNNL operates for the U.S. Department of Energy.

The course was the brainchild of Bob Houze, a PNNL Laboratory Fellow and UW professor emeritus of atmospheric sciences. He has worked on ARM field campaigns such as the ARM Madden-Julian Oscillation Investigation Experiment on Gan Island (AMIE-Gan) in the Maldives.

"In our department (at UW), we don't have the observation and instrumentation infrastructure for our students to become acquainted with," said Houze.

ARM staff and users who served as speakers or lecturers included Jennifer Comstock, Laura Riihimaki, Victor Morris, Connor Flynn, Nitin Bharadwaj, Joseph Hardin, Brad Isom, Andrei Lindenmaier, Rob Newsom, Jason Tomlinson, John Shilling, Alla Zelenyuk-Imre, Gourihar Kulkarni, Chitra Sivaraman, Krista Gaustad, Sherman Beus, and Ken Burk.

"We tried to present the students with information that went beyond textbooks and addressed the realities of working with these instruments in a research capacity," said Hardin, a radar engineer. "This is important because these students will eventually be our peers and colleagues in the field."



On September 22, 2017, Pacific Northwest National Laboratory/University of Washington class members and instructors gathered for a photo on the final day of their two-week instrumentation short course.

ARM Staff, ACE-ENA Scientists Teach Students about Earth System Processes

ARM staff and researchers from the Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign helped lead a workshop/summer course on earth system processes in the Azores.

The program took place July 2 to 7, 2017, at Academia de Juventude e das Artes da Ilha Terceira (Academy of Youth and Arts of Terceira Island) in Praia da Vitória. It coincided with the first intensive operational period of ACE-ENA, an ARM field campaign aimed at improving understanding of low clouds and atmospheric particles in a remote marine area. Program organizers geared the subject matter toward postgraduate students from earth and environmental sciences.

Kim Nitschke, facility manager for ARM's ENA atmospheric observatory, and Beat Schmid, ARM Aerial Facility manager, contributed lessons along with ACE-ENA team members Eduardo Azevedo, Scott Giangrande, David Mechem, Raymond Shaw, Seong Soo, and principal investigator Jian Wang.

Azevedo welcomed the 21 students with an overview of Azores geography and environment. Wang led a session on atmospheric particle processes that also included a look at ACE-ENA. ARM-specific courses included: ARM and ENA infrastructure (taught by Nitschke), ARM radar operations and science at ENA and ARM facilities (Giangrande), and ARM Aerial Facility-manned and unmanned aircraft to conduct atmospheric science (Schmid).

Students visited caves and lava flow sites related to the 1761 volcanic eruption on Terceira Island. They also toured ARM's Gulfstream-159 (G-1) research aircraft, which collected measurements of clouds and atmospheric particles in the summer of 2017 as part of ACE-ENA.

Twenty Years of ARM History Chronicled in Monograph

The ARM monograph, an online document written by ARM veterans and published by the American Meteorological Society (AMS), became fully available—all 30 chapters and three appendices—in December 2016.

The monograph, entitled *The Atmospheric Radiation Measurement (ARM) Program: The First 20 Years,* chronicles the first two decades of ARM. It covers:

- ARM's operational and scientific evolution
- how ARM expanded its fixed and mobile sites
- ARM's contributions to the science of earth system changes
- how ARM inspired international research analogs
- ARM data targets, from spectral radiation and aerosol optical properties to radiative fluxes and water vapor profiles
- ARM's impact on regional and large-scale earth system models.

The full ARM monograph is freely available to download at ***http://journals.ametsoc.org/toc/amsm/57***.

Students and teachers from a workshop/summer course on earth system processes in the Azores visited the Gulfstream-159 aircraft, which is part of the ACE-ENA field campaign. The aircraft was stationed at Lajes Field, a base run by the Portuguese Air Force. *Image courtesy of Eduardo Azevedo, University of the Azores.*

Budget Summary **and Facility Usage**

Fiscal Year 2017 Statistical Overview

INFRASTRUCTURE BUDGET

$65,266K

1,127
TOTAL SCIENTIFIC USERS

USERS BY COUNTRY

United States 823	Netherlands 7	Russia 2
Brazil 46	South Korea 6	Singapore 2
China 44	Sweden 5	Bangladesh 1
Germany 35	New Zealand 5	Cameroon 1
United Kingdom 33	Argentina 4	Estonia 1
Finland 14	Switzerland 4	Ireland 1
Australia 12	Taiwan 4	Libya 1
Portugal 12	Denmark 3	Luxembourg 1
Canada 11	Israel 3	Norway 1
India 10	Iran 2	Peru 1
Japan 9	Belgium 2	Poland 1
France 7	Colombia 2	Saudi Arabia 1
Italy 7	Puerto Rico 2	Spain 1

39
Countries

USER STATISTICS

University	529	47%
Foreign	308	27%
DOE Labs	153	14%
Other Fed	109	10%
Industrial	28	2%

FACILITY USAGE

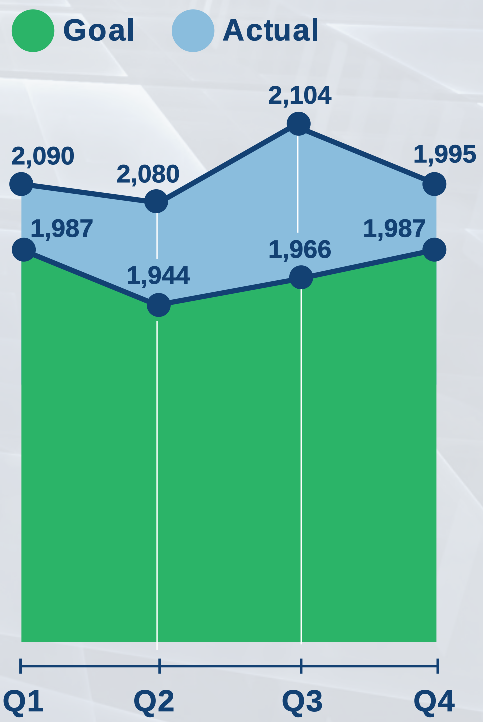
Onsite	219	19%
Remote	220	20%
Data	688	61%

400+ Instruments Collect Atmospheric Data

1,200+ Datastreams

4,000+ Journal Articles Since 1990

FACILITY HOURS OF OPERATION

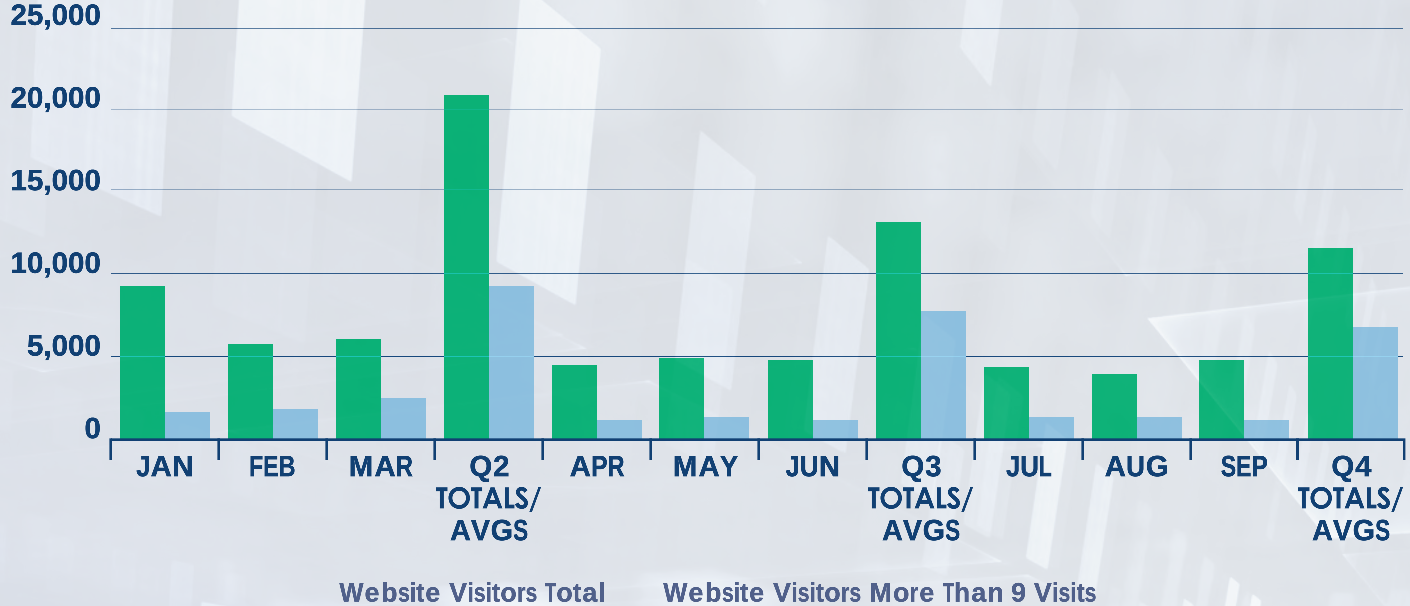


PUBLICATIONS USING ARM

665 TOTAL

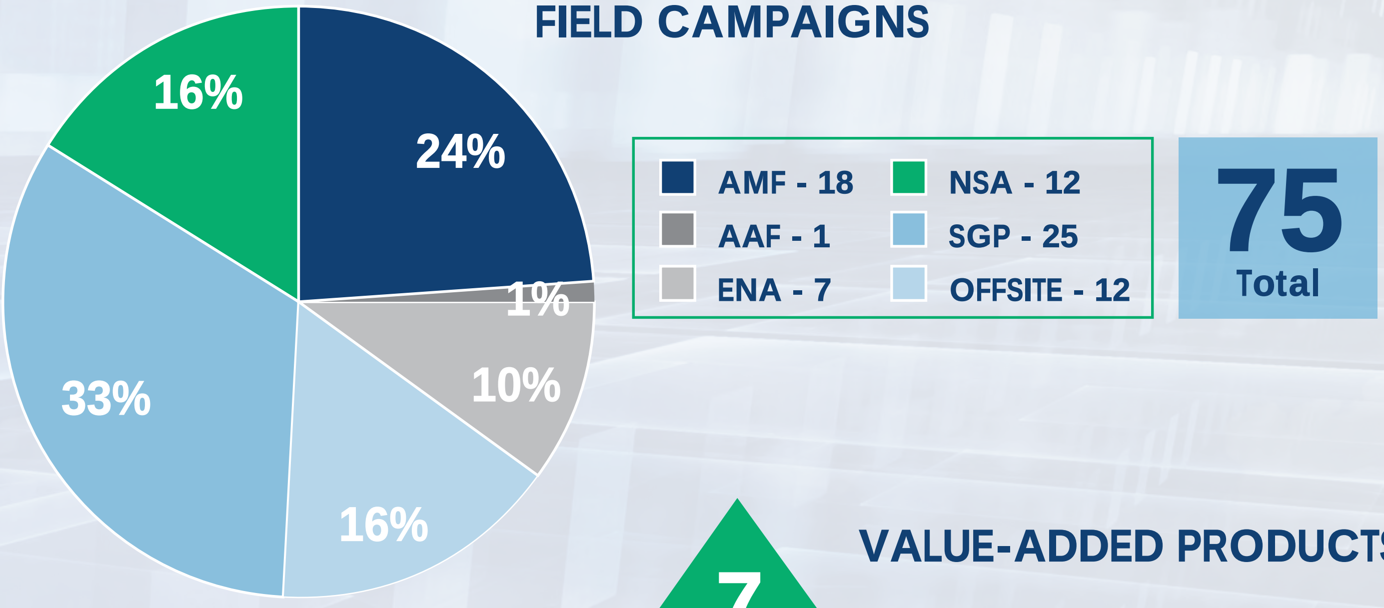
- ABSTRACTS OR PRESENTATIONS: 390
- TECHNICAL REPORTS: 43
- BOOKS: 4
- JOURNAL ARTICLES: 192
- CONFERENCE PAPERS: 36

WEBSITE VISITORS



Note: Web statistics began reporting in fiscal year 2017 when the new ARM website design was put in place in January.

FIELD CAMPAIGNS



VALUE-ADDED PRODUCTS

On the covers:

First ARM Mobile Facility on Ascension Island

Front – Midway between Angola and Brazil—the latitude zone for maximum aerosol outflow—on Ascension Island in the South Atlantic Ocean, the first ARM Mobile Facility completed the Layered Atlantic Smoke Interactions with Clouds (LASIC) campaign in fiscal year 2017. ARM deployed atmospheric profiling instrumentation, such as the scanning and zenith radars pictured, to gather data on how the properties of smoke evolve after long-range transport through the atmosphere, in particular their ability to absorb shortwave radiation, and assess how such smoke affects low clouds.

Inside – High above the LASIC site, over 50 mobile facility instruments and data systems, similar to ARM's fixed atmospheric observatories, are captured between the Ascension Island scenery and South Atlantic Ocean.

Photo credits: Brad Isom, Pacific Northwest National Laboratory

DOE/SC-ARM-17-038

www.arm.gov