ARM

U.S. DEPARTMENT OF ENERGY

2018 ANNUAL REPORT

ATMOSPHERIC RADIATION MEASUREMENT

From the Technical Director
A Year of Elevating Service to Science

In fiscal year 2018 (FY2018), the Atmospheric Radiation Measurement (ARM) user facility carried out important measurement missions around the globe and worked to better couple ARM measurements with the needs of the science community through the evaluation of priorities and the continued development of new capabilities, including efforts to better link data and models.

While many of these efforts have been ongoing, their importance was supported by recommendations from the 2017 ARM Triennial Review.

In February 2018, we submitted the final plans to the U.S. Department of Energy (DOE) that ARM will commit to accomplish over the next two years to address the Triennial Review recommendations. We then began implementing activities to:

- improve and track communications effectiveness at conferences and through the User Executive Committee
- implement additional metrics to track ARM's scientific impact, including on model improvement
- engage users beyond the traditional DOE Office of Biological and Environmental Research (BER)/Atmospheric System Research (ASR) communities
- increase the timely production and delivery of ARM Mobile Facility value-added products (VAPs) and create a mechanism to better set expectations for VAP delivery to users
- improve Data Discovery, ARM's portal for accessing more than 25 years' worth of data, for users
- define a clear process for biennially reviewing instrumentation, data products, and other activities with the goal of determining where resources should be applied
- update the radar plan and create a plan for optimizing aerosol data collection
- implement operational plans for the Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) project and establish a plan for selecting the next science target for LASSO.

We have made great progress in all of these areas, much of which is shared in this report, including plans for setting priorities for aerosol measurements and data product development.

In FY2018, ARM also brought many plans to fruition that were outlined in its 2014 Decadal Vision strategy, such as the implementation of the LASSO project that integrates observations and models and the continued advancement in the use of unmanned aerial systems (UAS).

For instance, ARM-operated DataHawks—small and lightweight UAS—and tethered balloons were deployed to Oliktok Point, Alaska, as part of the Profiling at Oliktok Point to Enhance YOPP Experiments (POPEYE). These instruments conducted routine profiling activities supporting a special Year of Polar Prediction (YOPP) observing period to obtain measurements on atmospheric thermodynamic structure and cloud, precipitation, and aerosol properties. This activity was an important phase of a very active period for ARM in the Arctic over the next few years that will attract the focus of organizations and researchers from around the world.

During FY2018, ARM provided unique measurements in three oceanic regions that have posed particular problems for earth system models—the Eastern North Atlantic, Southern Ocean, and tropical Atlantic. The world's oceans are a critical and under-sampled part of the climate system.

These three marine campaigns involved deployments to very different environments. The Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean (MARCUS) campaign had ARM instruments aboard the *Aurora Australis*, which traversed the extreme conditions of the stormy Southern Ocean. The data gathered in this remote area are vital to understanding and modeling the cloud-aerosol-radiation interactions in this region, which are a major source of uncertainty for earth system models.

The Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) campaign was conducted in the Azores off the coast of Portugal. Data collected during research flights by the ARM Aerial Facility, combined with the ground observations from our atmospheric observatory on Graciosa Island, will help scientists better understand marine low clouds and aerosols.

The first mobile facility completed a 17-month deployment to Ascension Island in the tropical Atlantic in October 2017 for the Layered Atlantic Smoke Interactions with Clouds (LASIC) experiment. LASIC provided an excellent opportunity to study the interaction of smoke with shallow marine clouds and is already yielding important scientific results.

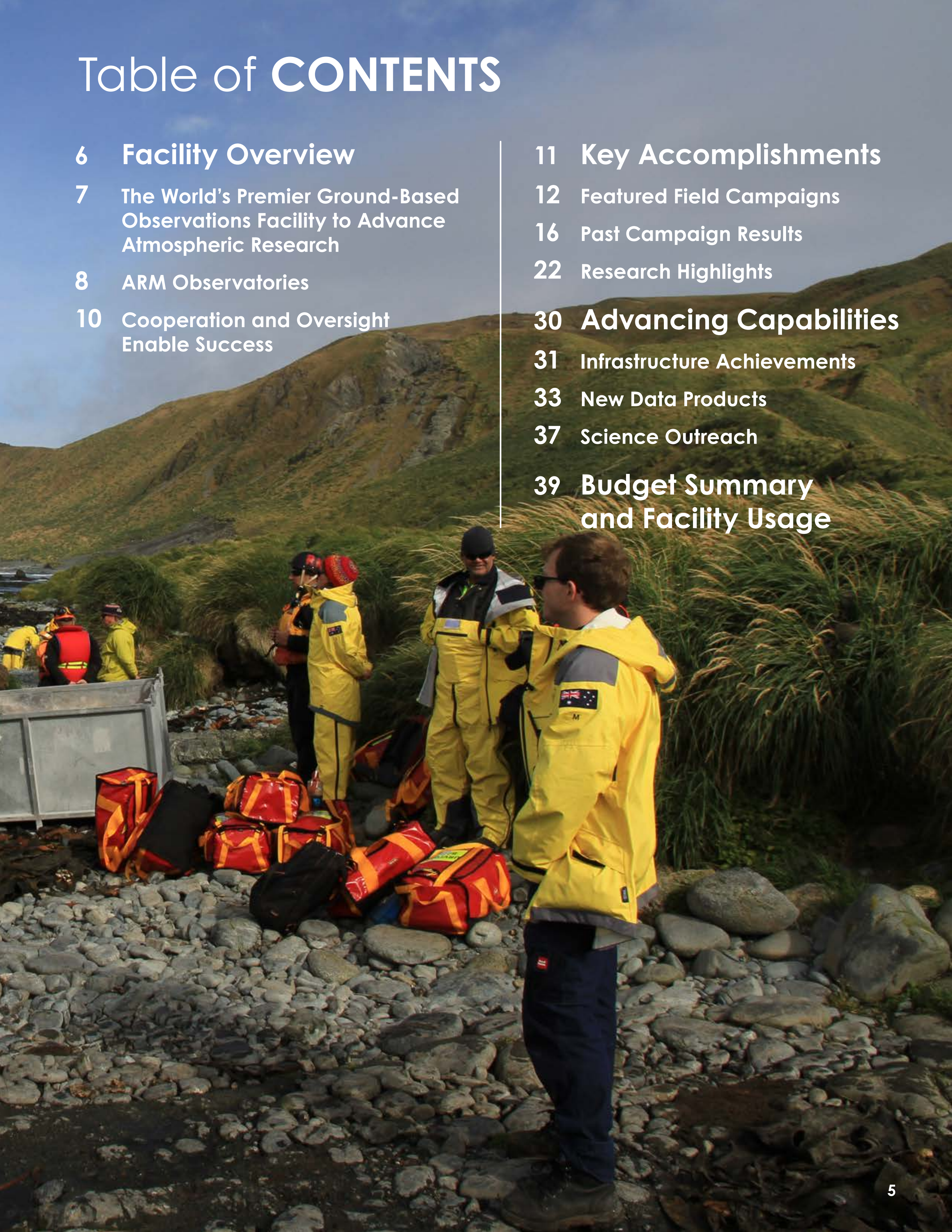
ARM carried out important measurements throughout its observational network this year supporting a broad range of science themes including the integrated water cycle and high-latitude processes, which were highlighted as goals in the 2018 to 2023 strategic plan for DOE's Climate and Environmental Sciences Division in BER.

All of these activities demonstrate our continued commitment to augment ARM's scientific impact—which is already significant. For instance, you will read about a group of four papers that focused on results from the Clouds Above the United States and Errors at the Surface (CAUSES) project. The papers used ARM measurements to explore why earth system models simulate warmer surface temperatures than ground-based observations show in the central United States.

ARM exists to support the science community, and the ultimate goal is to operate safely and ensure that we continue to deliver outstanding data for our scientific users. I am excited to report on the progress we made—and success we had—doing just that in FY2018.

Jim Mather
ARM Technical Director

ARM user facility, Australian Antarctic Division, and Australian Bureau of Meteorology staff await the skiff for the return trip aboard the *Aurora Australis* supply vessel after packing up ARM instrumentation at the conclusion of the Macquarie Island Cloud and Radiation Experiment in March 2018.



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Facility **OVERVIEW**

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

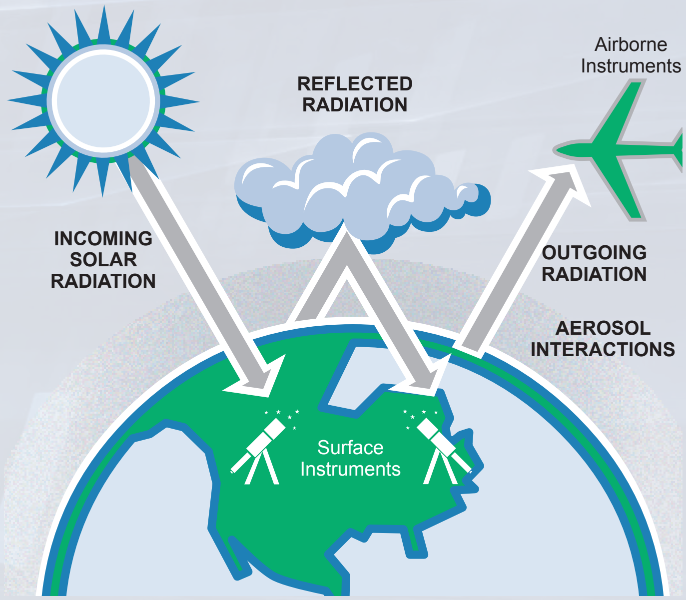
This report provides an overview of the Atmospheric Radiation Measurement (ARM) user facility and a sample of achievements for fiscal year 2018 (FY2018).

ARM is a multilaboratory, U.S. Department of Energy (DOE) scientific user facility and a key contributor to national and international atmospheric and climate research efforts. ARM offers scientists cutting-edge ground-based observatories, manned and unmanned aerial capabilities, and more than 25 years of continuous measurements of cloud and aerosol properties and their effects on Earth's energy balance.

Collected since 1992 in diverse climate regimes around the world, ARM data are helping researchers answer basic science questions about clouds, aerosols (small particles in the air), cloud formation, and Earth's energy balance. These data have yielded insights into a range of scientific issues, including measuring absorption of radiation (energy) from the sun by clouds, aerosols, 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.

In addition to advancing scientists' understanding of how the atmosphere works, ARM observations are being used to improve the accuracy of how clouds, aerosols, precipitation, and their interactions with Earth's radiant energy are represented in regional- and global-scale weather and 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 ground-based, cutting-edge instruments to continually measure cloud and aerosol properties and their effects 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.



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 ARM 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, ARM would not be the state-of-the-art facility that it is today.

ARM Observatories

ARM operates three 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)**—Established in 1992, the first ARM observatory includes a heavily instrumented Central Facility near Lamont, Oklahoma, and smaller satellite facilities covering a 150-by-150-kilometer (93-by-93-mile) area in Oklahoma and Kansas.
- **North Slope of Alaska (NSA)**—This includes a site at Barrow (officially known as Utqiaġvik) that was established in 1996 near the edge of the Arctic Ocean, and a location at Oliktok Point, where ARM has secured special-use arctic airspace.
- **Eastern North Atlantic (ENA)**—In operation since 2013, the youngest ARM observatory is located on Graciosa Island in the Azores, an area characterized by a wide variety of meteorological conditions and cloud types including marine stratocumulus clouds.

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 FY2018 collected ship-based data in the Southern Ocean, aircraft-based measurements around ARM's ENA observatory, and data from unmanned aerial systems at Oliktok Point. In addition, about 50 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 at no cost for the science community through the ARM Data Center to aid in further research.

ARM Data Provide Insights for Developing New High-Resolution Earth System Model

After four years of development, including contributions from ARM, a new Earth modeling system—the Energy Exascale Earth System Model (E3SM)—became available to the broader scientific community. The DOE Office of Science supports the E3SM project through the Office of Biological and Environmental Research.

Those involved with E3SM sought to overcome previous modeling limitations by taking advantage of the latest high-performance computing technologies. With this capability, the new high-resolution, coupled earth system model will help researchers explore the challenges posed by interactions of weather-climate variability with energy and related sectors.

Measurements from ARM's Southern Great Plains, Tropical Western Pacific, and North Slope of Alaska atmospheric observatories were useful in constraining and guiding the development of representations of clouds and aerosols for the E3SM atmosphere model.

"The quality and quantity of observations really makes us constrain the models," said David Bader, E3SM project lead and scientist at Lawrence Livermore National Laboratory in California. "With the new system, we'll be able to more realistically simulate the present, which gives us more confidence to simulate the future."

ARM data contributed to the development of E3SM, which will provide insights on earth system interactions in the Arctic and their influence on midlatitude weather.

High-Powered LASSO Simulations Sharpen View of Cloud Cover

Puffy, rain-free shallow cumulus clouds commonly inhabit about 40 percent of the sky on the days they appear. Exactly how many of these clouds and other types are within a modeler's grid at any one time—their "cloud fraction profile" (CFP)—is of obvious interest to those trying to estimate the role of clouds in the transfer of heat and moisture between the boundary layer and the free atmosphere.

A paper in the journal *Geophysical Research Letters* demonstrated the utility of the Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) modeling project. Driven by measurements from ARM's Southern Great Plains (SGP) atmospheric observatory, LASSO simulations combine simulated and observational cloud fields and are powered by new high-performance computing.

Researchers used virtual radars within LASSO simulations to develop an algorithm that outlines how to deploy scanning radars. Deployed virtually, for example, ARM's scanning cloud radars are more likely to capture the critical morphology of cloud fractions.

The paper confronted a basic question: To adequately capture a shallow cumulus CFP, how many vertically pointing radars would you need? They have higher sensitivity than the scanning radars, but they sample a much smaller area of the sky.

To the right, a bowl-like Ka-Band ARM Zenith Radar (pictured in 2010) at ARM's SGP atmospheric observatory points upward to retrieve a straw-like "zenith" profile of clouds.

"The conclusion is you need too many of them," said co-author William Gustafson, LASSO principal investigator and an atmospheric scientist at Pacific Northwest National Laboratory in Washington state. "There's no way to go out there and actually do that experiment, but we can insert virtual radars into the model. The LASSO simulations are readily available."

Computation Clusters Meet the Needs of High-Volume Users

Not long ago, high-volume ARM users typically downloaded and worked with data using their own computing resources. However, with data volume and complexity escalating, new computing options for large-scale projects were needed.

Last year ARM introduced new computation clusters to the ARM Data Center, placing capabilities and resources where the data reside and eliminating the need for large-volume downloads.

"It is important to meet the needs of scientific users who use large volumes of ARM data, which significantly reduces the data processing time for tasks like large-scale radar processing, complex synthesis product developments, and advanced analytics and visualizations," said ARM Technical Director Jim Mather. "The goal is to make it simple for users to migrate computational scripts from single workstations to the new computation clusters."

The Stratus cluster allows users to develop and run computer-intensive retrieval algorithms and perform large-scale ARM data analysis and extractions with direct access to ARM data. The Cumulus cluster is used for routine operations of the Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) workflow.

"They support model simulations, petascale data storage, and big-data analytics for successful ARM science research," said Giri Prakash, ARM Data Services manager from Oak Ridge National Laboratory in Tennessee.

There are no formal application deadlines to use these high-performance computing resources. Requests are reviewed quarterly and are subject to scientific peer review.

The first proposals were awarded last year, and Prakash said those users tapped into the computation clusters with great success.

Cooperation and Oversight Enable Success

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

- **DOE's Office of Biological and Environmental Research in the Office of Science –** Program managers provide oversight and accountability for ARM operations.
- **Infrastructure Management Board (IMB) –** DOE works with the IMB, whose members represent all areas of the facility, to coordinate the scientific, operational, data, financial, and administrative functions of ARM.
- **ARM Science Board –** An independent review body that reviews proposals for the ARM Mobile Facility and ARM Aerial Facility to ensure appropriate scientific use. Members are selected by the DOE ARM program manager.
- **Atmospheric System Research (ASR) Program –** A DOE-funded, observation-based atmospheric research program that represents the largest group of ARM users. ASR is an important source of scientific guidance for establishing ARM priorities.
- **ARM User Executive Committee –** An elected constituent group that provides feedback on the facility's activities and serves as the official voice of the user community in its interactions with ARM management.

User Executive Committee Increases Visibility With New and Current Users

The ARM User Executive Committee (UEC) is the official voice of the user community in its interactions with ARM management. Below are a few of the UEC's key accomplishments in FY2018:

- Increased efforts to talk about ARM—and interact with users—at meetings in both the United States and internationally. This included hosting a networking lunch at the 2018 Joint ARM User Facility/Atmospheric System Research (ASR) Principal Investigators Meeting for those new to ARM/ASR. Following up on a request from the 2017 ARM Triennial Review, the UEC also focused on reaching out to scientists and organizations outside the ASR community.
- Described—from the user perspective—how ARM is addressing or could address the "Grand Challenges" identified by the Biological and Environmental Research (BER) Advisory Committee (BERAC). The review looked at how to advance capabilities within all BER and DOE Office of Science user facilities.
- Provided feedback on a three-year ARM translator vision plan. Translators are liaisons between the scientific community and ARM infrastructure staff members. They develop value-added products, or VAPs, from the direct output of ARM instruments.
- Gave user feedback on the continual development of Data Discovery, ARM's portal for accessing more than 25 years' worth of data.
- Worked with ARM communications staff to create a video tutorial for the arm.gov website and a social media campaign to help new users learn key ARM acronyms.

Elections for UEC members occur every two years, and in August, nominations were sought for six positions opening in January 2019.

Snow Does Not Dampen the 2018 Joint ARM/ASR PI Meeting

For the second year in a row, a major snowstorm hit during the Joint ARM User Facility/Atmospheric System Research (ASR) Principal Investigators (PI) Meeting in Tysons, Virginia. Despite the snow, most of the 300 people who registered were able to attend the March 19 to 23, 2018, event.

During the meeting, progress was made in planning for upcoming field campaigns. Plenary sessions included updates from the DOE program managers and ARM technical director and four very successful poster sessions shared over 220 science and facility posters with attendees. The four ASR working groups—Aerosol Processes, Warm Boundary-Layer Processes, High-Latitude Processes, and Convective Processes—gathered at the end of the event to summarize and build on meeting discussions.

Key **ACCOMPLISHMENTS**

Featured Field Campaigns

In addition to providing continuous data collections from fixed observatories around the world, ARM sponsors field campaigns for scientist to obtain specific data sets or to test and validate instruments. The following pages highlight key campaigns in fiscal year 2018.

Cracking the Mysteries of Remote Oceanic Clouds and Aerosols

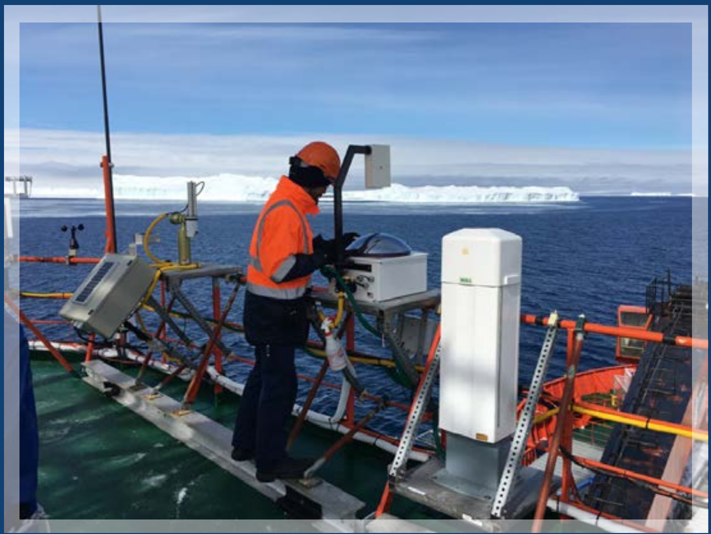
The Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean (MARCUS) field campaign, which used an ARM Mobile Facility to obtain key atmospheric data aboard an Australian Antarctic supply vessel, can claim a Southern Ocean research milestone.

From October 2017 to April 2018, the *Aurora Australis* made voyages from Hobart, Australia, to Australian Antarctic research stations Mawson, Casey, and Davis, and to Macquarie Island. Along the way, shipborne instruments gathered continuous measurements that captured the properties of clouds and aerosols north and south of the oceanic polar front (typically around 60 degrees south) in spring, summer, and autumn.

"It's really the first set of comprehensive data that describe the seasonal properties of clouds and aerosols south of the oceanic polar front," said Greg McFarquhar, the campaign's principal investigator.

McFarquhar, director of the National Oceanic and Atmospheric Administration (NOAA) Cooperative Institute for Mesoscale Meteorological Studies and a professor in the School of Meteorology at the University of Oklahoma, noted how pristine the clouds were in the region.

"There seems to be lots of supercooled water in them, and we just need to do a better job of quantifying that," he said.



Instruments aboard the *Aurora Australis* collected atmospheric data while traveling across the Southern Ocean during the MARCUS field campaign.

"It's really the first set of comprehensive data that describe the seasonal properties of clouds and aerosols south of the oceanic polar front."

—Greg McFarquhar, MARCUS lead scientist from University of Oklahoma

In July 2018, presentations on cloud properties over the Southern Ocean and statistical distributions of macrophysical cloud and aerosol properties over the ocean during MARCUS were given at the 15th Conference on Cloud Physics, hosted by the American Meteorological Society in Vancouver, Canada.

Unique Marine Campaign Confirms Variations in Cloud and Aerosol Properties

Findings from a combined ground and aerial field campaign in the Azores could help improve the representation of aerosols and low clouds in earth system model simulations.

The Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign took place during two intensive operational periods: summer 2017 (June and July) and winter 2018 (January and February). ACE-ENA combined ground-based measurements from ARM's Eastern North Atlantic (ENA) atmospheric observatory on Graciosa Island with data acquired aboard ARM's Gulfstream-159 (G-1) research aircraft.

During early data analysis, researchers confirmed several key seasonal variations in aerosol and cloud properties. Higher aerosol concentrations were seen during the summer, while winter observations showed layers with very low aerosol concentrations. The boundary layer was deeper and remained more well mixed in the winter. More warm rain and thicker clouds were observed during the winter, with increased precipitation contributing to lower aerosol concentrations.

ACE-ENA is an important campaign because of the combination of ground- and air-based measurements in the marine environment. Ground-based cloud radars deliver information on the coverage and structure of cloud and drizzle fields. Airborne instruments glean data on what occurs within the clouds, such as the number and size of cloud droplets and drizzle drops.

"There is a lot of interest from the scientific community for this field campaign," said ACE-ENA principal investigator Jian Wang, an atmospheric scientist at Brookhaven National Laboratory in New York. "I hope that it will lead to major discoveries in cloud and aerosol research."

To begin, an ACE-ENA science workshop is being planned for January 2019 at Brookhaven.

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—Jian Wang, ACE-ENA lead scientist from Brookhaven National Laboratory

The ACE-ENA field campaign in the Azores required measurements from ARM's Eastern North Atlantic atmospheric observatory, seen from the sky, and the Gulfstream-159 research aircraft.

ARM Campaign Provides Field Opportunities for Female Scientists

The Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign, which ended in February 2018, had one of the largest—if not the largest—groups of women working on an ARM field campaign.

"There are a lot of great women scientists and women engineers," said ACE-ENA principal investigator Jian Wang, an atmospheric scientist at Brookhaven National Laboratory (BNL) in New York. "They play a really important role. They made a great contribution or, in some cases, led certain aspects of the campaign as well."

The ACE-ENA team, including co-investigators, forecasters, data analysts, instrument mentors, and ARM Aerial Facility (AAF) staff, traveled to the Azores in summer 2017 and winter 2018 to study aerosols and low clouds in a remote marine setting. ACE-ENA required ground-based measurements from ARM's Eastern North Atlantic atmospheric observatory on Graciosa Island and data acquired aboard ARM's Gulfstream-159 (G-1) research aircraft.

Eight women worked on the G-1 during ACE-ENA—the most on an ARM field campaign, said Beat Schmid, ARM Aerial Facility manager from Pacific Northwest National Laboratory (PNNL) in Washington state.

Another milestone was when women filled all three science seats at the back of the G-1, doing everything from operating cutting-edge instruments to determining the flight path for the most scientific impact.

ACE-ENA co-investigator Christine Chiu, an associate professor in the Department of Atmospheric Science at Colorado State University, said ARM sets a unique example for the opportunities it makes available to women.

"I hope ARM becomes a role model in the community for supporting female scientists," said Chiu.

"I hope ARM becomes a role model in the community for supporting female scientists."

—Christine Chiu, associate professor from Colorado State University

Female AAF staff and instrument mentors during ACE-ENA gather in front of ARM's G-1 research aircraft during the winter 2018 intensive operational period.

Campaign Focuses on Shining New Light on Atmospheric Processes in the Arctic

A heavy flight schedule of unmanned aerial systems (UAS) and tethered balloon systems (TBS) took place in the summer and early fall of 2018 at ARM's Oliktok Point site in northern Alaska.

The flights were part of a field campaign called Profiling at Oliktok Point to Enhance YOPP Experiments (POPEYE). YOPP stands for the Year of Polar Prediction, a large international effort aimed at gathering observations to help improve modeling and forecasting capabilities around both poles.

At Oliktok Point, where DOE controls restricted airspace supporting ARM's UAS and TBS efforts, campaigns have usually consisted of several measurement periods lasting a few weeks at a time, and often over a couple of years.

POPEYE, which ran from July 1 to September 30, was a different kind of undertaking. Tethered balloons and DataHawk UAS operated continuously during the campaign, with the two teams alternating in two-week shifts.

When POPEYE started, Oliktok Point was under 24-hour daylight. During summer in the Arctic, this sunlight can drive a convective boundary layer over land in which the formation of eddies generates turbulence and clouds—sometimes even a thunderstorm.

POPEYE principal investigator Gijs de Boer, a research scientist at the Cooperative Institute for Research in Environmental Sciences at the University of Colorado, Boulder, said researchers hoped to see stable boundary layers—warm air sitting on top of cold air—as the dark hours returned in the campaign's final weeks. These layers and the limited turbulence within them have historically been difficult for models to represent.

The tethered balloon team from Sandia National Laboratories is hard at work during the POPEYE field campaign.

Long-Term Southern Ocean Data Help Gauge Satellite Accuracy

ARM cloud, aerosol, precipitation, and radiation measurements from the two-year Macquarie Island Cloud and Radiation Experiment (MICRE), which ended in March 2018, are being used to check the accuracy of satellite data in the region.

Satellite data analysis suggests that models struggle to correctly calculate how much sunlight reaches the surface at high southern latitudes, largely because of clouds. However, concern exists about the quality of satellite data over the Southern Ocean because "they were designed based primarily on Northern Hemisphere observations," said MICRE principal investigator Roger Marchand, a research associate professor of atmospheric sciences at the University of Washington.

The MICRE field campaign on Macquarie Island collected data over a two-year period—much longer than can typically be done with ship or aircraft campaigns—with a goal of studying seasonal and diurnal variability.

Past Campaign Results

ARM Campaign Results in Revelations About Smoke Over South Atlantic Ocean

In FY2018, researchers completed the first study to gather comprehensive, daily data with ground-based instruments on the properties of prolific smoke crossing the Atlantic from biomass fires in Africa within a remote cloudy trade-wind regime.

Data from the Layered Atlantic Smoke Interactions with Clouds (LASIC) field campaign, conducted by ARM from June 2016 to October 2017, revealed that high amounts of aerosols that can affect the Earth's energy balance and cloud properties are common in the marine boundary layer during the African burning season from June to October.

Southern Africa releases smoke particles from primarily agricultural burning, such as wood and grasses, that can travel as far west as Brazil. Smoke particles can either warm or cool the planet, depending on how much sunlight they absorb and whether or not the smoke is above a reflective low cloud deck. Many aspects of this large subtropical aerosol-cloud system remain poorly understood, and modeling and predicting how smoke affects atmospheric processes needs to be improved.

LASIC gathered data on how smoke properties (e.g., ability to absorb shortwave radiation) change after long-range atmospheric transport, as well as the smoke's effect on clouds. The campaign captured data from two biomass-burning seasons over a span reflecting repeatable trends across two summers.

ARM Field Campaigns Add to Year of Polar Prediction Research

In FY2018, ARM contributed to an international initiative called the Year of Polar Prediction (YOPP), which seeks observations to help improve polar modeling and forecasting capabilities.

During the Profiling at Oliktok Point to Enhance YOPP Experiments (POPEYE) field campaign in northern Alaska, unmanned aerial systems and tethered balloon systems collected data on atmospheric boundary-layer properties, clouds, aerosols, and precipitation from July 1 to September 30, 2018.

Shipborne ARM instruments played a key role in the Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean (MARCUS) field campaign from October 2017 to April 2018. The instruments helped capture cloud and aerosol properties north and south of the oceanic polar front (typically around 60 degrees south).

John Hubbe (left) and Lexie Goldberger, both of Pacific Northwest National Laboratory, pose with the DataHawk unmanned aerial system during the POPEYE field campaign.

“There is clear evidence of drizzle suppression from smoke in certain cloud types. I think we’re in store for more surprising results.”

—Paquita Zuidema, LASIC lead scientist from University of Miami

Data were obtained at the latitude zone for maximum aerosol outflow: Ascension Island, in the middle of the South Atlantic Ocean. Winds carry smoke over one of Earth’s largest stratocumulus cloud decks, with the clouds transitioning to shallow cumulus at Ascension.

Early LASIC measurements showed that one type of light-absorbing smoke aerosol was present over Ascension Island approximately 94 percent of the time—at times in extremely high concentrations.

Concentrations of this smoke aerosol, light absorption coefficients, and cloud condensation nuclei concentrations varied and peaked in August. Smoke was more predominantly present in the boundary layer early in the biomass-burning season and more likely in the lower troposphere in autumn, when it typically rested on the cloud-top inversion. The most light absorption occurred in June, and the single-scattering albedo appeared to increase from August to October.

“We were surprised by the high levels of smoke and the unique composition,” said Paquita Zuidema, LASIC principal investigator and a professor at the University of Miami. “There is clear evidence of drizzle suppression from smoke in certain cloud types. I think we’re in store for more surprising results.”

Smoke envelopes the first ARM Mobile Facility during a hazy day on Ascension Island in the South Atlantic Ocean.

Finnish Campaign Brings a Blizzard of Strong Papers

Despite dark, dreary days early on, everyone involved in the Biogenic Aerosols – Effects on Clouds and Climate (BAECC) field campaign is sunny about the results, which include about 20 papers so far.

The 2014 campaign in southern Finland deployed the second ARM Mobile Facility (AMF2) to better understand the role of organic vapors and other natural emissions (such as pollen) on the formation of clouds. BAECC also provided critical new data on the microphysical processes of snow, which have a great effect on global water resources.

Finland hosted BAECC under the direction of principal investigator Tuukka Petäjä, an atmospheric physicist from the University of Helsinki. BAECC was located at the Station for Measuring Ecosystem-Atmosphere Relations II (SMEAR II), which is co-located with the Hyytiälä Forestry Field Station. In a 2016 paper summarizing BAECC, Petäjä described SMEAR II as "one of the world's most comprehensive surface in situ observation sites in a boreal forest environment."

Several young researchers got their start with BAECC. Heike Kalesse, now at the Leibniz Institute for Tropospheric Research in Germany, led a paper on the "fingerprints" of a riming event as observed on cloud radars. Riming is a coating process that occurs as snowflakes fall through the cold, wet atmosphere, gaining mass and falling faster as they strip water out of the air and increase their density.

Before BAECC, the ARM Mobile Facility site at the Hyytiälä Forestry Field Station in Finland was a soccer field.

"Now, measurements similar to AMF2 are carried out continuously. BAECC had a tremendous impact on our research."

—Dmitri Moisseev, a cloud and precipitation physicist from University of Helsinki

Stefan Kneifel, who is at the University of Cologne in Germany, was lead author of a paper on the advantage of using the triple-frequency radar sets available during BAECC, which allows for better validation of present and future snow-scattering models.

Finnish scientist Annakaisa von Lerber collected data on falling ice particles during BAECC and then wrote a paper on the connection between snow properties and radar observations. She used three instruments to assemble a time series that elucidated the microphysical parameters of falling snow. Meanwhile, a paper led by Scottish researcher Victoria Sinclair was based on using dual-polarization radar observations to identify signatures of secondary ice production in precipitating clouds.

Since BAECC, because of Finnish investments and upgrades, the Hyytiälä Forestry Field Station has become "a fully equipped cloud profiling station," said Dmitri Moisseev, a cloud and precipitation physicist at the University of Helsinki. "Now, measurements similar to AMF2 are carried out continuously. BAECC had a tremendous impact on our research."

Flying ARM's Friendly Skies

Research planes, balloons, unmanned aerial systems, and satellites frequently sample the atmosphere over ARM observatories and provide a useful complement to the ARM ground-based observations.

In the spring of 2018, during a British-Canadian campaign intended to improve how the radiative effects of snow inform weather prediction models, research aircraft overflew ARM's North Slope of Alaska (NSA) atmospheric observatory.

Since 2012, radiosonde launches from both the NSA and ARM's Southern Great Plains (SGP) atmospheric observatories have been coordinated with the Joint Polar Satellite System, an interagency polar-orbiting system run by the National Oceanic and Atmospheric Administration and NASA.

Donna Holdridge (left), an ARM instrument mentor for balloon-borne sounding systems, participates in a balloon launch at ARM's Southern Great Plains atmospheric observatory. Sampling the atmosphere and coordinating measurements with other entities sometimes involves low-tech launches, said Holdridge.

For Storm-Wracked Science in Puerto Rico, ARM Steps Up

Since Hurricane Maria devastated Puerto Rico in September 2017, University of Puerto Rico-Rio Piedras atmospheric scientist Olga Mayol-Bracero has received funding, gear, and expert assistance to rebuild two observatories she has overseen for more than a decade.

ARM loaned Mayol-Bracero's science team a modified 20-foot SeaTainer converted to a Mobile Aerosol Observing System. The structure, on loan for two years, has lights, air conditioning, instrument racks, computers, monitors, an air-sampling inlet, a rail-protected roof, and a refurbished cloud condensation nuclei particle counter, which characterizes how particles interact with clouds.

"The container is a great help," said Mayol-Bracero. "It allows us to start measurements right away."

Ready for testing and calibration, instruments are racked inside the powered-up, air-conditioned ARM SeaTainer at Cape San Juan, Puerto Rico. The SeaTainer sits at the site of a long-term atmospheric observatory destroyed by Hurricane Maria. Photo is courtesy of John Ogren (retired from the National Oceanic and Atmospheric Administration).

Convective Cloud Research Spawns a Years-Long Storm of Good Papers

The Midlatitude Continental Convective Clouds Experiment (MC3E) has a name almost as big as the Midwestern sky it investigated more than seven years ago.

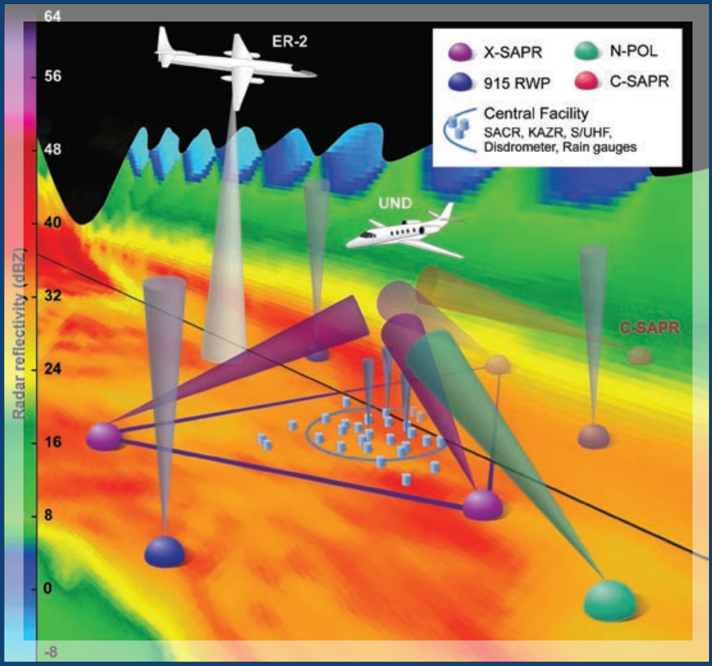
Then again, there was a lot to do. For one, improve what scientists know about the physical processes and life cycles of convective clouds. These huge assemblies of water, heat, and momentum play a critical role in earth system processes.

A lot of research has been generated from MC3E since it unfolded between April 22 and June 6, 2011. At last count, 57 papers using MC3E data had been published, said campaign lead scientist Michael Jensen, a meteorologist at Brookhaven National Laboratory in New York.

MC3E—a joint field campaign between ARM and NASA's Global Precipitation Measurement (GPM) Ground Validation Program—took place at ARM's Southern Great Plains atmospheric observatory, which spans thousands of square miles in Oklahoma and Kansas. This midlatitude continental region is famous for its dramatic convective storms during spring and summer.

MC3E researchers sought observations to advance the understanding of convective simulations in models, along with the microphysical parameterizations that would inform them. They also intended to collect data sets to improve satellite estimates of rainfall in deep convective systems over land.

Jensen called MC3E "one of the most successful campaigns ARM has ever done."



In this representation of MC3E, research aircraft fly above and within the clouds, radar systems scan through the storm from multiple locations, and additional ground-based instruments measure surface precipitation and wind speed. Image courtesy of Brookhaven National Laboratory.

Seconding that sentiment was Walt Petersen, the GPM lead scientist from the NASA Marshall Space Flight Center. "MC3E was a joint, multiagency campaign in every sense of the word," he said. "That is one of the successes to be touted as well."

Researchers employed a three-part operational field strategy that included aircraft, radiosondes, and ground-based radars and other instrumentation. MC3E provided cloud and precipitation data sets that were "used to model and confirm satellite-based remote methods for estimating precipitation from the vantage point of space," said Petersen.

Among the research to come out of MC3E is a study that used wind profiler data to characterize vertical velocity in convective updrafts. Another paper demonstrated that polarimetric radars, which supply data on the horizontal and vertical dimensions of cloud particles, can be used to both locate and see inside updrafts.

A third paper documented an improved convective ice parameterization for the NASA Goddard Institute for Space Studies Global Climate Model: A better way to represent the character of ice inside convective storms, which presents a challenge for earth system models in general.

"[MC3E is] one of the most successful campaigns ARM has ever done."

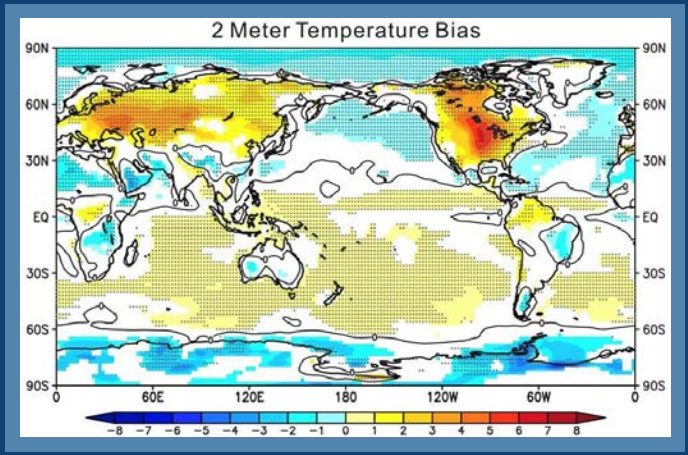
—Michael Jensen, MC3E lead scientist from Brookhaven National Laboratory

A Great Plains Divide: Investigating Temperature Differences Between Models and Observations

A group of four papers published online by *Journal of Geophysical Research: Atmospheres* in February 2018 explored why earth system models simulate warmer surface temperatures than ground-based observations show in the central United States.

Led by authors from Lawrence Livermore National Laboratory in California and the U.K. Met Office, the papers focused on results from the Clouds Above the United States and Errors at the Surface (CAUSES) project. Measurements from ARM's Southern Great Plains atmospheric observatory helped with evaluating numerical weather prediction models and Coupled Model Intercomparison Project Phase 5 earth system models. CAUSES sought to identify how cloud, radiation, and precipitation processes contributed to the warm bias, or offset from observations, of surface air temperature.

Researchers attributed differences between models and observations to simulations of deep convective clouds and the evaporative fraction (a ratio of latent heat flux to the sum of sensible and latent heat fluxes) at the surface.



The CAUSES model intercomparison study—with a focus on the Southern Great Plains region, where model errors are particularly large—is providing additional understanding of the role of clouds, radiation, and precipitation errors in contributing to the common temperature biases in earth system models. Small dots indicate the regions where analyzed models agree in the sign of their bias, (Ma et al. 2014). *(Copyrighted image from the journal.)*

Reference

Ma H, S Xie, SA Klein, KD Williams, JS Boyle, S Bony, H Douville, S Fermepin, B Medeiros, S Tyteca, M Watanabe, and DL Williamson. 2014. "On the correspondence between mean forecast errors and climate errors in CMIP5 models." *Journal of Climate*, 27(4), doi:10.1175/jcli-d-13-00474.1.

Research Highlights

How Do Shallow Clouds Deepen and Produce Rain?

Fair-weather shallow cumulus clouds can deepen and transition to the kind of clouds that produce rain. This transition is commonplace, but the mechanisms governing the transition still puzzle scientists.

A paper published in March 2018 explores the challenge of understanding this cumulus-to-congestus transition and the onset of precipitation. It is co-authored by University of Kansas atmospheric scientist David Mechem and Scott Giangrande, a research meteorologist at Brookhaven National Laboratory in New York.

Shallow cumulus clouds over continental regions deepen as an intrinsic part of the climatologically important diurnal convective cycle. Under the right conditions, these clouds transition to precipitating congestus clouds and may ultimately form into cumulonimbus clouds associated with thunderstorms.

The study looked at the process by which boundary-layer cumulus clouds transition to deeper, rainy cloud types.

The authors used a suite of 16 runs from a high-resolution large-eddy simulation model of a cloud-transition event that took place during the 2011 Midlatitude Continental Convective Clouds Experiment (MC3E) at ARM's Southern Great Plains (SGP) atmospheric observatory.

These 16 simulations were all configured slightly differently, and the authors focused on three of the simulations that best matched the ARM observations. But which one of these simulations was most correct? The answer, strangely enough, did not lie in differences of the evolution of environmental stability; all three simulations exhibited similar stability behaviors.

The authors found that only by conditionally sampling over cloudy regions in the model (predominantly looking at buoyancy) were they able to identify and understand differences among the simulations. They also considered a number of the worst simulations and explained why they performed so poorly. The paper argued for similar hybrid approaches that combine observation and modeling to enable a more complete understanding of cloud systems.

Reference

Mechem DB and SE Giangrande. 2018. "The challenge of identifying controls on cloud properties and precipitation onset for cumulus congestus sampled during MC3E." *Journal of Geophysical Research*, 123:3126-3144, doi:10.1002/2017JD027457.

BAMS Paper Details ARM's Unmanned Aerial Capabilities in the Arctic

A paper in the June 2018 issue of the *Bulletin of the American Meteorological Society (BAMS)* summarized ARM efforts, through collaborations with university and federal partners, to develop and use unmanned aerial capabilities for atmospheric research in the Arctic.

Over the past three years, ARM has managed field campaigns using unmanned aerial systems (UAS) and tethered balloon systems (TBS) at Oliktok Point in northern Alaska, where DOE controls restricted airspace supporting such efforts. The UAS and TBS measurements have supplemented ARM Mobile Facility data obtained at Oliktok Point—part of ARM's North Slope of Alaska atmospheric observatory—to help improve understanding of atmospheric processes in the Arctic.

The paper discussed ARM field campaigns and initiatives to further UAS capabilities while collecting scientifically relevant measurements. It also detailed other steps taken to advance ARM's unmanned aerial capabilities and community access to ARM-managed UAS and TBS.

A tethered balloon system flies above Oliktok Point in northern Alaska.

Reference

de Boer G, M Ivey, B Schmid, D Lawrence, D Dexheimer, F Mei, J Hubbe, A Bendure, J Hardesty, M Shupe, A McComiskey, H Telg, C Schmitt, S Matrosov, I Brooks, J Creamean, A Solomon, D Turner, C Williams, M Maahn, B Argrow, S Palo, C Long, R Gao, and J Mather. 2018. "A bird's eye view: Development of an operational ARM unmanned aerial capability for atmospheric research in arctic Alaska." *Bulletin of the American Meteorological Society*, 99(6), doi:10.1175/BAMS-D-17-0156.1.

Insights on Land-Atmosphere Dynamics Emerge From Eclipse

When a solar eclipse swept over the continental United States on August 21, 2017, it simulated a rapid sunset-sunrise event.

Dave Turner, a meteorologist with the National Oceanic and Atmospheric Administration, was ready to take advantage of this unique opportunity to study the eclipse's effect on the land-atmosphere system and to evaluate how these interactions are represented in numerical weather prediction models and earth system models.

Land-atmosphere interactions play a crucial role in convection, precipitation, and the evolution of the boundary layer, where weather happens. The boundary layer is roughly the lowest kilometer—3,280 feet—of the atmosphere.

Turner was lead author of a paper published in February 2018 that documented the eclipse's effects in unprecedented detail. In general, he said, the event brought cooler, calmer, and slightly drier conditions.

Data came from a unique array of sensors deployed at three sites within ARM's Southern Great Plains atmospheric observatory. The sensors—augmented by instruments deployed for the Land-Atmosphere Feedback Experiment (LAFE)—measured changes in wind, temperature, humidity, turbulent motions, and surface properties.

The paper demonstrated how quickly turbulent fluxes of heat and momentum responded to the sudden change in solar radiation. In the layer of the atmosphere below 200 meters (about 650 feet), air temperatures fell fast and turbulent motions largely decreased.

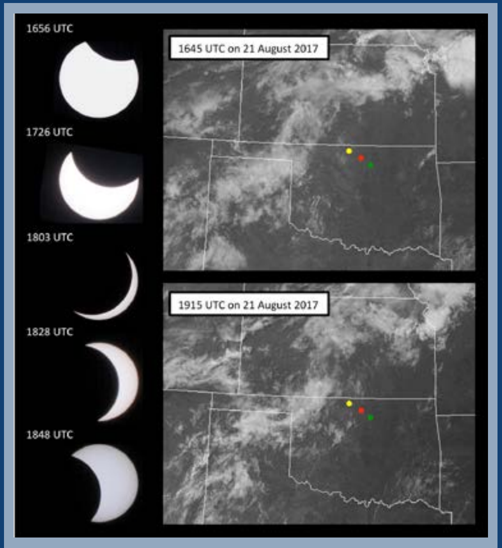
"The rapid sunset-sunrise eclipse event provides an excellent complement to normal sunset-sunrise events," said Turner. "The different time scales of the two cases provide clues on how to better represent the transition from daytime to nighttime—and vice versa."

The eclipse's simulated rapid sunset and sunrise will end up helping to correct deficiencies in understanding how the surface interacts with the boundary layer—a challenge largely driven by a lack of observational data.

Reference

Turner DD, V Wulfmeyer, A Behrendt, TA Bonin, A Choukulkar, RK Newsom, WA Brewer, and DR Cook. 2018. "Response of the land-atmosphere system over North-Central Oklahoma during the 2017 eclipse." *Geophysical Research Letters*, 45:1668-1675, doi:10.1002/2017GL076908.

Cloud snapshots from ARM's Southern Great Plains observatory in 2011 show the transition from shallow cumulus to precipitating congestus clouds.*(Copyrighted image from the journal.)*



Images of the progressing solar eclipse (left) on August 21, 2017, were taken at ARM's Southern Great Plains observatory represented by the red dot (right, the three colored dots represent sensor-equipped locations). *(Copyrighted images from the journal.)*

A Lot of Water in High-Up New Particles

Aerosols are tiny particles suspended in the atmosphere. Many are shaped from vapors in a process called new particle formation (NPF).

If they grow from their initial diameter of around 1 nanometer (nm) to over 50 nm, they may become cloud condensation nuclei (CCN). These nuclei influence the Earth's energy balance by forming clouds that reflect or absorb solar radiation.

Scientists ask: How do these particles form, and how do they grow? A January paper demonstrated the timing and location of NPF, and provides new insights into the particles' water content.

The authors concluded that ground-based observations alone do not capture NPF processes that take place higher in the boundary layer. Most prior field studies of NPF were performed at or near ground level. Here, the researchers looked at the vertical extent of NPF, supplemented by simultaneous ground-based measurements.

Using a tethered balloon, they measured concentrations of 11- to 16-nanometer diameter particles from ground level to 1,000 meters (3,280 feet) at ARM's Southern Great Plains atmospheric observatory during the 2013 New Particle Formation Study.

"The new particles soak up water like a sponge. We need to think of them more as concentrated water droplets and less as bits of dust."

—James N. Smith, senior author from University of California, Irvine

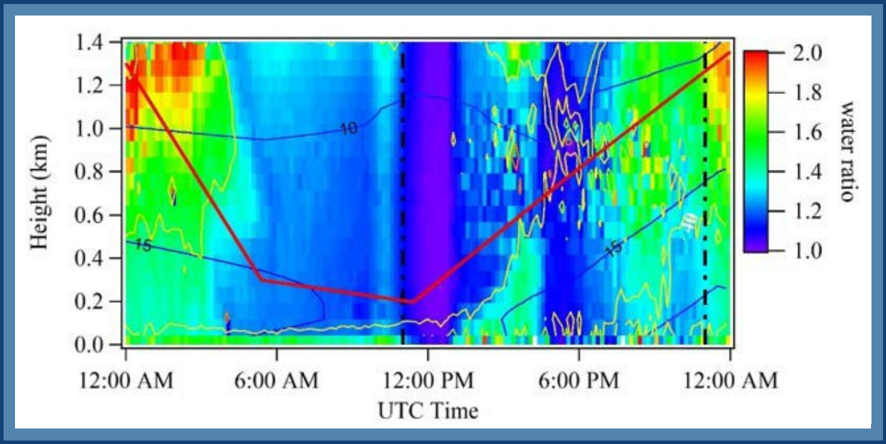
The researchers also concluded that newly formed nano-particles are highly hygroscopic, containing from 50 to even 95 percent water. Until now, the authors said, very little was known about the water content of newly formed particles.

The new particles "soak up water like a sponge," said senior author James N. Smith of the University of California, Irvine. "We need to think of them more as concentrated water droplets and less as bits of dust."

Smith was joined in the research by lead author and former Irvine colleague Haihan Chen, now at the University of Maryland, and by co-authors from California, Colorado, and Minnesota.

Reference

Chen H, AL Hodshire, J Ortega, J Greenberg, PH McMurry, AG Carlton, JR Pierce, DR Hanson, and JN Smith. 2018. "Vertically resolved concentration and liquid water content of atmospheric nanoparticles at the US DOE Southern Great Plains site." *Atmospheric Chemistry and Physics*, 18, 311-326, 2018, doi:10.5194/acp-18-311-2018.



A plot of the estimated water volume ratio of nanoparticles from May 12, 2012, shows one of the paper's novel findings that aerosol nanoparticles likely contain a lot of water.

Harnessing Specialized Radars to Estimate the Critical Shapes of Atmospheric Ice Particles in the Arctic

Ice particles in clouds and precipitation occur in a wide variety of shapes and types. These "habits" have a critical influence on microphysical and radiative properties, including how fast ice particles fall and how much light they reflect.

Understanding and quantifying these habits are critical for refining earth system models and improving quantitative snowfall estimates.

Many models use a "simple-shape assumption" to represent ice particles in models. However, such "pristine habits" describe only a very small percentage of observed ice particles—around 3 percent. That makes it imperative for remote-sensing technologies to find better ways to quantify the habits of precipitating ice.

A 2017 paper led by Sergey Matrosov, a senior scientist at the National Oceanic and Atmospheric Administration, outlines a novel remote-sensing approach to retrieving one key aspect of the shape-and-type measurements so critically needed: the degree of nonsphericity of ice hydrometeors (atmospheric ice particles).

The authors focused on quantifying ice particles by their aspect ratio—the ratio of a particle's minor and major dimensions. To do this, they demonstrated the utility of using a novel variant of polarimetric radar measurements available from ARM research radars.

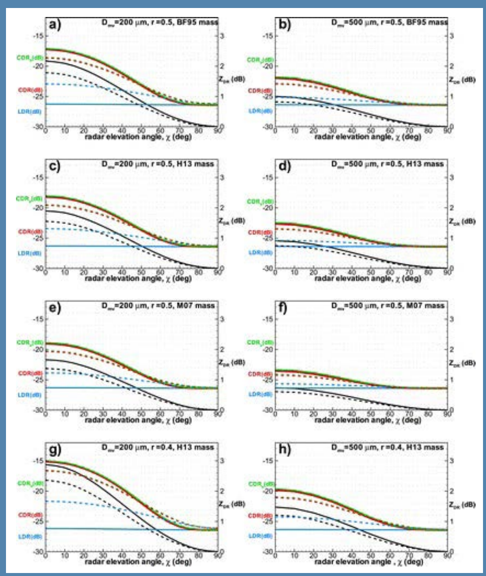
They derived their data from a scanning Ka-band (35 GHz) radar, which transmits horizontally and vertically polarized pulses and is part of an ARM Mobile Facility deployment in Oliktok Point, Alaska. The researchers used the radar measurements to estimate aspect ratios of irregular and aggregate ice particles. Then they compared the results to those from two co-located in situ sources: Oliktok's ground-based multiangle snowflake camera and a balloon-borne video ice particle sampler.

The polarimetric radar algorithm employed by the authors minimized the influence of particle orientations. It also allowed for more accurate estimates of particle aspect ratios and snowfall.

These improved polarimetric radar-based retrievals produce results comparable to in situ sources.

Reference

Matrosov SY, CG Schmitt, M Maahn, and G de Boer. 2017. "Atmospheric ice particle shape estimates from polarimetric radar measurements and in situ observation." *Journal of Atmospheric and Oceanic Technology,* 34:2569-2587, doi:10.1175/JTECH-D-17-0111.1.



The researchers modeled particles with different aspect ratios and sizes. This figure shows the results of modeling different Ka-band polarimetric radar variables for particles that are oblate nonspherical, a shape that appears flattened at the poles. *(Copyrighted image from the journal.)*

Analyzing the Complex Microphysics of Clouds in the Arctic

Arctic clouds present a challenge to researchers, largely because so many different types of ice particles can coexist in the same volume of cloud.

In particular, mixed-phase clouds—which contain both supercooled water droplets and solid ice crystals—are difficult to accurately observe and even more difficult to accurately represent in models. Breaking such clouds into understandable parts means defining ice species, their relative sizes, their variety of shapes and falling speeds, and the differing density and spatial orientation of a cloud's ice particles. These variables are called the "habits" of a cloud particle.

A paper published in early 2018 illustrates a new approach to analyzing the complex microphysical processes within mixed-phase clouds. Guiding the work was lead author Mariko Oue, a postdoctoral fellow at Stony Brook University in New York. The paper explores the analytical synergy between upward-pointing Ka-band radars and the near-vertical profiles obtained by multifrequency scanning radars. The idea is that both types of radars together can provide multiparameter observations based on Doppler spectra, polarimetry, and multiple wavelengths.

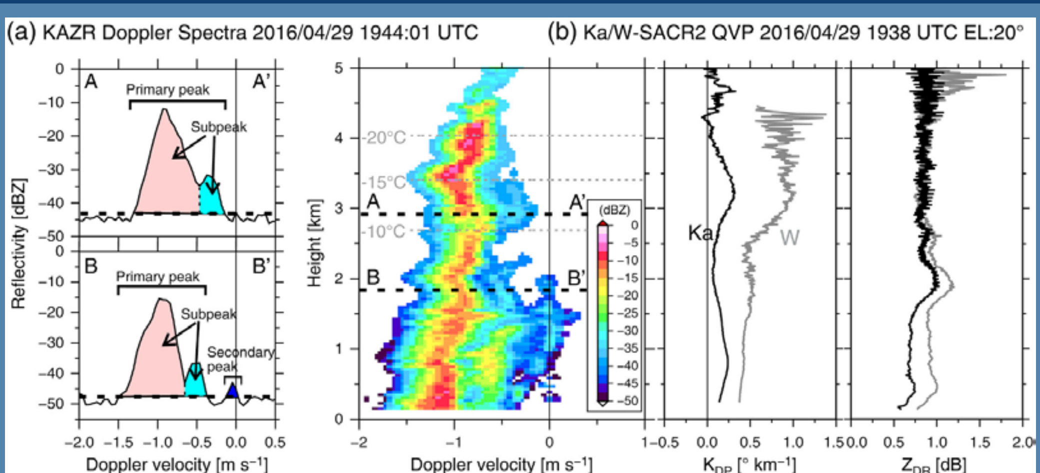
Doppler spectra reveal the varying speeds of slow and fast ice particles, which in turn influence cloud temperature and reflectivity. Measured by profiling millimeter wavelength radar, these spectra identify and separate the contributions of both liquid and ice hydrometeors.

Combining polarimetric measurements with Doppler spectra makes it easier to identify different habits of ice within a cloud and to measure their falling velocities. This joint method of analysis, the authors said, provides important insights into the microphysics of snow formation.

The new approach depended on April and May 2016 data from an ARM Mobile Facility deployment in Oliktok Point, Alaska. The authors said their radar-based approach to studying the microphysics of arctic clouds is a reliable complement to aircraft-based in situ measurements, which are difficult to perform routinely.

Reference

Oue M, P Kollias, A Ryzhkov, and EP Luke. 2018. "Toward exploring the synergy between cloud radar polarimetry and Doppler spectral analysis in deep cold precipitating systems in the Arctic." *Journal of Geophysical Research,* 123:2797-2815, doi:10.1002/2017JD027717.



The data plots show that Doppler spectra are multimodal, making it possible to identify different particle populations that coexist in one radar sampling volume. The tall (primary) peak at the top left, for example, shows how cloud reflectivity is dominated by ice particles and not cloud droplets. The color-shaded profile plot in the center offers another view of variances in reflectivity from different populations in the column above the radar. *(Copyrighted image from the journal.)*

To Reduce Cloud Bias in Models, a Study Looks at Marine Cold Fronts

Midlatitude clouds over storm-track regions impact the response of the atmosphere to anthropogenic climate change. Yet earth system models underestimate cloud cover over midlatitude oceans. The largest cloud bias occurs in the cold sector to the west of the low-pressure center of extratropical cyclones, in post-cold-frontal regions.

In this study, researchers explored how well the Weather Research and Forecasting (WRF) Model could accurately reproduce the passage of cold fronts at the ARM Eastern North Atlantic (ENA) observation site in the Azores.

The researchers employed three 2015 case studies to identify the optimal domain size for reproducing cold front passages at the ENA site. In each, they analyzed the impact of WRF domain size, position of the model boundary relative to the ENA site, grid spacing, and spectral nudging conditions.

The results showed model biases in the timing and duration of cold front passages change with the distance between the model domain boundary and the ENA site. The optimal distances between boundary and site were 1000 or 1500 kilometers. Integrations with small distances such as 500 kilometers were too small for the model to properly stabilize.

Surface biases were reduced by adjusting the distances of the lateral boundaries to the site. Biases in upper-level circulation, however, impacted the position and timing of the front regardless of domain size. This is most serious for domains of 4000 kilometers^2 or more, although cold-front biases were corrected by prolonged spectral nudging.

This study is the first step in a project aimed at understanding post-cold-frontal cloud physics in order to improve climate models. The present results provide a recipe for configuring WRF to generate hindcasts of surface frontal passages at a fixed location centered in a domain as large as computationally possible.

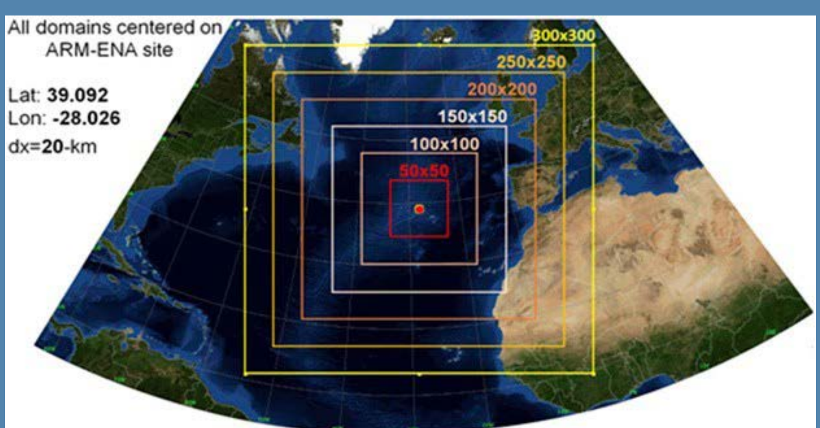
Reference

Lamraoui F, JF Booth, and CM Naud. 2018. "WRF hindcasts of cold front passages over the ARM Eastern North Atlantic site: A sensitivity study." *Monthly Weather Review,* 146:2417-2432, doi:10.1175/MWR-D-17-0281.1.

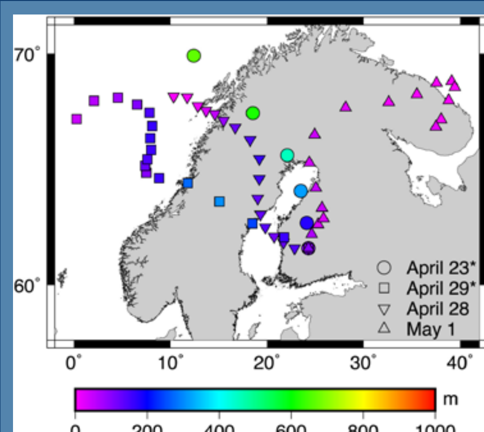
From Finnish Forests, Insights on Marine Influences in New Particle Formation

After the oceans, boreal forests make up the Earth's largest biome. This natural community of plants and animals, also called the taiga, represents nearly one-third of the planet's tree cover in a dense northern fringe of green bordering polar snows around the world.

Just like expanses of ocean, stretches of boreal forest contribute many of the microscopic atmospheric particles that go into making clouds. This vast source of particles is important to understand more fully. Clouds are highly



The six simulation domains chosen for this study all centered on ARM's Eastern North Atlantic atmospheric observatory (red dot) on Graciosa Island in the Azores. The legend in the top-right corner of each domain represents the number of grid points. *(Copyrighted image from the journal.)*



Days with rapid transport of marine air (marked with an asterisk) are linked to forest new particle formation. *(Copyrighted image from the journal.)*

critical to earth systems because they control the radiation entering and leaving the planet.

In a paper published in February 2018, Michael Lawler of the University of California, Irvine, and his co-authors studied the composition of what are potential cloud-forming particles in the Nordic boreal forest. The study opens the way to greater understanding of ocean-land-cloud interactions.

In particular, the results provide fresh insights into the chemical drivers behind atmospheric new particle formation (NPF). This process involves particle formation by way of airborne vapors, which is how perhaps half of cloud-forming atmospheric particles are generated.

The authors urge renewed study of the sources and role of transported marine compounds in NPF. For clouds forming over boreal forests, they said, oceans matter—especially when boreal air masses have been over the ocean within 36 hours or less.

The authors presented observations of the chemical composition of ambient aerosols at the Hyytiälä Forestry Field Station in Finland, where NPF has been the subject of intense recent interest. They took advantage of samples obtained during the 2014 Biogenic Aerosols—Effects on Clouds and Climate (BAECC) field campaign—in particular, samples from two intense NPF events in April.

To identify the organic and inorganic components of recently formed ultrafine particles, researchers used an on-site thermal desorption chemical ionization mass spectrometer in two-hour cycles of collection and analysis.

Reference

Lawler MJ, MP Rissanen, M Ehn, RL Mauldin III, N Sarnela, M Sipilä, and JN Smith. 2018. "Evidence for diverse biogeochemical drivers of boreal forest new particle formation." *Geophysical Research Letters,* 45:2038-2046, doi:10.1002/2017GL076394.

Paper Explores Southern Great Plains Warm and Dry Model Bias

Featuring data from ARM's Southern Great Plains (SGP) atmospheric observatory, an October 2017 *Nature Communications* paper examined causes of warm and dry model bias—or offsets from observations—in the region and how they affect earth system projections.

Because of limited computing power, models use simplified representations of clouds and convective systems to calculate their effects on earth system processes. Significant biases can form if those representations cannot accurately simulate heavy rain from organized convective systems—a common summertime occurrence in the central United States.

"The finding that the dry bias leads the warm bias helped us to narrow the search for the cause of the model deficiencies," said co-author Minghua Zhang, a researcher at Stony Brook University in New York.

With larger model biases leading to projected warmer temperatures in the region, Zhang said more accurate simulation of rain intensity and frequency distribution would be needed to reduce uncertainties in those projections.

Using long-term measurements from ARM's Southern Great Plains atmospheric observatory, researchers found that a longstanding warm model bias over the central United States stemmed from models' failure to capture strong summertime rain in the region.

Reference

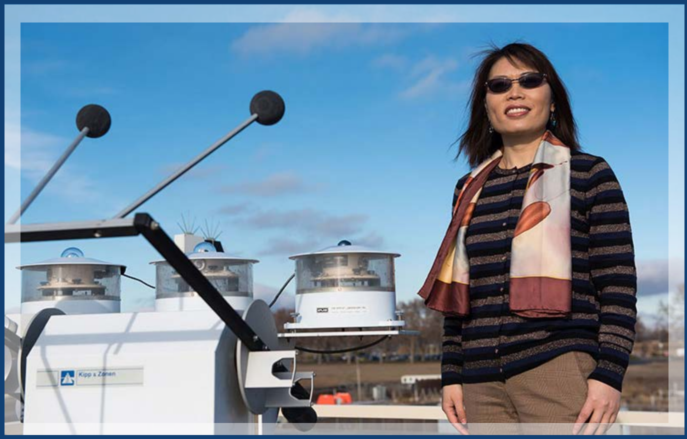
Lin Y, W Dong, M Zhang, Y Xie, W Xue, J Huang, and Y Luo. 2017. "Causes of model dry and warm bias over central US and impact on climate projections." *Nature Communications,* 8(1):881, doi:10.1038/s41467-017-01040-2.

GoAmazon Research Shows Small Particles Have Big Effects

A January 2018 paper in the journal *Science* concluded that the tiniest particles have big effects on storms. Based on research from ARM's Green Ocean Amazon (GoAmazon2014/15) campaign, scientists found that aerosols smaller than one-thousandth the width of a human hair can cause storms to intensify, clouds to grow, and more rain to fall.

During GoAmazon2014/15, researchers studied an urban environment set in the midst of the near-pristine vastness of Amazon rainforest that spans 1,500 kilometers (about 930 miles) in any direction.

"In a warm and humid area where atmospheric conditions are otherwise very clean, the intrusion of very small particles can make quite an impact," said lead author Jiwen Fan, an atmospheric scientist at Pacific Northwest National Laboratory in Washington state.



Pacific Northwest National Laboratory atmospheric scientist Jiwen Fan led a GoAmazon2014/15 paper on ultrafine aerosols in a January 2018 issue of *Science*.

Reference

Fan J, D Rosenfeld, Y Zhang, S Giangrande, Z Li, L Machado, S Martin, Y Yang, J Wang, P Artaxo, H Barbosa, R Braga, J Comstock, Z Feng, W Gao, H Gomes, F Mei, C Pöhlker, M Pöhlker, U Pöschl, and R de Souza. 2018. "Substantial convection and precipitation enhancements by ultrafine aerosol particles." *Science*, 359(6374), doi:10.1126/science.aan8461.

ARM Data Contribute to Consequential Methane Research

For the first time, scientists directly measured the increasing greenhouse effect of methane at the Earth's surface. A research team led by scientists at Lawrence Berkeley National Laboratory in California tracked a rise in the warming effect of methane over a 10-year period at ARM's Southern Great Plains (SGP) atmospheric observatory.

Scientists analyzed highly calibrated, long-term ARM measurements to isolate the changing greenhouse effect of methane and published their findings in the journal *Nature Geoscience*. The paper indicated that the greenhouse effect from methane tracked with a global pause in methane concentrations in the early 2000s and began to rise at the same time that concentrations began to rise in 2007.

Radiometers were among the many instruments at ARM's Southern Great Plains atmospheric observatory that researchers used to conduct a study on methane.

Reference

Feldman D, W Collins, S Biraud, M Risser, D Turner, P Gero, J Tadić, D Helmig, S Xie, E Mlawer, T Shippert, and M Torn. 2018. "Observationally derived rise in methane surface forcing mediated by water vapour trends." *Nature Geoscience*, 11, doi:10.1038/s41561-018-0085-9.

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.

Reports Outline Plans for Aerosol Measurement and Radars

ARM released two important strategic planning workshop reports in FY2018, the first about aerosol measurement and the second about radars. Both reports are on the ARM website.

The ARM Aerosol Measurement Science Group (AMSG) Strategic Planning Workshop 2017 report prioritized recommendations for ARM activities that will continue to support high-quality measurements and science-ready data products relevant to the atmospheric science community.

In February 2017, the AMSG held a strategic planning workshop at Argonne National Laboratory in Illinois to hammer out future priorities. Participants evaluated ARM's existing aerosol instrumentation, measurement strategies, and data products in the context of ARM and DOE Atmospheric System Research (ASR) science directions and data user needs. They agreed on measurements and data products to best align ARM's aerosol program with the needs of the scientific community. Topics included:

- priority measurements and instrumentation for ARM sites
- physical system configurations
- calibration strategies
- deployment strategies for Aerosol Observing Systems
- communication about and accessibility of data.

In October 2017, ARM's Sixth Radar Engineering and Radar Science Workshop was held at Stony Brook University in New York. ARM operates the world's largest array of meteorological research radars. These sophisticated instruments, deployed in challenging environments, require significant management, maintenance, and forward planning.

Workshop attendees included ASR-funded scientists, ARM users, and members of ARM's radar organization, consisting of two groups: Radar Science and Radar Engineering and Operations. These teams work closely to produce high-quality observations and products from ARM's radar network.

The workshop sought to maximize scientific usage of ARM radar data to improve understanding of atmospheric processes and, ultimately, earth system models. The workshop report documented recommendations on calibration, clutter mitigation, value-added products, forward simulators, scan strategies for the X-Band Scanning ARM Precipitation Radar at ARM's Southern Great Plains (SGP) atmospheric observatory, radar wind profiler scanning modes, and ancillary sensor data quality.

A recent ARM radar workshop report discussed scan strategies for the X-Band Scanning ARM Precipitation Radar at the Southern Great Plains atmospheric observatory.

Priorities Set for ARM Translators in New Three-Year Vision

ARM translators direct the creation of value-added products and analysis tools to make ARM measurements more accessible to a broader swath of the scientific community. They also collect information about scientific priorities and communicate details about ARM data and services to users.

In January 2018, ARM's Translator Group published a three-year vision plan that incorporated key feedback and aligned with ARM's mission priorities.

"Most new product development cycles are longer than one year, so if you think a little bit farther down the road, you have a chance to be a bit more strategic and coordinated," said Laura Riihimaki, ARM data products and translators lead from Pacific Northwest National Laboratory in Washington state.

To develop the plan, Riihimaki and four other ARM translators worked with representatives from the ARM Data Quality Office and software development, as well as ARM Engineering and Process Manager Jennifer Comstock, who provided input and direction from ARM priorities.

The Translator Group considered feedback from the ARM User Executive Committee, which represents the user community in its interactions with ARM management, and the 2017 ARM Triennial Review. It also reviewed priorities from the Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) project, new instrumentation and activities as described by ARM Technical Director Jim Mather, and working groups and principal investigators with DOE's Atmospheric System Research program.

The group decided to prioritize work in the following areas from 2018 to 2020:

- tools and products to facilitate use of ARM data by modelers, including LASSO and the earth system modeling community
- producing core value-added products for ARM Mobile Facility deployments
- creating data products to facilitate use of new instrumentation, including Aerosol Observing System instruments, radars, lidars, and radiometers
- uncertainty assessment of strategic measurements
- improving and communicating data quality of those strategic measurements.

"Most new product development cycles are longer than one year, so if you think a little bit farther down the road, you have a chance to be a bit more strategic and coordinated."

—Laura Riihimaki, ARM data products and translators lead from Pacific Northwest National Laboratory

Left to right, ARM translators Laura Riihimaki, Scott Collis, Connor Flynn, Scott Giangrande, and Shaocheng Xie helped develop the new three-year ARM translator vision plan.

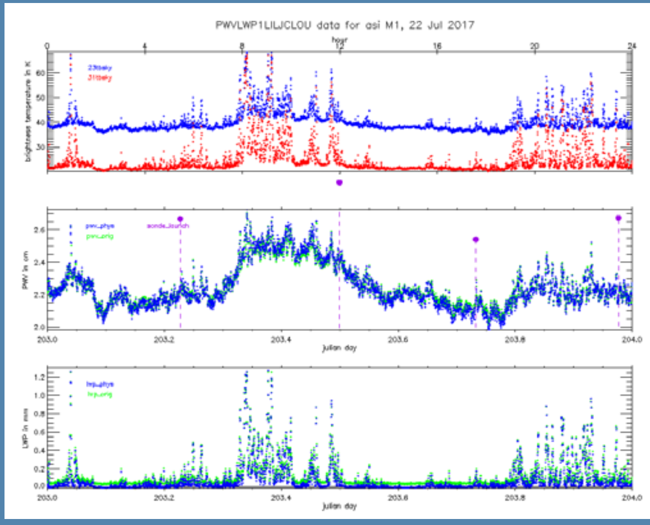
New Data Products

Two More LASIC Data Sets Processed and Issued

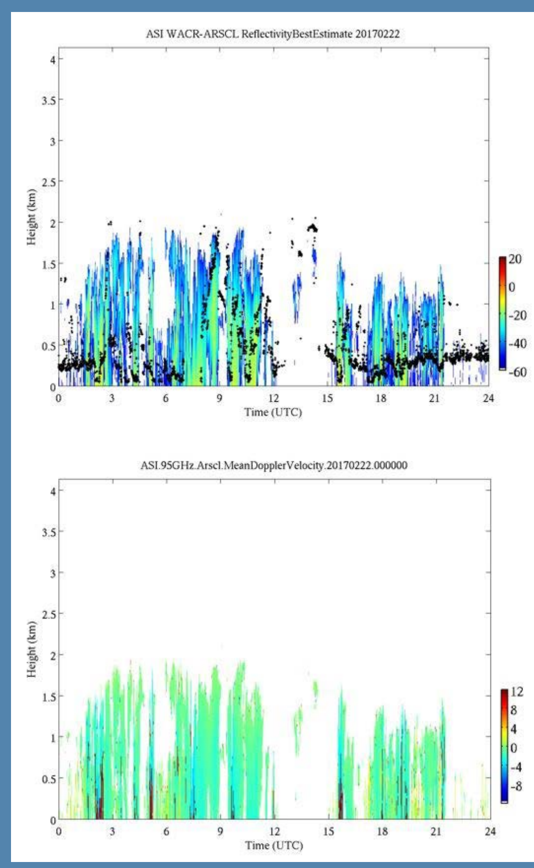
A year after the ARM Mobile Facility deployment to Ascension Island came to a close for the Layered Atlantic Smoke Interactions with Clouds (LASIC) field campaign, two high-priority and higher-effort value-added products (VAPs) have been prepared and made available in the ARM Data Center. This brings the total number of core VAPs released for the campaign to 11 and is part of the ARM science translator efforts to release core VAP data more quickly for ARM mobile deployments.

First, the Microwave Radiometer Retrievals (MWRRET) VAP was processed for the full campaign from October 2016 to February 2017. MWRRET gathers column precipitable water vapor and liquid water path from the 2-channel microwave radiometers using a physical retrieval methodology and bias correction that provides improved retrievals over the standard statistical coefficient method. These data are available from two locations on Ascension Island during LASIC: The main ARM Mobile Facility site and a supplementary deployment at the airport.

The second set was evaluation data for the W-band ARM Cloud Radar-Active Remotely Sensed Cloud Locations (WACR-ARSCL) VAP. WACR-ARSCL provides cloud boundaries and best-estimate time-height fields of radar moments. WACR observations are corrected for velocity aliasing, then significant detection masks are produced. The corrected WACR measurements are combined with observations from the micropulse lidar, ceilometer, soundings, rain gauge, and microwave radiometer, and low-level clutter is identified and removed.



Precipitable water vapor (PWV) and liquid water path (LWP) data are seen for the main ARM Mobile Facility site on Ascension Island on July 22, 2017.



Plots from the WACR-ARSCL value-added product show reflectivity best estimate (top) and mean Doppler velocity (bottom) as captured February 22, 2017, during the LASIC field campaign on Ascension Island.

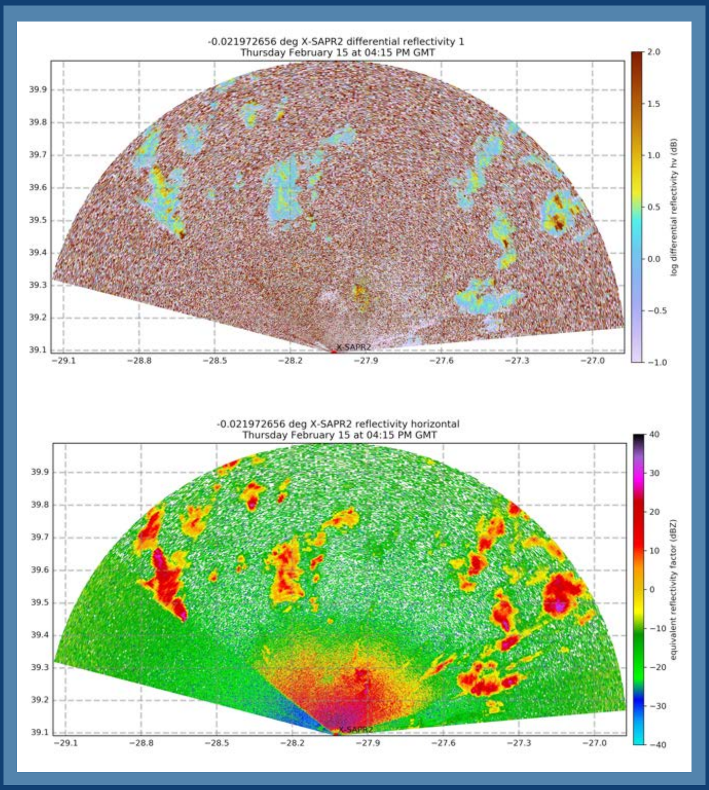
New Version of Python ARM Radar Toolkit Produced

The latest version of the Python ARM Radar Toolkit (Py-ART), an open-source architecture for interacting with radar data in the Python programming language, was released in fiscal year 2018. Py-ART 1.9.0, also known as Picasso, is the first named release aligned with the five-year Py-ART development road map. It features numerous improvements over previous Py-ART versions, including:

- a faster convolution-based technique for texture calculations
- cost function-based correction for the region-based dealiasing code
- two new methods for processing polarimetric phase information
- a new gridding method for using only the nearest radar gate for discrete fields.

Picasso (Py-ART 1.9.0) works with all raw formats produced by the X- and C-band scanning radars and with the ingested format (CF-Radial) of all ARM radars. It includes visualization for all modes of radar scanning. In addition, many community formats, including NEXRAD, ODIM HDF5, and UF, are supported.

Since its release in February 2018, Picasso has been downloaded nearly 10,000 times from the open-source packaging site Conda-Forge.



Plots of differential reflectivity (top) and reflectivity factor are shown from the X-band Scanning ARM Precipitation Radar on Graciosa Island in the Azores. Py-ART has a new experimental reader allowing the new format to be read.

ASR Scientists Share GoAmazon2014/15 Field Campaign Research Data

A new principal investigator provided product—the Merged Multisensor Cloud-Precipitation Mask and Cloud Type Data for GoAmazon2014/15—was provided by Atmospheric System Research (ASR) supported researchers, Zhe Feng of Pacific Northwest National Laboratory and Scott Giangrande of Brookhaven National Laboratory, as an outcome of a breakout session at the 2018 ARM-ASR joint meeting. These data can be used by scientists to better characterize cloud and precipitation profiles of all conditions, including periods of heavy precipitation from storms, as well as validate-model simulations.

This data product combines the Radar Wind Profiler (RWP) calibrated radar reflectivity data with the W-band ARM Cloud Radar-Active Remotely Sensed Cloud Locations (WACR-ARSCL) data set to improve cloud mask in precipitating clouds and to provide cloud-type profile classification. WACR-ARSCL cloud profiles were replaced with RWP profiles during substantial precipitation periods where severe attenuation affects the accuracy of WACR cloud-top detections. The merged RWP-WACR-ARSCL cloud mask is then used to produce a cloud-type profile classification.

Since these data were released, there have been over 150 requests from 46 users to download over 700,000 files.

Aerosol Optical Properties VAP Announced

Featuring fully corrected aerosol scattering and absorption measurements from all ARM Aerosol Observing System (AOS) deployments within the past two years, the Aerosol Optical Properties (AOP) VAP made its debut in fiscal year 2018.

The AOP 1-minute VAP provides 60-second averages of a fully corrected set of aerosol extensive properties—scattering and absorption—with consistent intensive properties (Angstrom [Å] exponents, asymmetry parameter, and single-scattering albedo) at a uniform temporal grid. These properties are critical for aerosol direct radiative forcing and indirect forcing studies, and for radiation closure.

This VAP was developed for AOS deployments at all ARM observatories and succeeds the Aerosol Intensive Properties (AIP) VAP, which produced results only for AOSs deployed before 2011. It was released for routine next-day generation of products and processing at ARM's fixed observatories. Data are available through 2015.

End-to-end processing of older historical data is underway to provide a consistent set of aerosol optical properties at each site.

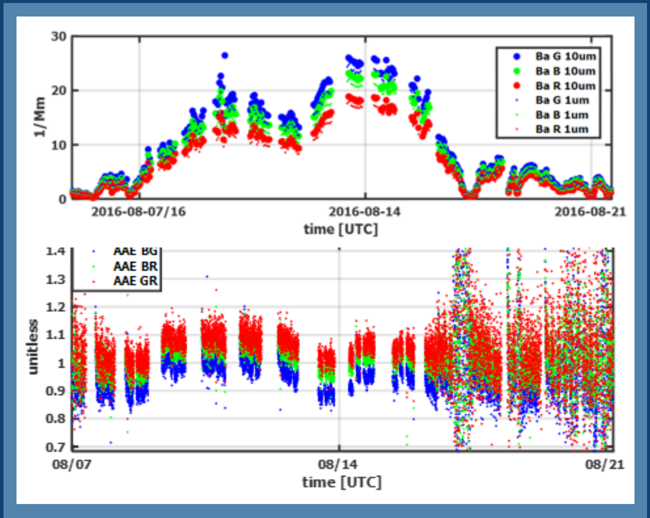
New Cloud Type VAP and Visualization Available

In 2018, the Cloud Type Classification (CLDTYPE) value-added product (VAP) was developed to provide an automated cloud type classification based on macrophysical quantities derived from vertically pointing lidar and radar.

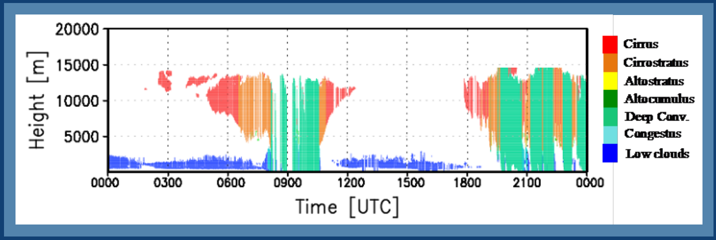
Up to 10 layers of clouds are classified into seven cloud types based on predetermined and site-specific thresholds of cloud-top height, cloud-base height, and thickness. Developed for use by the Shallow Cumulus VAP to identify potential periods of interest for the Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) workflow, CLDTYPE is also intended to help users find clouds of interest for a variety of research purposes.

Data from the CLDTYPE VAP are currently available for the Southern Great Plains (SGP) and Tropical Western Pacific (TWP) observatories because of their long historical records. Additional data from the SGP will be run operationally on Active Remotely Sensed Cloud Locations (ARSCL) data as it becomes available in the ARM Data Center.

In addition, a prototype interactive visualization tool was created using hourly averages of the CLDTYPE data at SGP to analyze cloud and atmospheric properties. The tool allows users to create histograms of variables in the ARM Best Estimate product based on time; it is available on the ARM website.



On top, aerosol extensive property of light absorption for "red," "green," and "blue" light is shown over a two-week period at Ascension Island. On bottom, wavelength dependence of aerosol absorption describes the nature rather than the abundance of the absorption.



A time series is shown here of cloud types classified based on ARSCL cloud boundaries. Observations are taken at the ARM Southern Great Plains atmospheric observatory on May 24, 2008.

Continuous Large-Scale Forcing Data Released for Cloud Modeling from Southern Great Plains

Using version 2 of the continuous large-scale forcing value-added product (VAP), known as VARANAL, data were created for the years 2004 to 2015 from the Southern Great Plains (SGP) atmospheric observatory.

The VARANAL product includes both the large-scale forcing terms and the evaluation fields, which can be used for driving single-column models, cloud-resolving models, or large-eddy simulations (LES), including LASSO—the LES ARM Symbiotic Simulation and Observation—workflow, and validating model simulations.

The updated VARANAL VAP incorporated Eddy Correlation Flux Measurement System (ECOR) data into the analysis to better represent various surface types within the analysis domain. Surface latent and sensible fluxes were a merged product from Energy Balance Bowen Ratio (EBBR) and ECOR measurements. Turbulent fluxes were from the Quality-Controlled ECOR (QCECOR) and Bulk Aerodynamic Technique EBBR (BAEBBR) VAPs. Background data were also updated using the Rapid Update Cycle (RUC) product before May 2012 and the Rapid Refresh (RAP) analysis for data after May 2012. In addition, top-of-atmosphere radiative fluxes were used with improved algorithm and bug fixes.

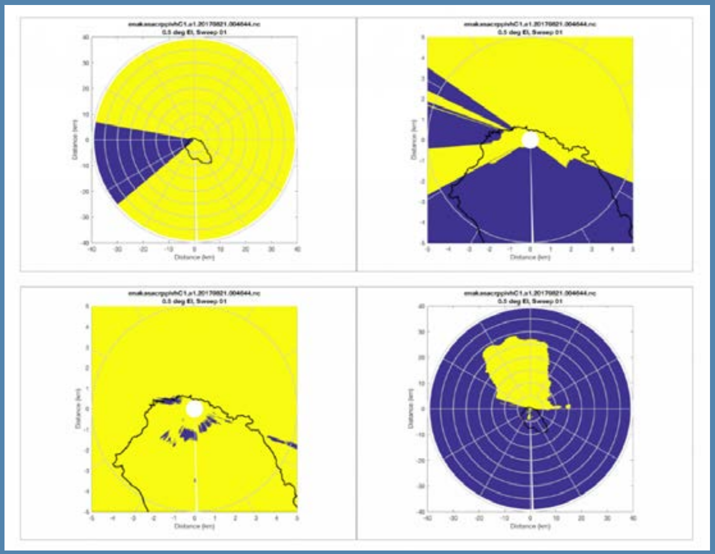
Scientists can use these forcing data from VARANAL for model simulation and evaluation.

KASACR Data Quality Masks Value-Added Product Made Available in Evaluation

Evaluation data for the Ka-Band Scanning ARM Cloud Radar (KASACR) Data Quality Masks were processed for the Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign for June 18 through July 31, 2017. Data quality masks help users remove data not suited for their work. Generally, signals from non-meteorological targets, such as ground clutter, or with weak echoes are undesirable for radar data processing.

Five data quality masks were generated for the KASACR at the Eastern North Atlantic (ENA) atmospheric observatory: clutter, blockage, blanking, and single- and dual-polarization significant echo. The masks can and should be used by end users to identify meteorological echoes and remove unwanted or poor-quality signals.

The rest of the ACE-ENA KASACR campaign data are being processed and will be ready to use in FY2019.



The example masks shown here are associated with the ENA scanning radars and are for plan position indicator (PPI)-type scans. The masks are also applied to range height indicator (RHI)- and vertically pointing (VPT)-type scans. The scan types are denoted by the datastream name, which is part of the file name identified above the plot.

Science Outreach

Cultivating the Next Generation of Atmospheric Scientists

In July 2018, 24 graduate students and early career scientists arrived in Oklahoma and immersed themselves in the second ARM Summer Training and Science Applications event.

Students were divided into six areas of emphasis—precipitation microphysics, ice/snow microphysics, high-latitude cloud systems, shallow cloud modeling, cloud fraction and liquid water content, and boundary-layer studies. The weeklong training included a full day at ARM's Southern Great Plains atmospheric observatory, where students had hands-on exposure to 50-plus observation platforms.

"It is important to recruit and develop early career scientists and highly capable graduate students to prepare them for the next step in their career," said ARM Technical Director Jim Mather. "For ARM, this is about cultivating the next generation of scientists who are passionate about their research and showing them how ARM can be a valuable part of their work."

The training was "very intense," said event instructor and organizer Pavlos Kollias, who works at Stony Brook University and Brookhaven National Laboratory in New York. "Each day we started working at 8 in the morning,

"It is important to recruit and develop early career scientists and highly capable graduate students to prepare them for the next step in their career. For ARM, this is about cultivating the next generation of scientists who are passionate about their research and showing them how ARM can be a valuable part of their work."

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

and we finished at 6 in the evening. In addition to keynote lectures and discussion, students received in-depth, interactive instruction, and they participated in group learning activities. Moreover, they worked with world-renowned scientists using state-of-the-art instruments on real research."

The students impressed Kollias, a member of the ARM User Executive Committee, which is the official voice of the user community in its interactions with ARM management.

"They were motivated, open to learning, and produced real science in just a short time," he said. "Each has a bright future in atmospheric science."

In July 2018, 24 graduate students and early career scientists from around the world visited ARM's Southern Great Plains atmospheric observatory during a rigorous weeklong training program in Oklahoma.

Big Data in Brazil: ARM Shares Best Practices at São Paulo Workshop

ARM data from the Green Ocean Amazon (GoAmazon2014/15) field campaign were a focus of an open science data management workshop in October 2017 in São Paulo, Brazil.

Giri Prakash, ARM Data Services manager from Oak Ridge National Laboratory (ORNL) in Tennessee, gave the keynote address for the workshop at the Engineering School of the University of São Paulo.

This third workshop in a series on open data for science brought together researchers and data professionals from several science and information technology disciplines. About 135 participants attended in person or remotely via the web.

The workshop and Prakash's keynote address focused on analysis of ARM GoAmazon2014/15 data collected near Manacapuru in northwestern Brazil. GoAmazon2014/15 looked at aerosol and cloud life cycles, particularly the susceptibility to cloud-aerosol-precipitation interactions, within the Amazon Basin.

Prakash and ORNL colleague Bhargavi Krishna, an ARM scientific software engineer, also conducted a two-day course in which about 80 participants learned to access, extract, and visualize ARM data using big-data analytics technologies.

"It was a great opportunity to promote ARM's approach to open data management," said Prakash.

ARM's Scientific Impact Seen at 2017 AGU Fall Meeting

The 2017 American Geophysical Union (AGU) Fall Meeting was held December 11 to 15 in New Orleans, Louisiana. Nearly 22,000 scientists from 92 countries gathered to present. ARM's scientific impact was demonstrated throughout the meeting, as ARM data were featured in about 100 workshops, presentations, posters, and more.

Meeting highlights included a town hall led by DOE ARM Program Manager Sally McFarlane on interagency coordinated observational activities of the U.S. Global Change Research Program and how they can be improved.

About 40 people attended a town hall on the Large-Eddy Simulation (LES) ARM Symbiotic Simulation and Observation (LASSO) project, gathering recommendations on what ARM should implement for routine operations.

Sessions featured data from ARM field campaigns, including the Midlatitude Continental Convective Clouds Experiment (MC3E), Layered Atlantic Smoke Interactions with Clouds (LASIC), and the ARM West Antarctic Radiation Experiment (AWARE).

Future field campaigns were also discussed, including Cloud, Aerosol, and Complex Terrain Interactions (CACTI), which will position cutting-edge atmospheric instruments nearly 3,500 feet above sea level near the rugged Sierras de Córdoba mountain range of north-central Argentina to study the formation and evolution of clouds using ARM's mobile and aerial facilities.

ARM Data Services Manager Giri Prakash (center) helps during an open science data management workshop in October 2017 in São Paulo, Brazil. Prakash and Bhargavi Krishna (ARM software engineer) conducted a two-day training course using ARM GoAmazon2014/15 data.

Scott Collis (far left), science lead for the Python ARM Radar Toolkit, and Nicki Hickmon (third from right), ARM's associate director for operations, host Argonne National Laboratory colleagues at the ARM booth during the 2017 AGU Fall Meeting.

Budget Summary **and Facility Usage**

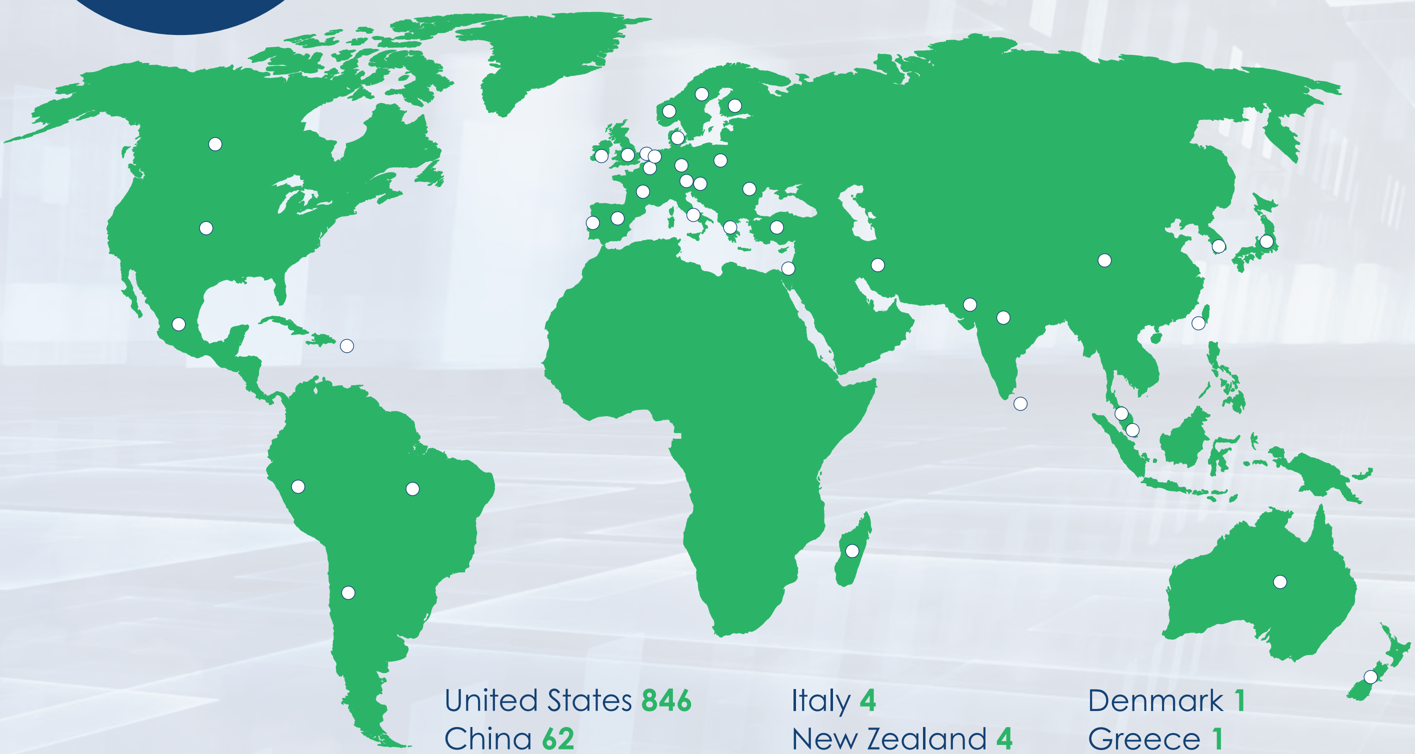
Fiscal Year 2018 Statistical Overview

INFRASTRUCTURE BUDGET

$69,305K

1,173
TOTAL SCIENTIFIC USERS

USERS BY COUNTRY



United States **846**
China **62**
United Kingdom **44**
Germany **38**
Brazil **30**
Australia **18**
Finland **15**
France **14**
Canada **12**
South Korea **12**
India **10**
Israel **9**
Portugal **8**
Netherlands **5**

Italy **4**
New Zealand **4**
Spain **4**
Switzerland **4**
Taiwan **4**
Japan **3**
Poland **3**
Argentina **2**
Iran **2**
Norway **2**
Singapore **2**
Sweden **2**
Belgium **1**

Denmark **1**
Greece **1**
Hungary **1**
Ireland **1**
Madagascar **1**
Malaysia **1**
Mexico **1**
Moldova **1**
Pakistan **1**
Peru **1**
Puerto Rico **1**
Sri Lanka **1**
Turkey **1**

40
Countries

USER STATISTICS

University	507	43%
Foreign	328	28%
DOE Labs	213	18%
Other Fed	94	8%
Industrial	31	3%

FACILITY USAGE

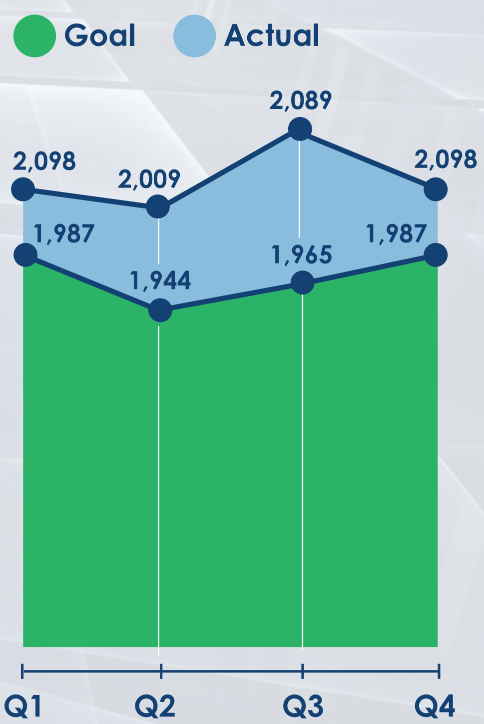
Onsite	377	32%
Remote	86	7%
Data	710	61%

400+ Instruments Collect Atmospheric Data

6,000+ Publicly Available Datastreams

4,000+ Journal Articles Since 1990

FACILITY HOURS OF OPERATION



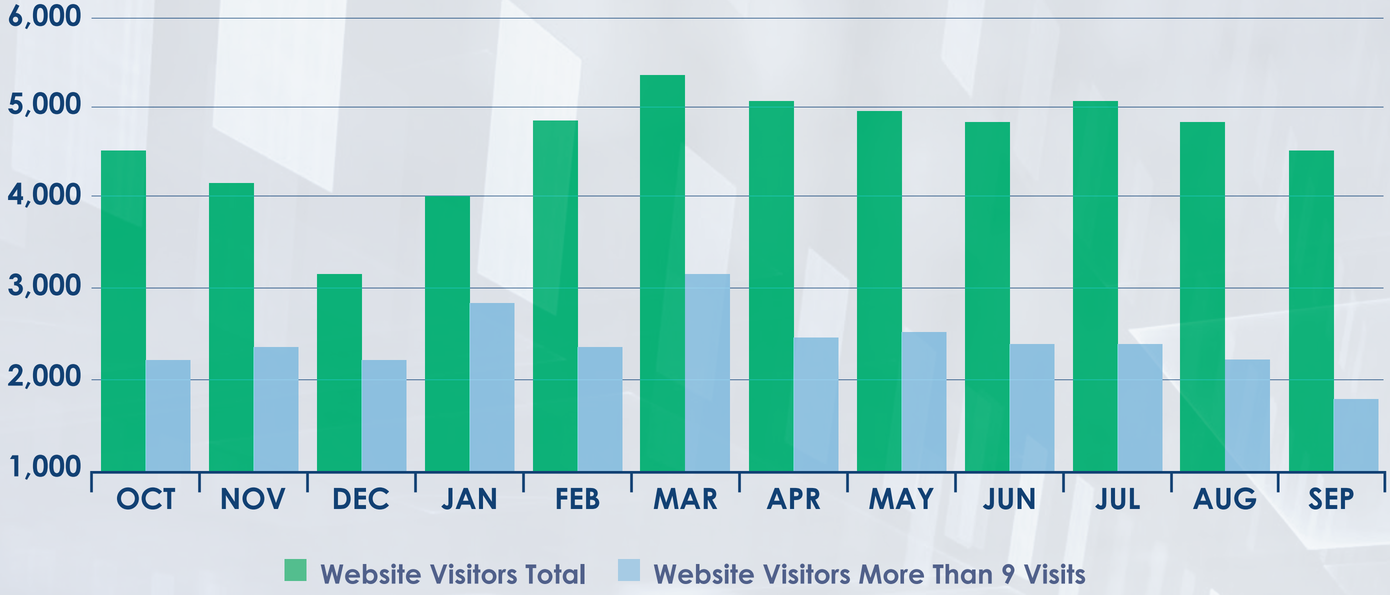
PUBLICATIONS USING ARM*

594 TOTAL

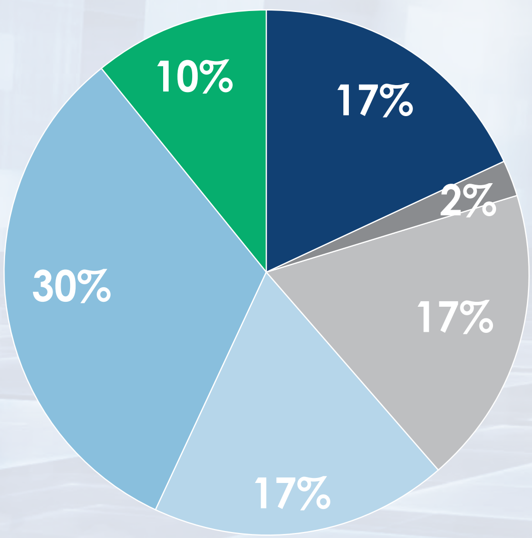
ABSTRACTS OR PRESENTATIONS	303
TECHNICAL REPORTS	63
BOOKS	1
JOURNAL ARTICLES	192
CONFERENCE PAPERS	35

*Publication statistics were collected as of November 2018. Journal article numbers will continue to increase over time.

WEBSITE VISITORS



FIELD CAMPAIGNS



AMF - 9
AAF - 1
ENA - 9
NSA - 10
SGP - 16
OFFSITE - 9

54 Total

VALUE-ADDED PRODUCTS

8 released to operations

- MPLCMASK
- QCRAD Data at SGP E39, E40, and E41
- ARMBE 2D
- MWRRET1
- RADFLUX
- QCECOR
- RLPROF CALIB
- QCRAD OLI, NSA

5 released to evaluation

- KAZRCFAD
- Forcing Data
- KASACR
- GoAmazon
- WACRARSCL

9 approved for development

- Velocity Azimuth Display (VAD)
- Moments Mapped to a Cartesian Grid (MMCG)
- Quazi Vertical Profiles (QVP)
- Disdrometer Surface precipitation (DisDSDQ)
- ADI Corrected Moments in Antenna Coordinates 2 (ADI_CMAC2)
- Radar Wind Profiler Planetary Boundary Layer Wind (RWPBLWIND)
- Point Cloud of Cloud Points (PCCP)
- Radar Wind Profiler boundary layer wind estimates (RWPWINDWINDS)
- Deep Neural Network to identify cloud boundaries in MPL data and an improved MPL linear depolarization ratio (MPLCMASK2)

On the covers:

Second ARM Mobile Facility on *Aurora Australis*

Front – The *Aurora Australis* supply vessel carried the second ARM Mobile Facility during the Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean (MARCUS) field campaign while routinely traveling between Hobart, Australia, and the Antarctic from October 2017 to April 2018.

Inside – A skiff departs for the *Aurora Australis*, which stopped at Macquarie Island, the location of the Macquarie Island Cloud and Radiation Experiment (MICRE), to pick up ARM instrumentation at the conclusion of the field campaign.

Cover images courtesy of Los Alamos National Laboratory.

DOE/SC-ARM-18-029

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