NCAR UCAR | National Center for Atmospheric Research 2017 Annual Report

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2017 NCAR ANNUAL REPORT

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A MESSAGE FROM THE NCAR DIRECTOR

PLANETARY WAVES, FIRST FOUND ON EARTH, ARE DISCOVERED ON SUN

WAVES MAY INFLUENCE SPACE WEATHER, OFFER A SOURCE OF PREDICTABILITY

The same kind of large-scale planetary waves that meander through the atmosphere high above Earth's surface may also exist on the Sun, according to a 2017 study led by an NCAR scientist.

Just as the large-scale waves that form on Earth, known as Rossby waves, influence local weather patterns, the waves discovered on the Sun may be intimately tied to solar activity, including the formation of sunspots, active regions, and the eruption of solar flares.

"The discovery of magnetized Rossby waves on the Sun offers the tantalizing possibility that we can predict space weather

much further in advance," said Scott McIntosh, director of NCAR's High Altitude Observatory and lead author of the paper.

The study was published on March 27 in the journal *Nature Astronomy*. It was co-authored by William Cramer of Yale University, Manuel Pichardo Marcano of Texas Tech University, and Robert Leamon of the University of Maryland, College Park.

The research was funded by the National Science Foundation (NSF), which is NCAR's sponsor, and by NASA.

AN UNPRECEDENTED VIEW OF THE SUN

On Earth, Rossby waves are associated with the path of the jet stream and the formation of low- and high-pressure systems, which in turn influence local weather events.

The waves form in rotating fluids — in the atmosphere and in the oceans. Because the Sun is also rotating, and because it's made largely of plasma that acts, in some ways, like a vast magnetized ocean, the existence of Rossby-like waves should not come as a surprise, McIntosh said.

And yet scientists have lacked the tools to distinguish this wave pattern until recently. Unlike Earth, which is scrutinized at numerous angles by satellites in space, scientists historically have been able to study the Sun from only one viewpoint: as seen from the direction of Earth.

But for a brief period, from 2011 to 2014, scientists had the unprecedented opportunity to see the Sun's entire atmosphere at once. During that time, observations from NASA's Solar Dynamics Observatory (SDO), which sits between the Sun and Earth, were supplemented by measurements from NASA's Solar TErrestrial RElations Observatory (STEREO) mission, which included two spacecraft orbiting the Sun. Collectively, the three observatories provided a 360-degree view of the Sun until contact was lost with one of the STEREO spacecraft in 2014. McIntosh and his co-authors mined the data collected during the window of full solar coverage to see if the large-scale wave patterns might emerge.

"By combining the data from all three satellites we can see the entire Sun, and that's important for studies like this because you want the measurements to all be at the same time," said Dean Pesnell, SDO project scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "They're pushing the boundary of how we use solar data to understand the interior of the Sun and where the magnetic field of the Sun comes from."

Coronal bright points identified in images of the Sun taken simultaenously from three

FINDING WAVES IN THE DATA

The team used images taken by instruments on SDO and STEREO to identify and track coronal bright points. These small bright features dot the entire face of the Sun and have been used to track motions deeper in the solar atmosphere.

The scientists plotted the combined data on Hovmöller diagrams, a diagnostic tool developed by meteorologists to highlight the role of waves in Earth's atmosphere. What emerged from the analysis were bands of magnetized activity that propagate slowly across the Sun — just like the Rossby waves found on Earth.

distinct vantage points in space. From left, images were captured by STEREO-Behind, SDO, and STEREO-Ahead. (Image courtesy Scott McIntosh, NCAR.).)

The discovery could link a range of solar phenomena that are also related to the Sun's magnetic field, including the formation of sunspots, their lifetimes, and the origin of the Sun’s 11-year solar cycle. "It's possible that it's all tied together, but we needed to have a global perspective to see that," McIntosh said. "We believe that people have been observing the impacts of these Rossby-like waves for decades, but haven't been able to put the whole picture together."

With a new understanding of what the big picture might really look like, scientists could take a step closer to predicting the Sun's behavior.

"The discovery of Rossby-like waves on the Sun could be important for the prediction of solar storms, the main drivers of space weather effects on Earth," said Ilia Roussev, program director in NSF's Division of Atmospheric and Geospace Sciences. "Bad weather in space can hinder or damage satellite operations, and communication and navigation systems, as well as cause power-grid outages leading to tremendous socioeconomic losses. Estimates put the cost of space weather hazards at $10 billion per year."

But to advance our predictive capabilities, scientists must first gain a better understanding of the waves and the patterns that persist on them, which would require once again having a 360-degree view of the Sun.

"To connect the local scale with the global scale, we need to expand our view," McIntosh said. "We need a constellation of spacecraft that circle the Sun and monitor the evolution of its global magnetic field."

ABOUT THE ARTICLE

Title: The detection of Rossby-like waves on the Sun
Authors: Scott W. McIntosh, William J. Cramer, Manuel Pichardo Marcano, and Robert J. Leamon
Journal: *Nature Astronomy*,DOI: 10.1038/s41550-017-0086

WRITER/CONTACT:

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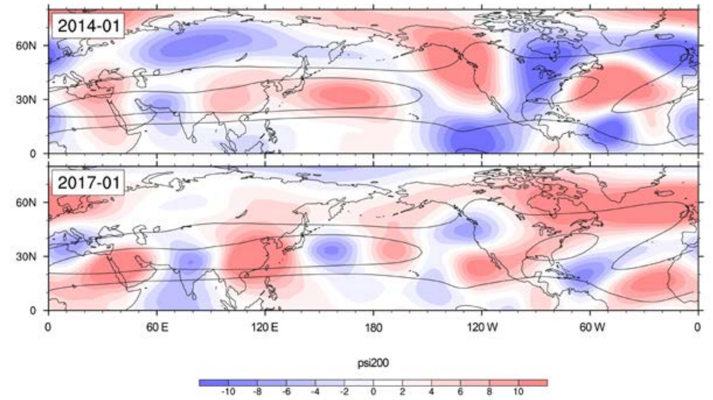
SCIENTISTS LINK RECENT CALIFORNIA DROUGHTS AND FLOODS TO DISTINCTIVE ATMOSPHERIC WAVES

UPPER ATMOSPHERE PATTERN MAY OPEN WINDOW TO LONG-TERM PREDICTION

The crippling wintertime droughts that struck California from 2013 to 2015, as well as the unusually wet California winter of 2016–17, appear to be associated with the same phenomenon: a distinctive wave pattern that emerges in the upper atmosphere and circles the globe.

Scientists at NCAR found in a 2017 study that the persistent high-pressure ridge off the west coast of North America that blocked storms from coming onshore during the winters of 2013–14 and 2014–15 was associated with the wave pattern, which they call wavenumber-5. Follow-up work showed that wavenumber-5 emerged again in winter 2016–17, but with its high- and low-pressure features in a different position, allowing drenching storms from the Pacific to make landfall.



The high- and low-pressure regions of wavenumber-5 set up in different locations during January 2014, when California was enduring a drought, and January 2017, when it was facing floods. The location of the high and low pressure regions (characterized by anticylonic vs. cyclonic upper-level air flow) can act to either suppress or enhance precipitation and storms. The black curves illustrate the jet streams that trap and focus wavenumber-5. (Image by Haiyan Teng and Grant Branstator, ©UCAR. This image is freely available for media & nonprofit use.)

"This wave pattern is a global dynamic system that sometimes makes droughts or floods in California more likely to occur," said NCAR scientist Haiyan Teng, lead author of the California paper with NCAR colleague Grant Branstator. "As we learn more, this may eventually open a new window to long-term predictability."

The finding is part of an emerging body of research into the wave pattern that holds the promise of better understanding seasonal weather patterns in California and elsewhere. Another paper by the two scientists in 2017, this time led by Branstator, examines the powerful wave pattern in more depth, analyzing the physical processes that help lead to its formation as well as its seasonal variations and how it varies in strength and location.

The California study was published in the *Journal of Climate*, while the comprehensive study into the wave pattern appeared in the *Journal of the Atmospheric Sciences*. Both papers were funded by the National Science Foundation, which is NCAR's sponsor, as well as by the Department of Energy, the National Oceanic and Atmospheric Administration, and NASA.

The 2017 papers follow a 2013 study by Teng and Branstator showing that a pattern related to wavenumber-5 tended to emerge about 15–20 days before major summertime heat waves in the United States.

STRONG IMPACTS ON LOCAL WEATHER SYSTEMS

Wavenumber-5 consists of five pairs of alternating high- and low-pressure features that encircle the globe about six miles (10 kilometers) above the ground. It is a type of atmospheric phenomenon known as a Rossby wave, a very large-scale planetary wave that can have strong impacts on local weather systems by moving heat and moisture between the tropics and higher latitudes, as well as between oceanic and inland areas, and by influencing where storms occur.

The slow-moving Rossby waves at times become almost stationary. When they do, the result can be persistent weather patterns that often lead to droughts, floods, and heat waves. Wavenumber-5 often has this stationary quality when it emerges during the northern winter, and, as a result, is associated with a greater likelihood of persistent extreme events.

To determine the degree to which the wave pattern influenced the California drought, Teng and Branstator used three specialized computer models, as well as California rainfall records and 20th century data about global atmospheric circulation patterns. The different windows into the atmosphere and precipitation patterns revealed that the formation of a ridge by the California coast is associated with the emergence of the distinctive wavenumber-5 pattern, which guides rain-producing low-pressure systems so that they travel well north of California.

Over the 2016–17 winter, as California was lashed by a series of intense storms, wavenumber-5 was also present, the scientists said. But the pattern had shifted over North America, replacing the high-pressure ridge off the coast with a low-pressure trough. The result was that the storms that were forced north during the drought winters were, instead, allowed to make landfall.

CLUES TO SEASONAL WEATHER PATTERNS

Forecasters who predict seasonal weather patterns have largely looked to shifting sea surface temperatures in the tropical Pacific, especially changes associated with El Niño and La Niña. But during the dry winters of 2013–14 and 2014–15, those conditions varied markedly: one featured the beginning of an El Niño, while the sea surface temperatures during the other were not characteristic of either El Niño or La Niña.

The new research indicates that the wave pattern may provide an additional source of predictability that at times may be more important than the impacts of sea surface temperature changes. First, however, scientists need to better understand why and when the wave pattern emerges.

In the paper published in *Journal of the Atmospheric Sciences*, Branstator and Teng explored the physics of the wave pattern. Using a simplified computer model of the climate system to identify the essential physical processes, the pair found that wavenumber-5 forms when strong jet streams act as wave guides, tightening the otherwise meandering Rossby wave into the signature configuration of five highs and five lows.

"The jets act to focus the energy," Branstator said. "When the jets are present, the energy is trapped and cannot escape." But even when the jets are present, the wavenumber-5 pattern does not always form, indicating that other forces requiring study are also at play.

The scientists also searched specifically for what might have caused the wave pattern linked to the severe California drought to form. In the paper published in the *Journal of Climate*, the pair found that extremely heavy rainfall from December to February in certain regions of the tropical Pacific could double the probability that the extreme ridge associated with wavenumber-5 will form. The reason may have to do with the tropical rain heating parts of the upper atmosphere in such a way that favors the formation of the wavenumber-5 pattern.

But the scientists cautioned that many questions remain.

"We need to search globally for factors that cause this wavenumber-5 behavior," Teng said, "Our studies are just the beginning of that search."

ABOUT THE ARTICLES

Title: Causes of Extreme Ridges That Induce California Drought
Authors: Haiyan Teng and Grant Branstator
Journal: *Journal of Climate*, DOI: 10.1175/JCLI-D-16-0524.1

Title: Tropospheric Waveguide Teleconnections and Their Seasonality
Authors: Grant Branstator and Haiyan Teng
Journal: *Journal of the Atmospheric Sciences*, DOI: 10.1175/JAS-D-16-0305.1

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CAPTURING A DETAILED PORTRAIT OF WIND

PROJECT IN PORTUGAL WILL OBSERVE WIND AT UNPRECEDENTED RESOLUTION

For two autumns in the early 1980s, researchers covered an isolated, gently sloping hill in Scotland with dozens of scientific instruments to measure the behavior of wind as it blew up and over from the nearby coast.

More than three decades later, the resulting data set gathered on Askervein hill is still the benchmark for validating how well a computer model can simulate winds flowing over complex terrain.

But that's about to change.

NCAR partnered with colleagues in Europe and the United States on a spring 2017 field project in Portugal, called Perdigão, that measured wind at an unprecedented resolution, both in time and space, as it moved through a more topographically diverse study area.

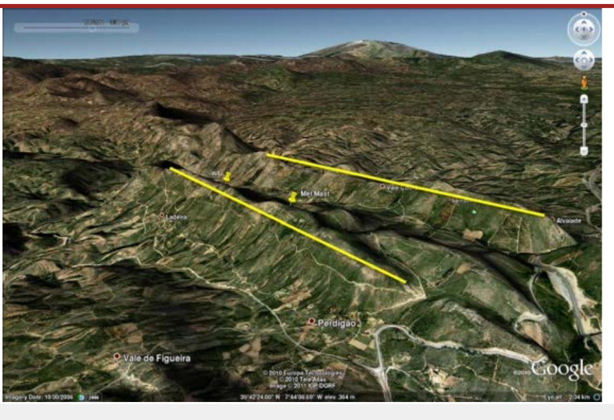
An image of the hill at Askervein. (Image courtesy of York University.)

Data from the experiment will help scientists improve their understanding of the basic physics of wind in the boundary layer (the lowest few hundred feet of the atmosphere). The completed data set will also serve as a new, more detailed, and more complex benchmark for testing the accuracy of the next generation of wind models.

Having accurate models of wind behavior in the boundary layer, where most weather occurs, is critical for a wide range of applications, from harvesting wind energy to predicting the spread of air pollution to piloting drones.

'NO EASY FEAT'

When scientists selected the Perdigão study area in central Portugal, they were looking for a place more complex than the single hill at Askervein but still relatively simple and easy to model.



The Perdigão study area, with its nearly parallel ridges, as seen using Google Earth. (©UCAR. Courtesy NCAR Earth Observing Laboratory. This image is freely available for media & nonprofit use.)

Perdigão has two nearly parallel ridgelines that stand just a couple of kilometers apart, and the wind typically hits these ridges at a perpendicular angle, either from the southwest or the northeast. Unlike the Askervein hill, which was covered largely in heather and small shrubs, the landscape at Perdigão includes both forested and agricultural lands. Such differences in terrain and land cover can have important influences on local winds.

For the project, NCAR's Earth Observing Lab was tasked with outfitting 47 observational towers with instruments that collected data on wind speed and direction, as well as temperature and humidity, from a variety of heights. The NCAR team was also in charge of networking all the instruments being used for the field campaign so they could talk to each other and to the researchers.

"This is the largest ground-based project we have ever taken on," said Alison Rockwell, who managed the project for NCAR.

"Networking that many towers with that many instruments — it's no easy feat."

A UNIQUE LOOK AT THE WIND'S MYSTERIES

The measurements taken by the instruments on the 47 towers outfitted by NCAR, along with those from five additional towers provided by project partners, were supplemented by observations from a variety of other balloon-borne and ground-based instruments. Those included lidars, which can remotely measure the basic structure of the wind field using laser beams.

"One of the totally unique aspects of this experiment is the use of lidars to measure the main wind field," said NCAR scientist Steve Oncley, a contributing investigator on the project. "It frees up the instruments on the towers to measure the fine-scale turbulence close to the ground."

This ability to measure the wind at multiple scales simultaneously is another reason that data gathered during Perdigão is expected to be a vast improvement over the 1980s data set. While a similar number of towers were deployed at the Askervein hill, the instruments primarily measured wind at only one height, leaving much of the structure of fine-scale turbulence occurring close to ground a mystery.

One of the questions that Oncley hopes the experiment will answer in particular — which the 1980s data could not — is how wind behaves as it blows over the crest of the ridge: "When you have a strong wind, does it actually blow through the trees, down to the soil? Or does it just graze the tops of the trees as it flows over?"

The answer matters for understanding how much momentum is extracted from the wind, as well as how much heat and carbon dioxide are transferred between wind and landscape.

The Perdigão project is part of a larger effort to publish a digital New European Wind Atlas, supported by a European Union funding instrument called ERANET+. The Europeans are particularly interested in the detailed wind velocity data for use in wind energy development.

U.S. principal investigators were Joe Fernando (University of Notre Dame), Julie Lundquist (University of Colorado, Boulder), Petra Klein (University of Oklahoma), Rebecca Barthelmie (Cornell University), Sara Pryor (Cornell University), Tina Katopodes Chow (University of California, Berkeley), Chris Hocust (U.S. Army Research Laboratory), and Laura Leo (University of Notre Dame).

DATA FROM A LONG-RANGE WIND SCANNER AT THE PERDIGÃO SITE

[redacted]

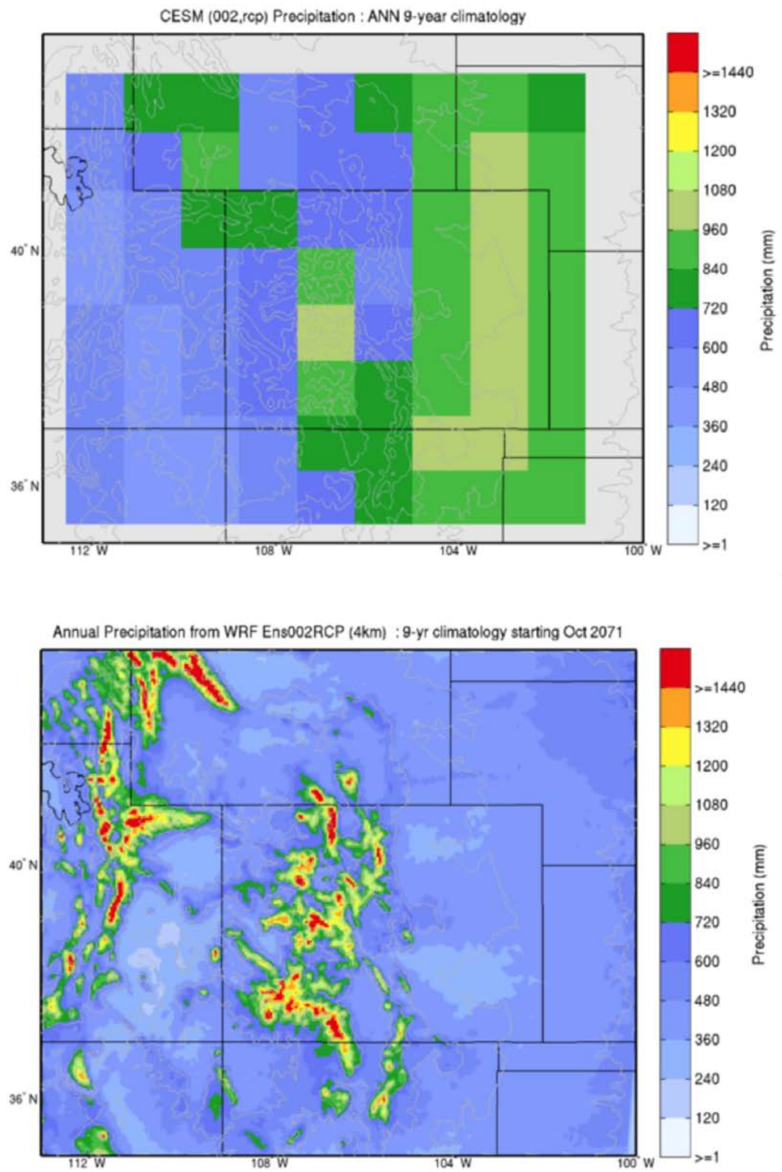
WRITER/CONTACT:

Laura Snider, Senior Science Writer and Public Information Officer

HIGH-RESOLUTION REGIONAL MODELING (NO SUPERCOMPUTER NEEDED)

HYBRID MODEL GIVES HYDROLOGISTS GOOD ACCURACY AT 100 TIMES THE SPEED

In global climate models, the hulking, jagged Rocky Mountains are often reduced to smooth, blurry bumps.



Annual precipitation over Colorado as modeled by the low-resolution, global Community Earth System Model (top) compared to the high-resolution, regional Weather Research and Forecasting model (below). (Images courtesy Ethan Gutmann, NCAR.)

It's a practical reality that these models, which depict the entire planet, typically need to be run at a relatively low resolution due to constraints on supercomputing resources. But the result, a virtual morphing of peaks into hills, affects the ability of climate models to accurately project how precipitation in mountainous regions may change in the future — information that is critically important to water managers.

To address the problem, hydrologists have typically relied on two methods to "downscale" climate model data to make them more useful. The first, which uses statistical techniques, is fast and doesn't require a supercomputer, but it makes many unrealistic assumptions. The second, which uses a high-resolution weather model like the Weather Research and Forecasting model (WRF), is much more realistic but requires vast amounts of computing resources.

At NCAR, hydrologists have been developing an in-between option: The Intermediate Complexity Atmospheric Research Model (ICAR) gives researchers increased accuracy using only a tiny fraction of the computing resources.

"ICAR is about 80 percent as accurate as WRF in the mountainous areas we studied," said NCAR scientist Ethan Gutmann, who is leading the development of ICAR. "But it only uses 1 percent of the computing resources. I can run it on my laptop."

DRIER MOUNTAINS, WETTER PLAINS

How much precipitation falls in the mountains — and when — is vitally important for communities in the American West and elsewhere that rely on snowpack to act as a frozen reservoir of sorts. Water managers in these areas are extremely interested in how a changing climate might affect snowfall and temperature, and therefore snowpack, in these regions.

But since global climate models with low resolution are not able to accurately represent the complex topography of mountain ranges, they are unsuited for answering these questions.

For example, as air flows into Colorado from the west, the Rocky Mountains force that air to rise, cooling it and causing moisture to condense and fall to the ground as snow or rain. Once these air masses clear the mountains, they are drier than they otherwise would have been, so there is less moisture available to fall across Colorado's eastern plains.

Low-resolution climate models are not able to capture this mechanism — the lifting of air over the mountains — and so in Colorado, for example, they often simulate mountains that are drier than they should be and plains that are wetter. For a regional water manger, these small shifts could mean the difference between full reservoirs and water shortages.

"Climate models are useful for predicting large-scale circulation patterns around the whole globe, not for predicting precipitation in the mountains or in your backyard," Gutmann said.

A MODELING MIDDLE GROUND

A simple statistical fix for these known problems may include adjusting precipitation data to dry out areas known to be too wet and moisten areas known to be too dry. The problem is that these statistical downscaling adjustments don't capture the physical mechanisms responsible for the errors. This means that any impact of a warming climate on the mechanisms themselves would not be accurately portrayed using a statistical technique.

That's why using a model like WRF to dynamically downscale the climate data produces more reliable results — the model is actually solving the complex mathematical equations that describe the dynamics of the atmosphere. But all those incredibly detailed calculations also take an incredible amount of computing.

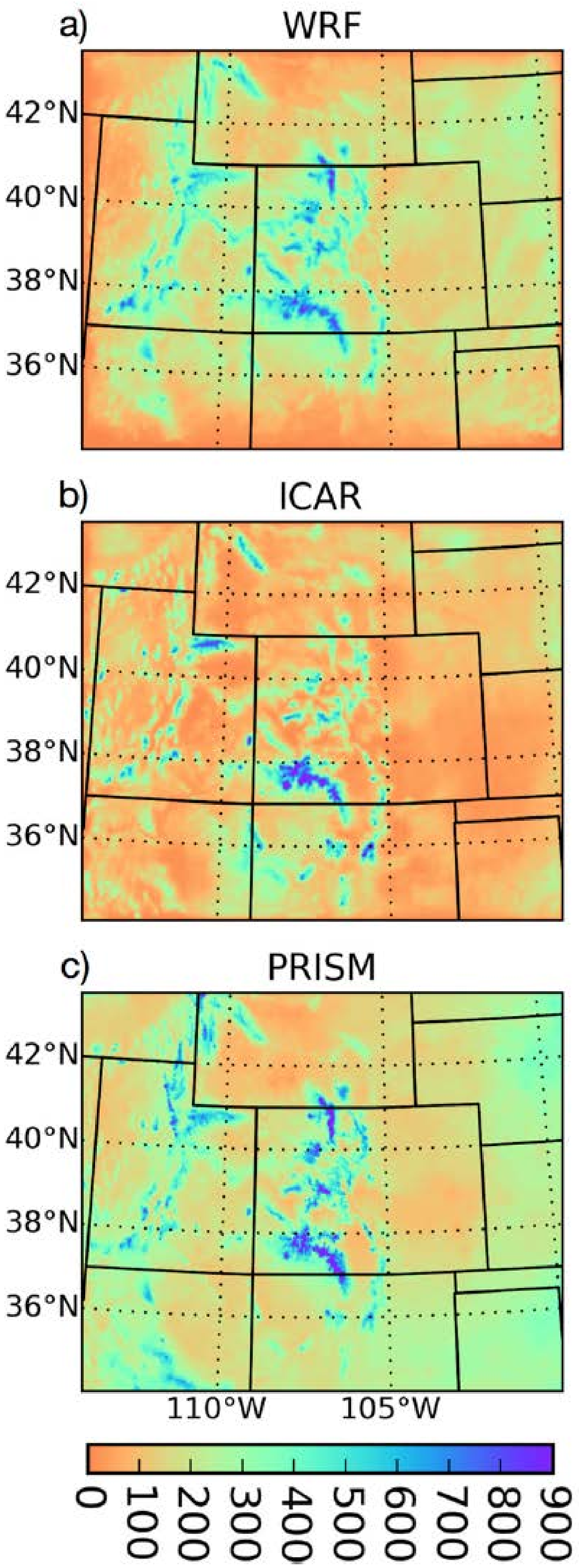
A few years ago, Gutmann began to wonder if there was a middle ground. Could he make a model that would solve the equations for just a small portion of the atmospheric dynamics that are important to hydrologists — in this case, the lifting of air masses over the mountains — but not others that are less relevant?

"I was studying statistical downscaling techniques, which are widely used in hydrology, and I thought, 'We should be able to do better than this,'" he said. "'We know what happens when you lift air up over a mountain range, so why don't we just do that?'"

Gutmann wrote the original code for the model that would become ICAR in just a few months, but he spent the next four years refining it, a process that's still ongoing.

100 TIMES AS FAST

Gutmann and his colleagues — Martyn Clark and Roy



Precipitation in millimeters over Colorado between Oct. 1 and May 1 as simulated by the Weather Research and Forecasting model (WRF), the Intermediate Complexity Atmospheric Research model (ICAR), and the observation-based Parameter-Elevation Regressions on Independent Slopes Model. (Images courtesy Ethan Gutmann.)

Rasmussen, also of NCAR; Idar Barstad, of Uni Research Computing in Bergen, Norway; and Jeffrey Arnold, of the U.S. Army Corps of Engineers — published a study in 2016 comparing simulations of Colorado created by ICAR and WRF against observations.

The authors found that ICAR and WRF results were generally in good agreement with the observations, especially in the mountains and during the winter. One of ICAR's weaknesses, however, is in simulating storms that build over the plains in the summertime. Unlike WRF, which actually allows storms to form and build in the model, ICAR estimates the number of storms likely to form, given the atmospheric conditions — a method called parameterization.

Even so, ICAR, which is freely available to anyone who wants to use it, is already being run by teams in Norway, Austria, France, Chile, and New Zealand.

"ICAR is not perfect; it's a simple model," Gutmann said.

"But in the mountains, ICAR can get you 80 to 90 percent of the way there at 100 times the speed of WRF. And if you choose to simplify some of the physics in ICAR, you can get it close to 1,000 times faster.""

ABOUT THE ARTICLE

Title: The Intermediate Complexity Atmospheric Research Model (ICAR)
Authors: Ethan Gutmann, Idar Barstad, Martyn Clark, Jeffrey Arnold, and Roy Rasmussen
Journal: *Journal of Hydrometeorology*, DOI: 10.1175/JHM-D-15-0155.1

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Collaborators:
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U.S. Army Corps of Engineers

WRITER/CONTACT:

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TURBOCHARGING SCIENCE

NEW SUPERCOMPUTER TRIPLES EARTH SYSTEM SCIENCE CAPABILITY WITH GREATER EFFICIENCY

Named "Cheyenne" in honor of the city where the NWSC is located, the 5.34-petaflop system is one of the fastest in the world, capable of more than triple the amount of scientific computing performed by the previous NCAR supercomputing system, "Yellowstone." It also is three times more energy efficient.

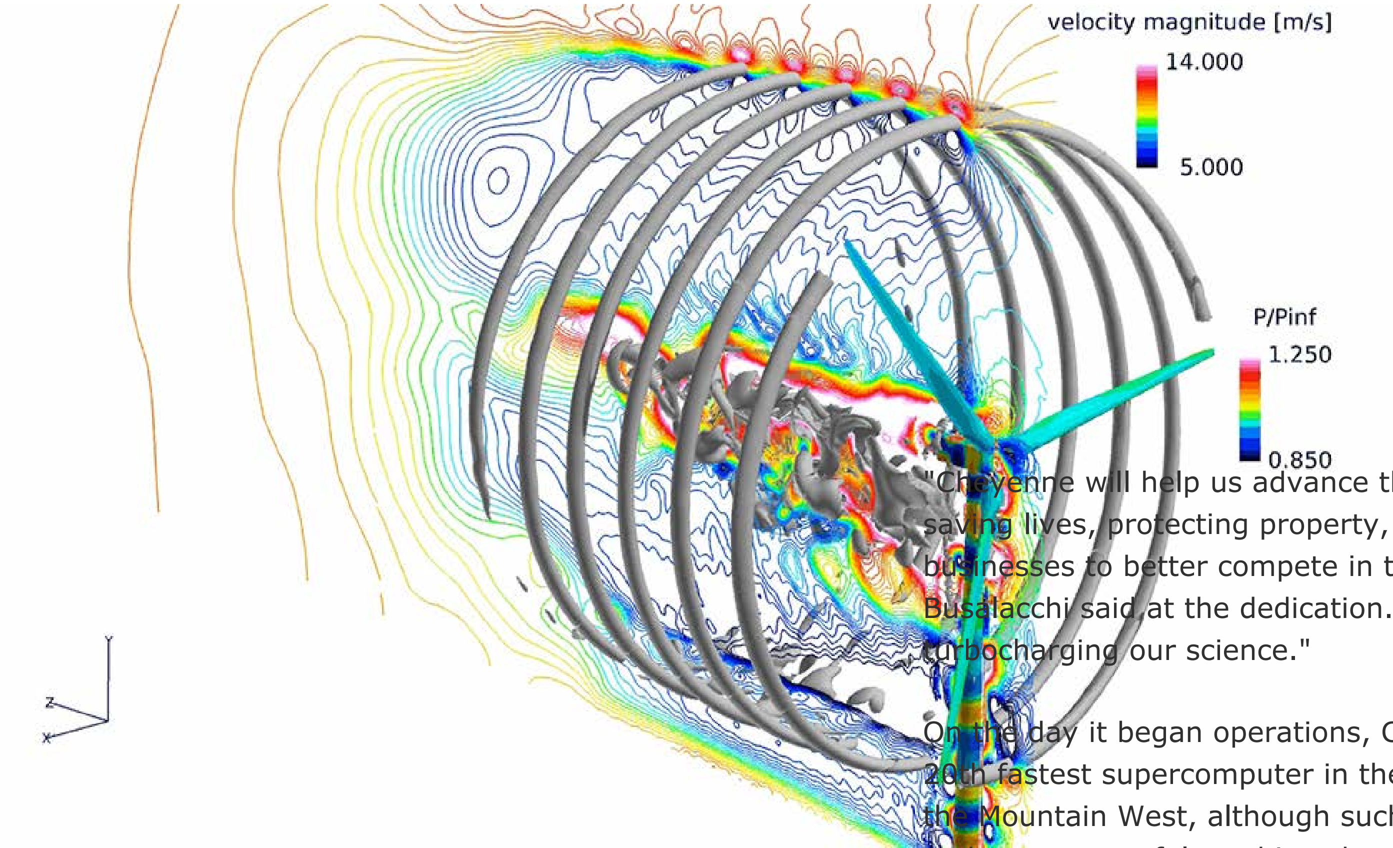
The system gives the nation a major new tool to advance understanding of atmospheric and Earth system science. It also provides Wyoming with new research and economic opportunities.

"For me, when we think about the economic benefits, they're tremendous," Mead said at the formal dedication on Aug. 8. "When we think about the pride in Wyoming citizens, it's tremendous."

In addition to Mead, the speakers included Cheyenne Mayor Marian Orr, University of Wyoming President Laurie Nichols, National Science Foundation Assistant Director of Geosciences William E. Easterling III, UCAR President Antonio Busalacchi, and NCAR Director James Hurrell.

FROM WILDFIRES TO WIND ENERGY

Scientists across the country have begun using Cheyenne to study phenomena ranging from wildfires and seismic activity to the wind gusts that generate power at turbine farms. Their findings will lay the groundwork for better protecting society from natural disasters, lead to more detailed projections of seasonal and longer-term weather and climate variability and change, and improve weather and water forecasts that are needed by economic sectors from agriculture and energy to transportation and tourism.



Contour lines and isosurfaces provide valuable information about turbulence and aerodynamic drag in this visualization of air flow through the blades of a wind turbine, the product of a simulation on the NCAR-Wyoming Supercomputing Center's Yellowstone system. (Image courtesy Dimitri Mavriplis, University of Wyoming.)

"Cheyenne will help us advance the knowledge needed for saving lives, protecting property, and enabling U.S. businesses to better compete in the global marketplace," Busalacchi said at the dedication. "This system is turbocharging our science."

On the day it began operations, Cheyenne ranked as the 20th fastest supercomputer in the world and the fastest in the Mountain West, although such rankings change as new and more powerful machines begin operations. It is funded by NSF as well as by the state of Wyoming through an appropriation to the University of Wyoming.

The NWSC is one of the nation's premier supercomputing facilities for research. Since it opened in 2012, more than 2,200 scientists from more than 300 universities and federal labs have used its resources.

"Through our work at the NWSC, we have a better understanding of such important processes as surface and subsurface hydrology, physics of flow in reservoir rock, and weather modification and precipitation stimulation," said William Gern, vice president of research and economic development at the University of Wyoming. "Importantly, we are also introducing Wyoming’s school-age students to the significance and power of computing."

INCREASED POWER, GREATER EFFICIENCY

Cheyenne was built by Silicon Graphics International, or SGI (now part of Hewlett Packard Enterprise Co.), with DataDirect Networks (DDN) providing centralized file system and data storage components. Cheyenne is capable of 5.34 quadrillion calculations per second (5.34 petaflops, or floating point operations per second).

The new system has a peak computation rate of more than 3 billion calculations per second for every watt of energy consumed. That is three times more energy efficient than the Yellowstone supercomputer, which is also highly efficient.

The data storage system for Cheyenne provides an initial capacity of 20 petabytes, expandable to 40 petabytes with the addition of extra drives. The new DDN system also transfers data at the rate of 220 gigabytes per second, which is more than twice as fast as the previous file system’s rate of 90 gigabytes per second.

Cheyenne is the latest in a long and successful history of supercomputers supported by NSF and NCAR to advance the

atmospheric and related sciences.

“We’re excited to provide the research community with more supercomputing power,” said Anke Kamrath, director of NCAR’s Computational and Information Systems Laboratory, which oversees operations at the NWSC. “Scientists have access to increasingly large amounts of data about our planet. The enhanced capabilities of the NWSC will enable them to tackle problems that used to be out of reach and obtain results at far greater speeds than ever.”

MORE DETAILED PREDICTIONS

High-performance computers such as Cheyenne allow researchers to run increasingly detailed models that simulate complex events and predict how they might unfold in the future. With more supercomputing power, scientists can capture additional processes, run their models at higher resolution, and conduct an ensemble of modeling runs that provide a fuller picture of the same time period.

"Providing next-generation supercomputing is vital to better understanding the Earth system that affects us all," Hurrell said. "We're delighted that this powerful resource is now available to the nation's scientists, and we're looking forward to new discoveries in climate, weather, space weather, renewable energy, and other critical areas of research."

Some of the initial projects on Cheyenne include:

Long-range forecasting, seasonal to decadal: Several studies led by George Mason University, the University of Miami, and NCAR aim to improve prediction of weather patterns months to years in advance. Researchers will use Cheyenne's capabilities to generate more comprehensive simulations of finer-scale processes in the ocean, atmosphere, and sea ice. This research will help scientists refine computer models to improve long-term prediction, including how year-to-year changes in Arctic sea ice extent may affect the likelihood of extreme weather events thousands of miles away.

Wind energy: Projecting electricity output at a wind farm is extraordinarily challenging, as it involves predicting variable gusts and complex wind eddies at the height of turbines, which are hundreds of feet above the sensors used for weather forecasting. University of Wyoming researchers will use Cheyenne to simulate wind conditions on different scales, from across the continent down to the tiny space near a wind turbine blade, and also investigate the vibrations within an individual turbine itself. An NCAR-led project will create high-resolution, 3D simulations of vertical and horizontal drafts to provide more information about winds over complex terrain. This type of research is critical as utilities seek to make wind farms as efficient as possible.

Space weather: Scientists are working to better understand solar disturbances that buffet Earth's atmosphere and threaten the operation of satellites, communications, and power grids. New projects led by the University of Delaware and NCAR are using Cheyenne to gain more insight into how solar activity leads to damaging geomagnetic storms. The scientists plan to develop detailed simulations of the emergence of the magnetic field from the subsurface of the Sun into its atmosphere, as well as gain a three-dimensional view of plasma turbulence and magnetic reconnection in space, which leads to plasma heating.

Extreme weather: One of the leading questions about climate change is how it could affect the frequency and severity of major storms and other types of severe weather. An NCAR-led project will explore how climate interacts with the land surface and hydrology over the United States, and how extreme weather events can be expected to change in the future. This work will use advanced modeling approaches at high resolution (down to just a few miles) in ways that can help scientists configure future climate models to better simulate extreme events.

Climate engineering: To counter the effects of heat-trapping greenhouse gases, some experts have proposed artificially cooling the planet by injecting sulfates into the stratosphere, which would mimic the effects of a major volcanic eruption. But if society ever tried to engage in such climate engineering, also known as geoengineering, the results could alter the world's climate in unintended ways. An NCAR-led project is using Cheyenne's computing power to run an ensemble of climate engineering simulations to show how hypothetical sulfate injections could affect regional temperatures and precipitation.

Smoke and global climate: A study led by the University of Wyoming will look into emissions from wildfires and how they affect stratocumulus clouds over the southeastern Atlantic Ocean. This research is needed for a better understanding of the global climate system, as stratocumulus clouds, which cover 23 percent of Earth's surface, play a key role in reflecting sunlight back into space. The work will help reveal the extent to which particles emitted during biomass burning influence cloud processes in ways that affect global temperatures.

BUILDING ROADS TO MATCH TOMORROW'S WEATHER

CLIMATE SCIENTISTS, ENGINEERS TEAM UP ON DRAINAGE SYSTEMS FOR TRANSPORTATION INFRASTRUCTURE

When engineers design roads, bridges, and other types of transportation infrastructure, they need to account for local weather patterns. Extreme heat or freeze-thaw cycles can lead to ruts and cracks in roads, and heavy rains can overwhelm inadequate drainage systems, washing out bridges and flooding key transportation corridors.

But how should engineers design new transportation projects, which may last for a half-century, if climate change will greatly alter weather patterns? The extent to which temperatures and precipitation may change in the future has become a major concern for the transportation industry.

To address this issue, climate scientists at NCAR have launched an innovative collaboration with civil and environmental engineers at Carnegie Mellon University and the RAND Corporation. They're using global and regional computer models, along with statistical techniques, to generate projections of future climate in ways that will be most helpful to infrastructure designers and planners, especially when it comes to drainage.

The three-year project, funded by the National Science Foundation, is focusing on Pittsburgh and several other cities across the country that will likely be affected in different

A girl looks at a washed-out road in Louisville, Colorado, after damaging floods in 2013. Engineers are teaming up with climate scientists to design transportation infrastructure that can withstand shifting weather patterns. (Photo by David Hosansky.)

ways by future climate.

The three-year project, funded by the National Science Foundation, is focusing on Pittsburgh and several other cities across the country that will likely be affected in different ways by future climate.

Several recent studies led by NCAR scientists have underscored the extent to which climate change may affect future temperature and precipitation extremes in the United States. One concluded that, if emissions of greenhouse gases continue along a business-as-usual course, record daily high temperatures will outpace record daily lows by about 15 to 1 later in the century. A second study, also looking at emissions continuing on a business-as-usual path, concluded that incidents of extreme rainfall may increase by as much as five times in parts of the country.

MORE DETAIL MEANS MORE UNCERTAINTY

To conduct the infrastructure project, Mearns and her colleagues have been working closely with local transportation officials and other stakeholders. Rather than analyzing the overall ways that climate is likely to change in the target cities, they're focusing on information that will be most useful to the design and construction of drainage infrastructure and other transportation systems.

"This requires very active engagement with stakeholders," Mearns said. "It's working together to determine what they want versus what we can actually provide and coming up with measures of uncertainty that are meaningful for them. This is in the realm of true coproduction of knowledge."

For example, an engineer designing a drainage system along a highway might want an estimate of how much precipitation will fall in 15-minute increments. Although climate models do not provide such detailed information, Mearns and her colleagues can provide a partial answer by using a combination of techniques to produce projections of future precipitation every hour to several hours, as well as characterizing the uncertainty around those projections.

A major challenge is that more detailed projections have greater uncertainty. While climate models consistently show that emissions of greenhouse gases lead to higher average global temperatures, the outlook is less clear for temperature and precipitation patterns by region. The type of information most needed by infrastructure planners and designers — projections of extreme temperatures and precipitation for specific locations and time periods — is even more uncertain. As a result, the study team has to make compromises between the need for high-resolution data and the need for reliable data.

Mearns said it's critical to give engineers a clear understanding of the uncertainty of a particular projection in order to prevent transportation projects from being based on a false sense of precision in climate projections. "The challenge," she said, "is developing sound engineering strategies for extremes under uncertainty."

In addition to Mearns, the NCAR scientists working on the project include Seth McGinnis, Melissa Bukovsky, Rachel McCrary, and Doug Nychka. The Carnegie Mellon team is being led by Costa Samaras, who directs the school's Center for Engineering and Resilience for Climate Adaptation.

“This project is a unique interdisciplinary collaboration that will advance the ways engineers and climate scientists will work together in the future,” said Samaras. “Infrastructure can last for many decades, and engineers need to design infrastructure to be resilient at the end of the infrastructure life span as well as in the beginning. Working with NCAR is critical to advancing the research needed to transform the way we design infrastructure in the United States."

THE BENEFIT OF DIFFERENT TECHNIQUES

To generate climate projections, Mearns and her colleagues will use two types of techniques to translate the coarse resolution of a global computer model, which typically simulates climate processes that are larger than about 100 miles, into the localized weather events that are of interest to transportation experts.

One of these techniques, known as dynamical downscaling, will use a combination of three coarser-resolution global climate models and two higher-resolution regional models (including the NCAR-based Weather Research and Forecasting model, or WRF). This will enable the researchers to simulate the entire globe in coarse resolution while zooming in on selected regions with much higher resolution. This approach doesn't need as much supercomputing power as trying to simulate the entire globe in high resolution, although it still can be computationally intensive./p>

The other technique, known as statistical downscaling, involves developing statistical relationships between large-scale atmospheric patterns and local temperatures and precipitation. This technique, which requires even less computing, can help scientists link conditions in a global model (such as a large area of low pressure) to a localized weather event (such as intermittent downpours).

The combined approaches will enable the scientists to generate projections for at least every six hours, and possibly — with the use of additional specialized techniques — as frequently as every hour. Using both the dynamical and statistical approaches also will enable the team to better understand the uncertainties around future climate, as well as evaluate the relative strengths of the techniques.

"Transportation systems are critical to the U.S. economy, and they represent some of the largest investments of our tax dollars," Mearns said. "We want to make sure that they'll hold up to a future climate."

Funders:
National Science Foundation

Collaborators:
Carnegie Mellon University
RAND Coroporation

WRITER/CONTACT:

David Hosansky, Manager of Media Relations

DRONES NEED AVIATION FORECASTS, TOO

NCAR SCIENTISTS DIRECT THEIR WEATHER EXPERTISE TO UAS NEEDS

The possible future uses for drones are spectacularly diverse. Unmanned aircraft systems (UAS) could make door-to-door

deliveries, search for a lost hiker, survey agricultural crops, inspect infrastructure, or collect scientific data from difficult-to-reach places, among other things.

Already Amazon is experimenting with drone delivery of packages, for example, and BNSF Railway is testing the use of drones to inspect hundreds of miles of railroad tracks.

Yet the ultimate success of efforts like these may hinge on a good weather forecast.

NCAR, long a trusted provider of critical weather information to the aviation industry, is beginning to lend its expertise to the UAS community as well.

Staff in NCAR's Research Applications Laboratory are already working with NASA to provide low-level turbulence forecasts for NASA's project to create a UAS Traffic Management (UTM) system, which would be similar to the air traffic control system for crewed airplanes. And in May 2017, the NCAR team hosted a UAS Weather Forum in Dallas. The forum will be co-located with XPONENTIAL, a conference on "all things unmanned" that is organized by the Association of Unmanned Vehicle Systems International.

"As the aircraft get smaller and smaller, the challenges of providing the needed weather information increase," said NCAR scientist Matthias Steiner, deputy director of RAL's Aviation Applications Program. "These small UAS's are more sensitive to winds, temperature, turbulence, precipitation — essentially the full range of weather — than larger planes flying at higher altitudes."

WEATHER IMPACTS ON DRONES

Drones, at least the small ones allowed under current Federal Aviation Administration rules, fly in the lowest few hundred feet of the atmosphere, where weather can be highly dynamic and less predictable.

This layer of the atmosphere is heavily affected by land surface and topography. Consider, for example, wind as it blows through a city. The buildings force the wind to speed through "urban canyons" and swirl into tight eddies behind structures. Uneven heating — the sunny side of the street warming more than the shady side, for example — can create circulating downdrafts and updrafts.

Piloting a drone through a built-up area could be tricky without a detailed understanding of the local atmospheric circulation patterns. And even with that information, it's important to understand how different drones will be affected. The tinier and lighter the drone, the more vulnerable it is to the vagaries of the weather, just as a small Cessna is more vulnerable to turbulence than a giant 747. And the type of drone, such as a fixed wing or a quadcopter, matters as well because each has a different

ability to respond.

NASA engineers prepare to launch a remotely piloted aircraft during practice runs for an Unmanned Aircraft Systems Traffic Management test. (Image courtesy NASA.)

The concern is not just crashing on the ground; severe weather conditions could also lead to a collision in the sky. NASA's UTM project is exploring the possibility of managing a high volume of drones by essentially assigning individual UAS's to a lane of airspace. But weather will affect the ability of a drone to stay in its lane. An abrupt updraft, for instance, could force a drone that is supposed to fly at a lower altitude into the higher-altitude lane assigned to another UAS (or a crewed aircraft in mixed airspace), increasing the possibility of a collision between the two.

Weather can have less obvious impacts on drone operation as well. Extremely cold weather, headwinds, or turbulence that requires a lot of flight control adjustments could drain the aircraft's battery more quickly, reducing its range and, potentially, its ability to return home.

FACILITATING A COMMUNITY DIALOGUE

These kinds of weather challenges would likely not surprise a seasoned aviator. But many of the organizations interested in using drones today come to the UAS community from the technology side, not the aviation side, and may lack a full understanding of the impacts that atmospheric conditions can have on flight.

This is where NCAR has expertise to offer. For decades, NCAR has been providing the aviation industry with the tools they need to increase flight safety, including wind shear alerts, turbulence forecasts, and information on inflight icing potential.

In an effort to stay on top of the latest weather challenges facing the aviation industry, NCAR launched the Friends and Partners in Aviation Weather Forum in 1997. The meeting, now held twice yearly, is an opportunity for stakeholders from the operational, regulatory, and research sectors to come together.

"We created these meetings as a means of fostering dialogue," Steiner said. "We want to know: 'What are your operational sensitivities? How can we help you?' Now we are emulating these forums with the UAS community."

The UAS Weather Forum at the XSPONENTIAL conference in May was the first effort at starting a similar meeting—and fostering the dialogue needed to advance drone safety, even in the face of challenging weather conditions.

"We want drone operators to know NCAR is a partner that can help them address their weather impacts," Steiner said.

WRITER/CONTACT:

Laura Snider, Senior Science Writer and Public Information Officer

NEW APPS DEVELOPED TO VISUALIZE ATMOSPHERIC DATA IN 3D

VIRTUAL- AND AUGMENTED-REALITY OPTIONS LET STUDENTS ENGAGE

Students of microbiology can grow bacteria in petri dishes to better understand their subject. Paleontology students have fossils, and chemistry students have beakers bubbling with reactions. But students of the atmospheric and related sciences are often left with something much less tangible: data, and lots of it.

Data sets in the atmospheric sciences cover everything from observations made by weather balloons to satellite measurements of cloud cover to output from climate model runs.

Now NCAR is helping make those data less abstract and more concrete — a little closer to a rock sample and a little further from a computer file. The result is two apps: one using virtual-reality and one using augmented-reality techniques to create 3D visualizations of data sets on a globe that students can move around and view from different perspectives. Meteo VR (Virtual Reality) and Meteo AR (Augmented Reality) are available for use on iPhone, iPad, and Android devices. They were developed by NCAR's Computational and Information Systems Laboratory (CISL).

"The goal is to make our data more accessible to the public, especially to students," said Tim Scheitlin, a senior software engineer at CISL's Visualization Lab. "We think it's a fun way to start a dialogue about atmospheric science. If people can get excited about using the app, then maybe they'll start asking questions that will lead to a deeper understanding."

THE 'WOW' FACTOR AND BEYOND

The Meteo AR app takes advantage of the camera on a

The Meteo AR app uses augmented-reality techniquest to make atmospheric science data more accessible to the public. (©UCAR. This animation is freely available for media & nonprofit use.)

personal device. When the camera's pointed at an image from a visualization — of sea surface temperature anomalies during an El Niño, or of the inner workings of a hurricane, for example — the visualization pops up onto a 3D globe that can be spun around with a finger.

The Meteo VR app requires a virtual reality headset, such as Google Cardboard, and allows the user to "fly around" the globe to look at the projected dataset from any angle.

Development of the two apps was led by Nihanth Cherukuru, a doctoral student at Arizona State University. He came to NCAR in 2016 as part of CISL's Summer Internships in Parallel Computational Science (SIParCS) program, which strives "to make a long-term, positive impact on the quality and diversity of the workforce needed to use and operate 21st century supercomputers."

Cherukuru said one of the challenges of the project was to wrestle the vast amounts of data into a format that wouldn’t crash a handheld device.

"Mobile phones are tiny devices and the atmospheric data can be really huge," Cherukuru said. "We needed to take that data and trim it down. We created a single image for each timestamp and then we made animations to reduce the computational

burden on the phones."

While Cherukuru has returned to Arizona State after his SIParCS internship, he is still working with the Visualization Lab. The goal is to expand the apps' capabilities, perhaps, for example, by having users click on parts of the data to get more information.

"There's kind of a 'wow' factor you get when you first use the app," Scheitlin said. "Our goal is to get past that and make it as educational as we can."

DOWNLOAD THE APPS

Meteo AR:
For iPhone or iPad
For Android

Meteo VR:
For iPhone or iPad
For Android

WRITER/CONTACT:

Laura Snider, Senior Science Writer and Public Information Officer

PROMOTING DIVERSITY IN HIGH-PERFORMANCE COMPUTING

NCAR TAPS NEW WAY TO REACH UNDERREPRESENTED GROUPS

Justin Moore was supporting his family of four with a job at an auto parts store while juggling classes at Salish Kootenai College, a Native American college in Montana, when he heard about a computing internship in 2014 at NCAR.

The internship, which used a small, low-cost computer called Raspberry Pi to teach key concepts of high-performance computing, quickly paid off. Today, Moore works full-time as an IT network specialist at Energy Keepers Inc., which manages the hydroelectric plant on the Flathead Indian Reservation in Montana, while he continues to chip away at his degree.

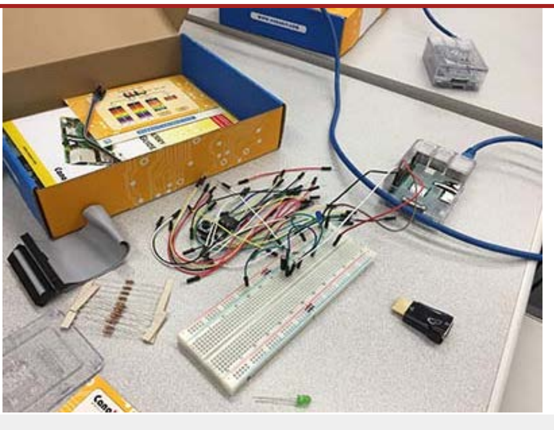
"I believe the skills I obtained in the internship can be directly attributed to my success in my field," Moore said. "It also gave me the chance to network with some of the brightest minds in the country."

Since 2014, NCAR has been using Raspberry Pi as part of the SIParCS (Summer Internships in Parallel Computational Science) program to teach leading-edge computing skills to small groups of university students each year, including one or two from communities that are underrepresented in the sciences. In March 2017, in an effort to reach more students, NCAR expanded to an "externship" model, bringing the Raspberry Pi training to Miami Dade College faculty who can teach the skills to dozens of students at a time.

Justin Moore turned a summer internship at NCAR into a full-time computer networking job at a hydroelectric plant on the Flathead Indian Reservation in Montana. (©UCAR. Photo by Carlye Calvin. This image is freely available for media & nonprofit use.)

“Raspberry Pi is a perfect platform for high-performance computing education because the credit-card sized mother boards can be linked together to mimic the parallel processing capabilities of a supercomputer and perform simplified geoscience applications,” said Rich Loft, director of technology development in NCAR's Computational and Information Systems Laboratory.

A Raspberry Pi, which costs $35 or less, can run a full Linux operating system — the same system used by nearly all supercomputers, in more than 90 percent of smartphones, and in many other electronic devices.



A Raspberry Pi kit used during the NCAR training at Miami Dade College. The Raspberry Pi circuit board is in the upper right-hand corner, connected to a blue cable. Components plug into a breadboard in the center of the picture (Photo courtesy Rich Loft, NCAR.)

"It's inexpensive. It levels the playing field," said Loft, who led the training at Miami Dade. "In my view it busts the digital divide."

Loft noted that the previous internship approach wasn't reaching as many students as NCAR had hoped, partly because many found it too difficult to relocate to Boulder during the summer. Miami Dade proved an ideal testbed for an externship model, since it's one of the country's largest universities, with eight campuses and more than 90,000 students, 70 percent of whom are Hispanic and 17 percent of whom are African American.

"This approach has scalability," Loft said, shortly after returning from the intensive two-day faculty workshop. "You can't scale up a program training one student at a time, even though it's very rewarding."

A LEGACY OF SUCCESS

The Raspberry Pi internship approach has yielded several success stories, with students going on to graduate school and

receiving prestigious scholarships.

Lauren Patterson, for example, was a student at Hampton University in Virginia when she spent the summer at NCAR as a SIParCs intern, also in 2014. "I loved that I was able to work hands-on and assemble the Raspberry Pi cluster myself," Patterson said.

Lauren Patterson has received an Apple scholarship and will start a job at Google after completing her summer internship on Raspberry Pi at NCAR. (@UCAR. Photo by Carlye Calvin. This image is freely available for media & nonprofit use.)

She said her experience led to a 12-week internship at Apple headquarters under its scholars program, which included a $25,000 scholarship for her final college year, and then to a software engineering residency at Google, which she began in fall 2017 in New York City.

Gaston Seneza, a senior at Philander Smith College in Arkansas, said that before NCAR's SIParCS 2015 internship he had no practical knowledge of computers.

He learned about Linux, sensors, programming, cloud storage, and scientific research, and now has a passion for computer science. "Raspberry Pi was a game-changer for me," he said. The Rwandan native also was named an Apple scholar, and aspires to go into the field of artificial intelligence. "My dream is to see a world where intelligent machines work for us."

Said Loft: "We're trying to get these kids on the hi-tech career onramp. You put machine learning or experience with parallel computing on your resume and you can get hired by Apple, Google, or Amazon – or get into graduate school. These are hot skills."

Gaston Seneza, who is from Rwanda, also won an Apple scholarship after his summer internship at NCAR. (@UCAR. Photo by Carlye Calvin. This image is freely available for media & nonprofit use.)

Moore, Patterson, and Seneza all praised the mentoring by Loft, an NCAR senior scientist, and Raghu Raj Prassana Kumar, an NCAR project scientist who has worked with the Raspberry Pi training project since its beginning.

"It's a lot of fun," Kumar said, "and it's very rewarding to help these young people learn."

Kumar is known at NCAR for creative uses of Raspberry Pi, including connecting 12 of them to calculate Pi to a million digits on Pi Day in 2015.

CONNECTING LEARNING TO EVERYDAY LIFE

At the recent Miami Dade workshop, Kumar and Loft, along with University of Wyoming Professor Suresh Muknahallipatna and three of his students, taught 20 Miami Dade faculty members how to set up and program simple projects with a Raspberry Pi. One group used sensors to measure things like temperature, pressure, and humidity, while another created a word frequency histogram from the complete works of William Shakespeare, using a Raspberry Pi Hadoop cluster.

David Freer, a Miami Dade computer science professor, said

Ana Guzman (far right), a Miami Dade College associate professor of electricial engineering, gets Raspberry Pi tips from Cena Miller, a University of Wyoming student. A group of Miami Dade faculty members were trained recently on using the low-cost computers for hands-on teaching by a team that included NCAR computer scientists and University of Wyoming students. (Photo courtesy Rich Loft, NCAR.)

he and his colleagues thought the workshop was terrific. "We worked with flame sensors that sent messages to users on their cell phones, along with other cool projects," he said.

Djuradj Babich, director of Miami Dade's School of Engineering and Technology, said he hopes to "ride the excitement wave" from the training and develop an ongoing relationship with NCAR. Loft said NCAR also hopes to reach out to additional universities.

Qiong Cheng, an assistant professor at Miami Dade, has since set up a Raspberry Pi in her office, complete with a motion detector. She said she will use the Raspberry Pi platform in her classes this fall, which are part of a new bachelor's program in data analytics.

Qiong Cheng, an assistant professor at Miami Dade, has since set up a Raspberry Pi in her office, complete with a motion detector. She said she will use the Raspberry Pi platform in her classes this fall, which are part of a new bachelor's program in data analytics.

That's the kind of talk that excites Loft.

"We want to continue to collaborate to drive this home. Which means that Miami Dade is using this in their curriculum as the workhorse in their computer lab for students," he said. "That's what's going to make me very happy."

WRITER/CONTACT:

Jeff Smith, Science Writer and Public Information Officer

MESA LAB MARKS 50TH ANNIVERSARY

CEREMONY HONORS ICONIC BUILDING'S ROLE IN FOSTERING SCIENTIFIC DISCOVERY

In 1967, a spectacular building opened its doors and began hosting world-class research. The NCAR Mesa Lab was immediately hailed as an architectural masterpiece as well as a catalyst for new discoveries in the atmospheric and related Earth system sciences, from weather and climate to the Sun and other areas of importance to society.

In August 2017, a formal rededication ceremony was held to mark the building's 50th anniversary. Current and former longtime NCAR staff joined visiting leaders from the National Science Foundation and elected officials on the federal, state, and local level to celebrate the occasion.

Sarah Ruth, head of the NCAR/Facilities Section at NSF, unveiled a mockup of the 50th anniversary plaque that has since been installed at the lab entrance. "The Mesa Laboratory represents a commitment to both the practice and the wonder of science," she said in her remarks. "It is a true architectural icon, symbolizing the pledge that was made more than 50 years ago … to mount an attack on the fundamental atmospheric problems."

"For 50 years, the Mesa Laboratory has been NCAR's iconic home," said NCAR Director James Hurrell, the master of

ceremonies at the rededication. "The Mesa Lab has been the site of countless advances in atmospheric and Earth system research."

The ceremony celebrated both the Mesa Lab's distinct design and the close and creative collaboration between architect I.M. Pei and founding head of NCAR and UCAR Walter Orr Roberts. Now 100 years old, Pei was represented by his son and fellow architect Li Chung (Sandi) Pei.

Heartfelt remembrances of first encounters with the Mesa Lab, its staff, and the research environment fostered there were shared by a number of speakers, including Clifford Jacobs (former NCAR/Facilities head), Scott McCarthy (grandson of Walter Orr Roberts), Robert Serafin (former NCAR director), and U.S. Rep. Jared Polis, whose district includes Boulder. Their remarks can be viewed on the NCAR & UCAR YouTube channel.

A PERMANENT HOME

The origins of the Mesa Lab can be traced back to NCAR's founding in 1960, when it became apparent that the new lab would need a permanent home to enable its research to move forward. After the Colorado state legislature donated a stunning tract of land in the foothills of south Boulder to NSF, a special UCAR committee selected I.M. Pei to design a building on the site.

Pei, a respected young architect at the time, came to know the site intimately. Often in the company of Roberts, he hiked it at all times of day, picnicked, camped, and watched the changing sunlight on the stony crags. Inspired by such ancient structures as Stonehenge and the cliff dwellings at Mesa Verde National Park, he sought to create a building that would complement the immensity of the setting, not compete with it. Thanks to his innovative approach and the vision that he and Roberts shared, the Mesa Lab was built in careful harmony with the surrounding land.

"This building is extremely meaningful to him," Sandi Pei said of his father at the rededication ceremony. "This place is very much in his heart."

UCAR President Antonio Busalacchi noted that the first chair of UCAR, Henry Houghton, often emphasized the importance of the partnerships that resulted in the creation of a unique building in a remarkable setting. At the original dedication, Houghton said: "This was not and could not have been the result of a small group of proponents. Rather, it has been achieved by the possibly unprecedented cooperation and support of many individuals and agencies from both the public and private sectors."

"While he was talking about the Mesa Lab,” Busalacchi said at the rededication," he could also have been describing what makes our organization so special to this day.”

The Mesa Lab quickly won widespread praise among scientists, architects, and the neighboring communities while fulfilling NSF's goal of an appropriate home for the national lab. Leland Haworth, the director of NSF 50 years ago, said at the original dedication: "We have met here in a beautiful building, which I certainly do not need to tell you. It is one of the most effective homes for an institution of this sort that I've ever seen."

In addition to hosting landmark scientific research, the Mesa Lab also draws more than 100,000 visitors yearly. They come both to see an architectural masterpiece and to explore the exhibits on weather, climate, and solar research.

"I'm sure I am not alone in recalling the first time I came to Boulder as a young postdoc, seeing the Mesa Laboratory, and thinking something truly special must happen here," Ruth said at the rededication. "I'm equally sure that 50 years from now, at the 100th anniversary of the Mesa Lab, our successors will still be awestruck by the beauty of this building and the

incredible science being conducted and enabled within its walls."

NCAR 2017 METRICS & PUBLICATIONS

FISCAL YEARS 2017 NCAR METRICS

The metrics featured below offer qualitative and quantitative measurements and assessments of the productivity, quality, and impacts that NCAR staff, programs and activities have on our research community, sponsors, and society in general for data reported in the Metrics Database, iVantage HRIS system and OpenSky Database as of October 30, 2017 for fiscal year 2017 (October 1, 2016 - September 30, 2017). Staff continue to update their entries and expand their contributions throughout the year so visit the Metrics Database for the most current data. (2017 METRICS AS OF OCTOBER 30, 2017). Date stamp 10/30/17.

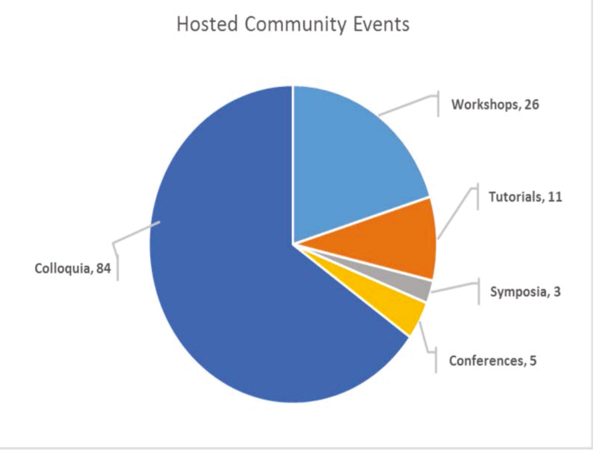
LAB/OBSERVATORY/PROGRAM-LEVEL METRICS

NCAR-Hosted Community Events

Each year, events are hosted by labs, divisions, and programs. These include colloquia, conferences, symposia, tutorials, and workshops.

Date Range	Total Hosted	Workshops	Tutorials	Symposia	Conferences	Colloquia
FY17	129	26	11	3	5	84

In FY17, a total of 129 events were hosted: 26 workshops, 11 tutorials, three symposia, five conferences, and 84 colloquia with an average audience of 58 colleagues per event and estimated total audience of 7,538. Event co-sponsors groups included the German Climate Computing Center, EUropean Facility for Airborne Research, the U.S. Department of Energy and universities including the University of Chicago, and Michigan State University.



Field Campaigns

NCAR's geosciences research facilities, instrumentation and field support services support field campaigns around the globe.

Date Range	Total Campaigns	Institutions	PIs	Undergraduate Students	Graduate Students
FY17	10	100	57	22	41

In FY17, NCAR participated in 10 field campaigns ranging in duration from 28 to 837 operational field days. A total of 100 institutions, including 35 UCAR member institutions participated in these campaigns. The projects involved 57 investigators, 22 undergraduate students, and 41 graduate students.

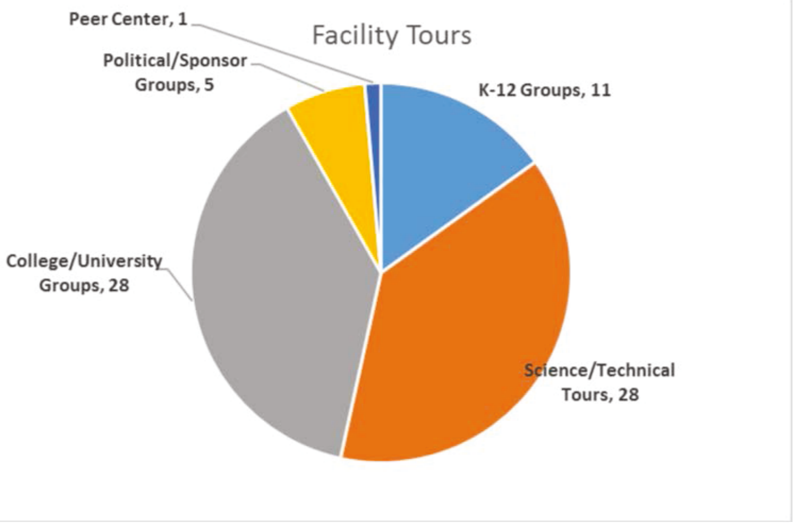
Campaign Acronym	Campaign Full Name
Rosetta Stone	Rosetta Stone
ARISTO 2017	Airborne Research Instrumentation Testing Opportunity
WE-CAN Test Flights	Western Wildfire Experiment for Cloud Chemistry, Aerosol, Absorption and Nitrogen
SNOWIE	Seeded and Natural Orographic Wintertime Clouds - the Idaho Experiment
Perdigao	The Perdigao Field Experiment
Eclipse 2017	Eclipse 2017
VERTEX	Vertical Enhanced Mixing
SPIFFY	Seasonal Particles in Forest Flux studY

SHOUT - HRR	Sensing Hazards with Operational Unmanned Technology - Hurricane Rapid Response
Eclipse Test	Eclipse 2017 Test Flights

One example is the VERTical Enhanced MiXing (VERTEX) project, an NSF sponsored field campaign focused on understanding how lower boundary airflow is altered by the presence of wind turbines.To help test this, EOL's Integrated Surface Flux System (ISFS) team installed 15 surface flux towers downwind of a turbine in Delaware's Great Marsh Preserve just outside the resort town of Lewes, Delaware. During operations, there were at least two EOL staff in Delaware at one time whose primary objective was to ensure the highest quality data was being ingested and equipment was running at all times.

Facility Tours

Each year, NCAR facilities host tours organized for a specific organization or group. This year, NCAR hosted a total of 69 tours, between the four locations.



NCAR-Wyoming Supercomputer

The NCAR-Wyoming Supercomputer Center (NWSC) is based in Cheyenne, Wyoming. The Center provides advanced computing services to scientists studying a broad range of disciplines, including weather, climate, oceanography, air pollution, space weather, computational science, energy production, and carbon sequestration. The Center is open to the public for self-guided tours, field trips for school groups, and non-school group special tours. In FY17, the Center received 1551 walk-in public visitors, and averaged 130 visitors per month.

Date Range	Hosted Tours	K-12 Groups	Science/Technical Tours	College/University Groups	Political/Sponsor Groups	Peer Center
FY17	28	7	9	8	3	1

NWSC hosted 28 tours in FY17, for groups ranging in size from 2 to 48 people. Seven tours were by K-12 groups, including the STEM Academy of Info Tech and various local high school visits. Nine groups took science- or technical-related tours, including a group from the Coop GIS of Laramie County. There were eight college or university groups, ranging from the Front Range Community College to the Malaysia & Myanmar Young Leader Delegation from Southeast Asia. There were three tours by political/sponsor groups, including the Wyoming Federation of Republican Women and the National Science Foundation. There was also a tour by the San Diego Supercomputing Center, a peer institution.

NCAR Research Aviation Facility at the Rocky Mountain Metropolitan Airport

Date Range	Total Hosted Tours	K-12 Groups	Science/Technical Tours	College/University Groups	Political/Sponsor Groups
FY17	23	2	8	11	2

The Rocky Mountain Metropolitan Airport hosted a total of 23 tours in FY17. Eleven tours were by college and university groups, including the University of Northern Colorado and Colorado State University. Two tours were by political and sponsor groups, including the City & County of Broomfield and CO-LABS Inc. . There were also two tours provided to a K-12 group from the Center of Science Education. This year there were eight science/technical tours provided to groups ranging from Innovative Research and the Korean Radio Research RRA.

The High Altitude Observatory

Date Range	Total Hosted Tours	K-12 Groups	Science/Technical Tours	College/University Group
FY17	20	2	11	7

The High Altitude Observatory hosted a total of 20 tours in FY17. Seven tours were by college or universities including groups from the University of Hawai'i and Cornell University Earth Sciences program. There were two tours for the Ouray High School and the Nakimi Secondary School High School, both from the K-12 group. There were also eleven science and technical tours provided to NOAA meteorologists and the Geology Society of America.

The Mesa Lab

Date Range	College/University Group
FY17	2

The Mesa Lab hosted a total of 2 tours in FY17 to college or universities including groups from PROGRESS (PROmoting Geoscience Research, Educations and Success) and Gustavus Adolphus College.

INDIVIDUAL STAFF METRICS

Contributions to Individual Graduate Student Education

NCAR staff members serve as research advisors and thesis committee members for graduate students around the world.

Date Range	Total Students	International Service	U.S. Service
FY17	226	27%	73%

In 2017, NCAR staff served as graduate advisors or committee members for 226 graduate students. Twenty-two are working on their master's degrees and 204 are working on their PhD. 73% hail from U.S. universities; 27% study at schools in 22 countries around the world, including a PhD student from the University of Lille who was advised by Geoff Tyndall, a PhD student from Oklahoma State University advised by Rebecca Morss, and a Master's student from Western Washington University advised by Carl Schmitt.

Editorships

NCAR staff members serve as publication editors. These positions recognize the appointee's leadership in the field and serve a critical role in developing a given field's future focus.

Date Range	Total Editorships	Different Publications/Journals
FY17	88	97

88 NCAR staff served in editorial roles for 97 different publications or journals. Tammy Weckwerth served as the Subject Matter Editor for the Bulletin of the American Meteorological Society while Dan Marsh served as a Guest Editor for the Journal of Atmospheric and Solar-Terrestrial Physics. Publications included top-tier journals such as the AMS Journal of Hydrometeorology and the Geoscience Data Journal.

External Awards

Every year a significant number of NCAR Staff are honored for their scientific excellence and community contributions to the Atmospheric and related sciences.

Date Range	Total External Awards
FY17	36

Peggy LeMone (MMM), Rich Rotunno, (MMM), Scott Ellis (EOL), Mary Barth, (ACOM) and Bob Sharman (RAL) were named American Meteorology Society Fellows. The AMS Fellow honor celebrates outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period of years.

Martyn Clark (RAL) was named a fellow of the American Geophysical Union (AGU). This special honor recognizes scientific eminence in the Earth and space sciences. It acknowledges Fellows for their remarkable contributions to their research fields, exceptional knowledge, and visionary leadership. Only 0.1% of AGU membership receives this recognition in any given year.

Fellowships

A fellowship is typically a special appointment granting support for a term in order to support advanced research or study.

Date Range	Total Fellowships
FY17	8

Eight UCAR staff received fellowships in 2017. Among the highlights: Sophie Hou (CISL) was awarded the Earth Science Information Partners Fellowship offered by the Foundation for Earth Science and James Done (MMM) was awarded the Willis Research Fellow Postdoctoral Fellowship from the Willis Research Network.

K-12 Outreach

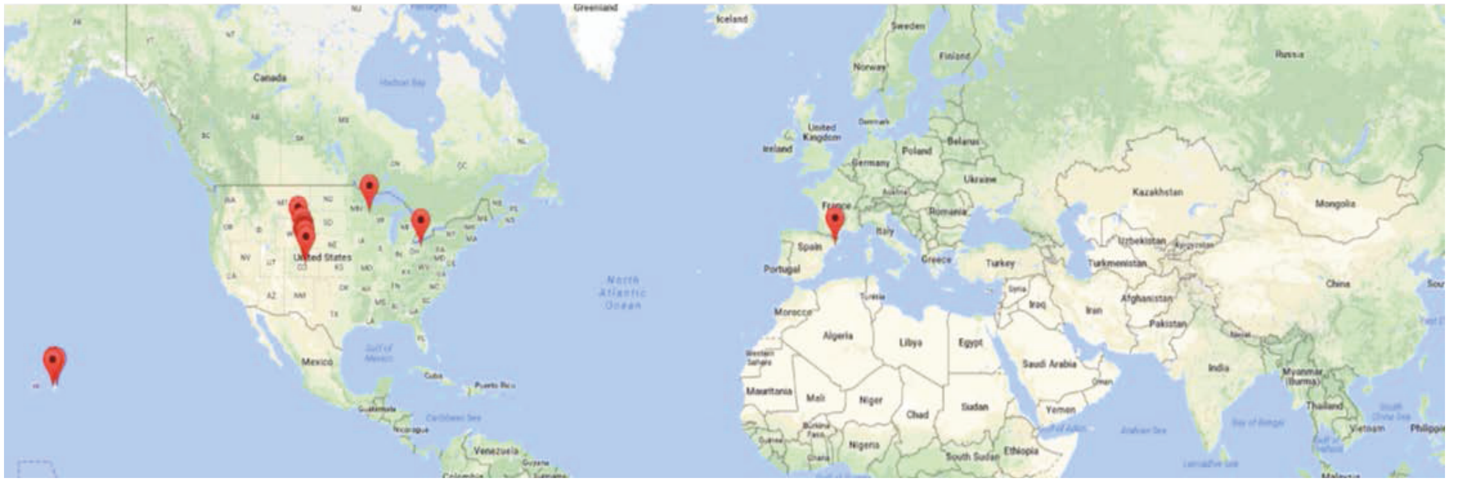
Staff across NCAR work directly with classes and groups of K-12 students to develop or deliver lectures, conduct tours, and lead or participate in field trips and other educational activities.

Date Range	Total K-12 Outreach	Schools/Events	Communities Reached
FY17	43	54	23

Forty-three NCAR Staff worked with K-12 students from 54 schools or other school based organizations. Activities included hosting a math olympiad at Blue Mountain Elementary School, helping teachers, mentoring, and field trips reaching 23 different communities. Examples range volunteering at Bear Creek Elementary School's 3rd grade robotics program in Boulder, Colorado to being a science fair judge at the Colorado Science and Engineering Fair (CSEF).

Among the highlights: Bill Mahoney (RAL) supports the Snow Plow Painting Art Project involving more than 200 kids, on an annual basis (since 2003). This project brings awareness of the City of Louisville's winter snow and ice control operations and the safety hazards associated with winter conditions by bringing together school students, city operations officials, and weather experts. Art classes at each of the participating schools design artwork consistent with the designated theme for the year and the artwork is then painted on the snow plows. Seven schools in Louisville participate in this project; Rebecca Bucholz (ACOM) was a Grand Awards Judge and Senior Division Chemistry and Biochemistry Assistant Captain for 500 students at the Colorado Science and Engineering Fair in Ft. Collins, Colorado; and David Gagne participated in the National Arctic Climate Game Jam in Boulder, Colorado.

K-12 Global Outreach for FY17



Mentoring

NCAR staff participate in mentoring colleagues and students.

Date Range	Total Mentoring
FY17	108

During this year, 108 staff members mentored mentees both inside and outside of NCAR. Mary Barth (ACOM) was a science mentor at both the University of Polytechnic Marche and the University of Rhode Island. Andreas Prein (MMM) was a science mentor to two students at the Aristotle University of Thessaloniki; John Dennis (CISL) was a computer and electrical engineering mentor to students from the University of Colorado and Colorado State University while Matthias Rempel (HAO) worked with students from the University of Glasgow and an ASP Post Doc at NCAR.

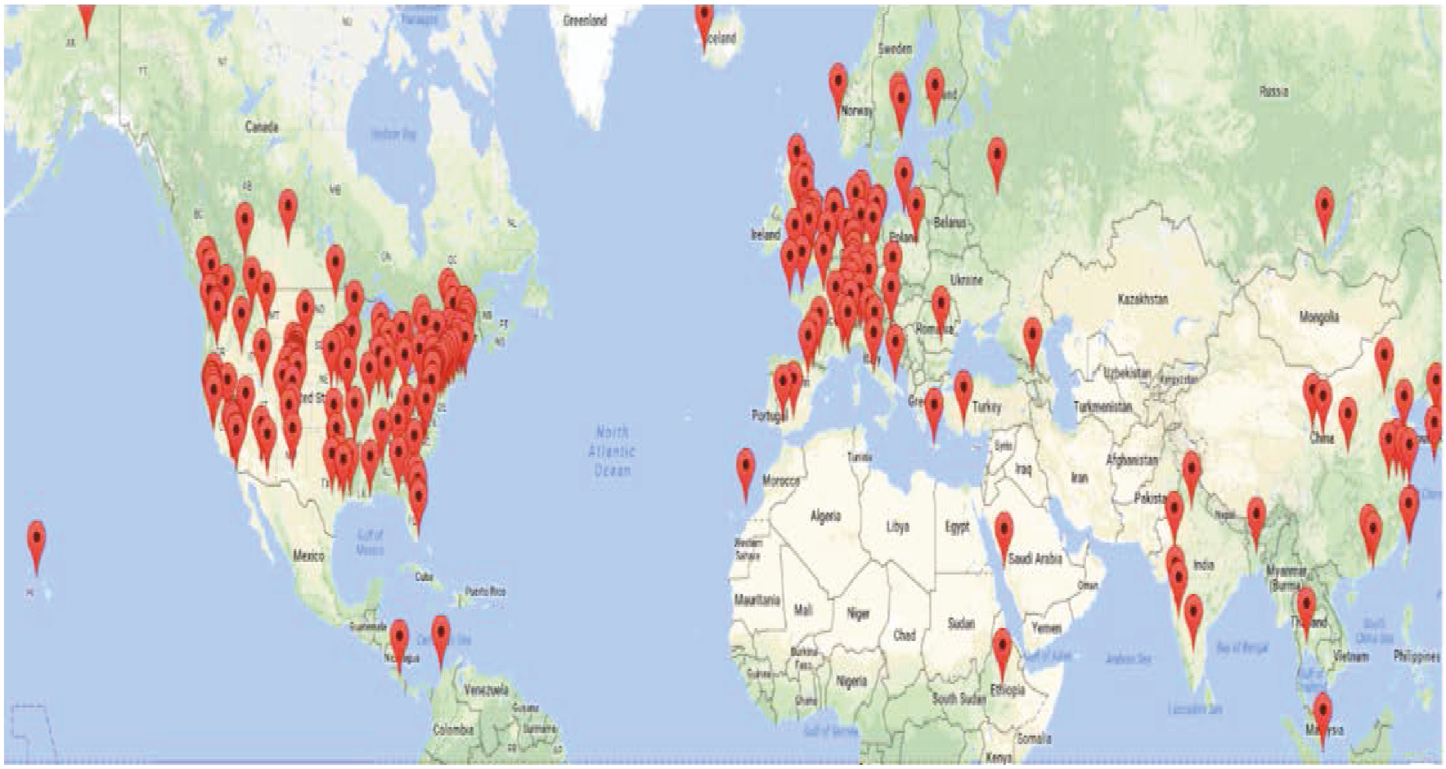
Talks and Posters

NCAR Staff give presentations about data, models, theories, hypotheses, reviews, and results around the world in talks and posters to audiences ranging from scientists and engineers to the general public.

Date Range	Audience Totals	Total Poster Session	NCAR Staff - Poster Presentations
FY17	1000+	242	170+

Many thousands of people were in the audience when 242 NCAR staff presented over 1,000 talks globally, from Monterey, California to Seoul, South Korea. Examples range from Joe Tribbia's (CGD)) talk on "Is the Atmosphere less predictable than we think?" at the Mathematical Research Institute of Oberwolfach in Oberwolfach, Germany, to Pedro Jimenez Munoz's (RAL) talk "A three dimensional PBL parameterization to improve wind simulations over complex terrain" at the AMS Eighth Conference on Weather, Climate, Water, and the New Energy Economy in Seattle, Washington.

Presentations Globally FY17



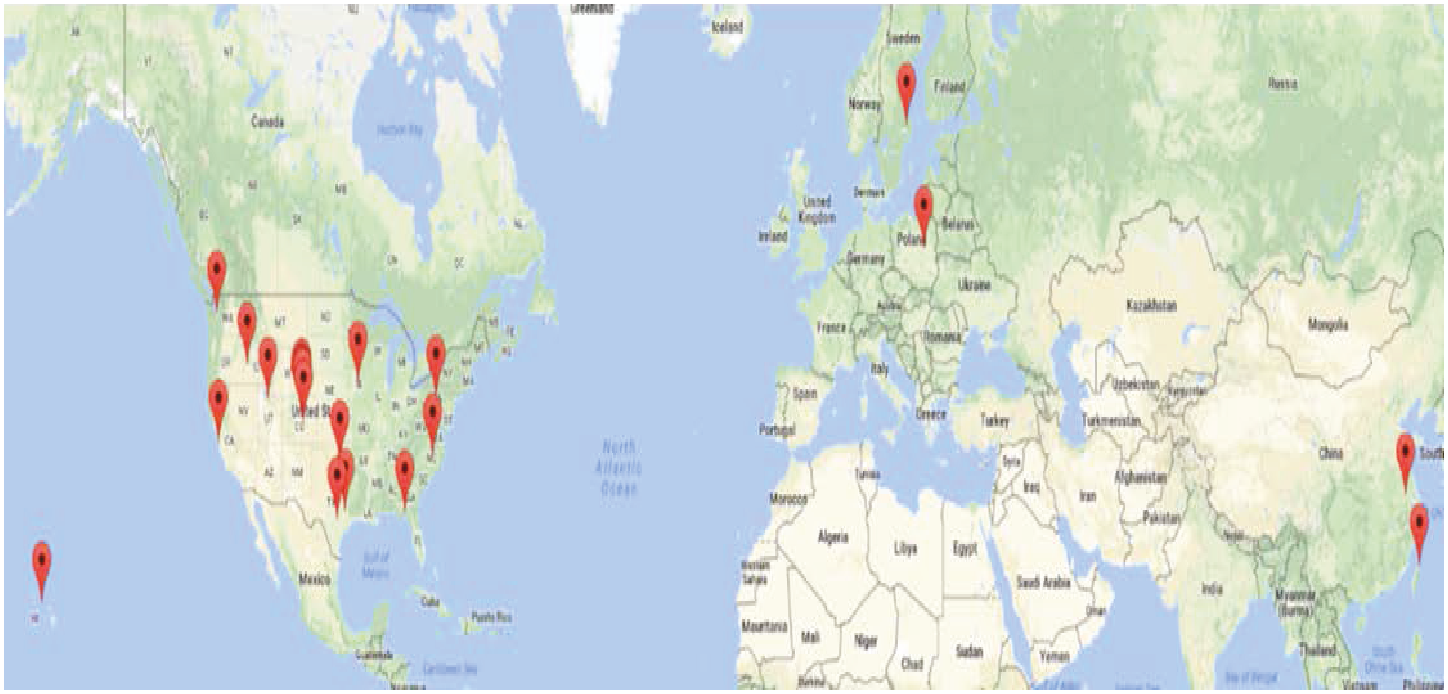
One Hundred and three NCAR staff made more than 170 poster presentations globally, from Bozeman, Montana to Buenos Aires, Argentina. Examples include Lulin Xue's (RAL) poster "High resolution regional climate simulation of the Hawaiian Islands – Validation of the historical run from 2002 to 2012" in San Francisco, California at the AGU Annual Meeting and Art Richmond's (HAO) poster "What Drives the Electrodynamics of the Low-Latitude Evening Ionosphere?" in Tokyo, Japan at the JpGU/AGU Joint Meeting.

Teaching in University/College Classroom

Date Range	Total Teaching Appointments	Countries	U.S. States
FY17	37	5	12

NCAR staff members make important contributions through teaching appointments at institutions of higher education in different positions ranging from Graduate Faculty to Professor.

Classroom Teaching in University/College FY17



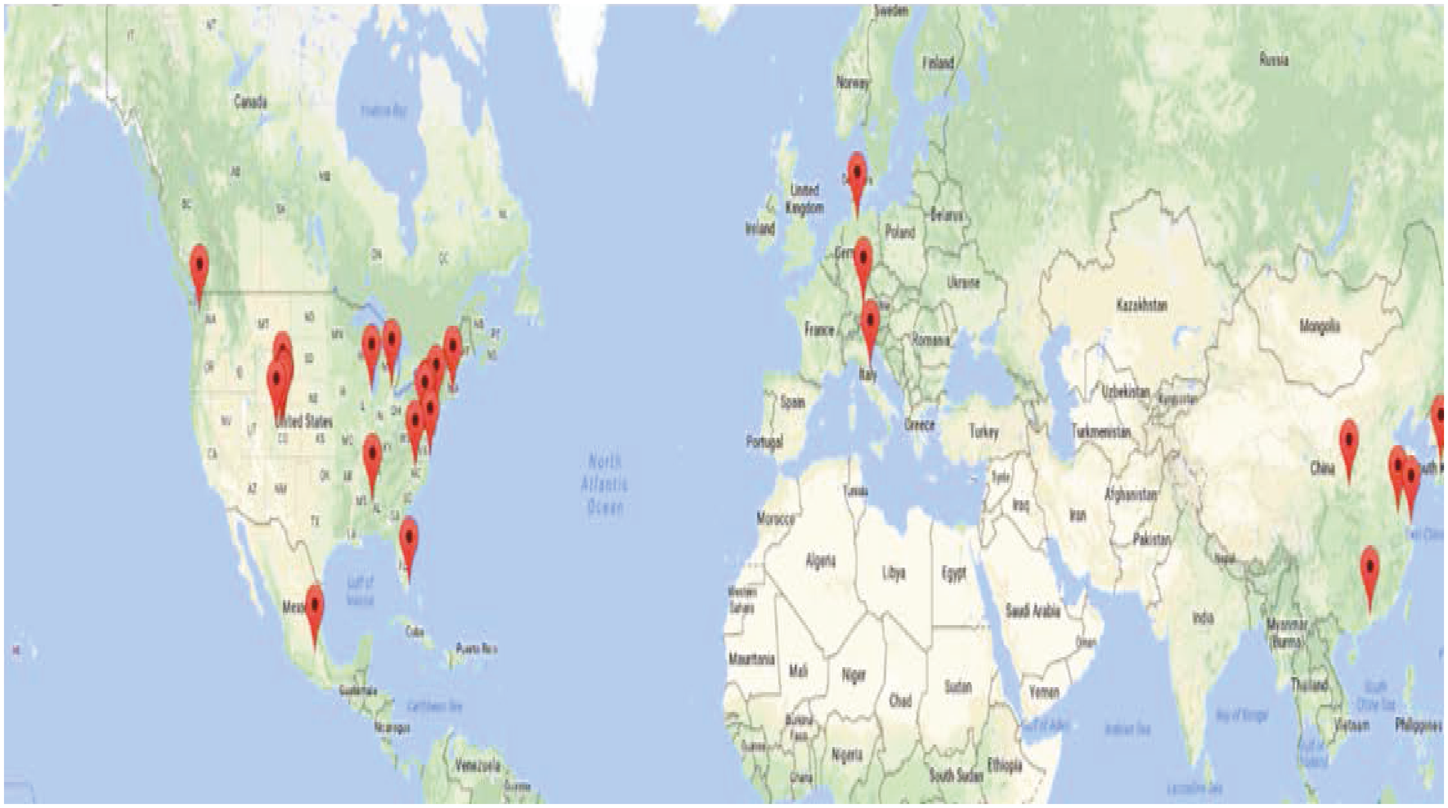
Teaching appointments at institutions of higher education currently number 37. Seven percent of these appointments occur in 5 countries around the world; 93% took place in 12 U.S. states. The longest term is 32 years, by Grant Branstator (CGD) who is an Adjunct Professor at Iowa State University. The class sizes range from 5 to 90 students.

Teaching or Training at Workshops/Tutorials/Colloquia

NCAR staff teach classes and offer training in workshops, tutorials, and colloquia to colleagues and students ranging from model users, to scholars, to fellow researchers.

Date Range	UCAR Staff Members	Workshops/ Tutorials/ Colloquia	Classes	Countries	U.S. States
FY17	76	90	562	6	15

Teaching or Training at Workshops/Tutorials/Colloquia FY17



During this year, 76 staff members taught at a total of 90 workshops, tutorials, and colloquia. In all, 562 individual classes were taught, with class sizes ranging from one to 125 people. Nine percent of these events occurred in 6 countries around the world including Italy and South Korea; 91% took place in fifteen U.S. states, including Maryland and Wisconsin. Examples range from Michael Wiltbergers' (HAO) appointment as Dean to the “CISM Space Weather Summer School” in Boulder, Colorado to Gokhan Danabaso’s (CGD) lecturing at the ICTP School on Ocean Climate Modeling: Physical and Biogeochemical Dynamics of Semi-Enclosed Seas in Ankara, Turkey.

External Committee Service

NCAR staff are called upon to participate in and often lead external scientific, technical, policy, and educational committees. These committees are instrumental to advancing and promoting the work of the scientific and technical community.

Date Range	Total External Committees	NCAR Staff Served	Service on more than one committee
FY17	529	183	63%

This year, 183 NCAR staff served in a multitude of roles on 529 external committees (an average of 2.9 committees per participating staff member) for national and international scientific, education, and governmental organizations, including entities such as the Water Research Foundation, the Western Education and Research Collaboration and the Research Council of Norway. More than 63% served on more than one committee.

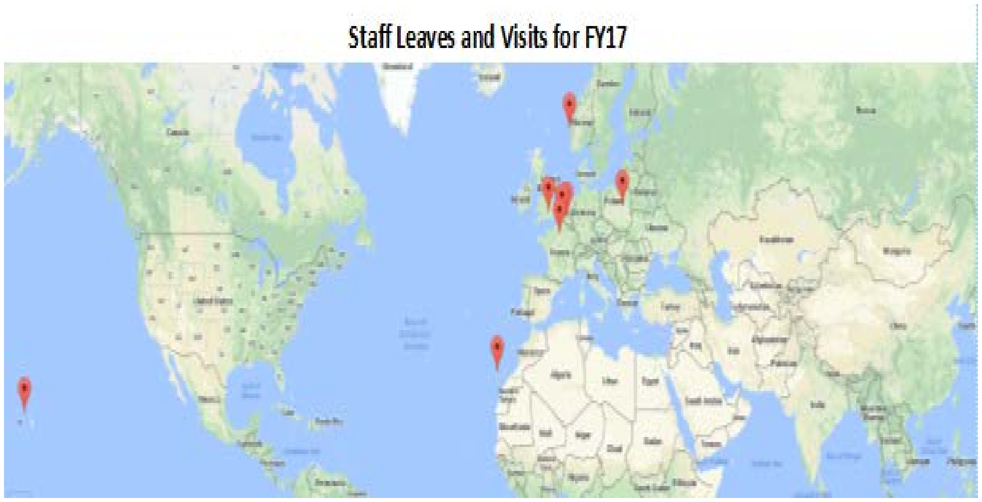
Staff Collaboration Visits to Universities

NCAR staff take leaves to visit other institutions for two weeks or more for intellectual growth, professional development, collaboration with research community peers, community support, teaching, or sabbatical. Examples of work include teaching courses or workshops, lecturing, giving tutorials, working with graduate students on dissertation-focused research, student mentoring, collaborative research, and participating in the host institution's outreach to community colleges, minority-serving

institutions, and high schools.

Date Range	NCAR Staff Members	Institutions
FY17	10	10

This year, 10 NCAR staff members took leaves at 10 different institutions, ranging from the University of Hawai'i to the Nansen Environmental and Remote Sensing Center. Among the highlights: Stephen Yeager visited and collaborated with a senior fellow at the University of Reading to conduct collaborative research and Wojciech Grabowski (MMM), a Senior Scientist Section Head, visited the University of Warsaw for a 1-year collaborative leave to teach at the university.



APPOINTMENT METRICS

Special Appointments

NCAR Affiliate Scientists

Select university and research-community scientists are invited to carry out long-term, highly interactive, collaborative work with UCAR scientists and are appointed as Affiliate Scientists with three-year terms (see list). This appointment is particularly suitable for parties who desire an extended, close-working relationship on scientific problems of mutual interest. Currently, 44 scientists hold appointments including Dr. Kevin Repasky of Montana State University. Dr. Repasky is collaborating with scientists in the Earth Observing Laboratory(EOL) on developing a deployable version of a low-cost water vapor differential absorption lidar (WV DIAL).

NCAR Affiliate Scientist	Home Institution
Dr. Elliot Atlas	University of Miami
Dr. Bernard Aumont	Laboratoire Interuniversitaire des Systemes Atmospherieques (LISA)
Dr. Ed Balistreri	Colorado School of Mines
Dr. Dale Barker	United Kingdom Meteorological Office
Dr. Alan Blyth	University of Leeds
Prof. Lance Bosart	State University of New York Albany
Dr. Natalia Calvo	Universidad Complutense de Madrid
Dr. Guido Cervone	Pennsylvania State University
Dr. Paul Charbonneau	University of Montreal
Dr. Shuyi Chen	University of Miami
Prof. Philip Chilson	University of Oklahoma
Prof. Cathy Clerbaux	CNRS

Dr. Enrique Curchitser	Rutgers University
Dr. Ineke de Moortel	University of St. Andrews
Dr. Leo J. Donner	NOAA GFDL
Dr. Veronika Eyring	German Aerospace Center
Dr. Jerome Fast	Pacific Northwest National Laboratory
Dr. Michael Ferrari	aWhere
Dr. Paul Field	Met Office
Dr. Silvano Fineschi	Osservatorio Astrofisico di Torino
Dr. John Finnigan	CSIRO, Australia
Viggo Hansteen	University of Oslo
Dr. Song-You Hong	Yonsei University
Dr. Joseph Huba	Naval Research Laboratory
Dr. Mary Hudson	Dartmouth College
Dr. Harm Jonker	Delft University of Technology
Dr. Reto Knutti	ETH Zurich, Switzerland
Dr. Hao-Sheng Lin	University of Hawai'i Manoa
Dr. Elisabeth Lloyd	Indiana University
Dr. William Lotko	Dartmouth College
Dr. Latty Mahrt	Oregon State University
Dr. Marty Mlynczak	NASA Langley Research Center
Dr. Antonio Navarro	Instituto Nazionale di Geofisica e Vulcanologia
Dr. Phiippe Naveau	Laboratoire des Sciences du Climat et I'Environnement (LSCE) CNRS
Dr. Bart Nijssen	University of Washington
Prof. Lorenzo Polvani	Columbia University
Dr. Mark Rast	University of Colorado
Dr. Kevin Repasky	Montana State University
Dr. Alfonso Saiz-Lopez	Ministerio de Ciencia e Innovaction, Madrid
Prof. Gunilla Svennson	University of Stockholm
Dr. Laurent Terray	CERFACS
Prof. Javier Trujillo-Bueno	Instituto de Astrofisica de Canarias
Dr. Lian-Ping Wang	University of Deleware
Prof. Mei Zhang	Chinese Academy of Sciences

Emeritus/Emerita

Scientific and Research Engineering staff who have made significant contributions to NCAR through long and distinguished service in senior positions in research may be granted emeritus or emerita status (see list). This designation confers a life-long honorary distinction. Approval of the President and the Board of Trustees is required. Currently the ranks of Emeritus/Emerita number 28 with the recent appointment of Mr. Richard “Rit” Carbone who is continuing his research on root causes of tropical oceanic rainfall errors in highly parameterized global models.

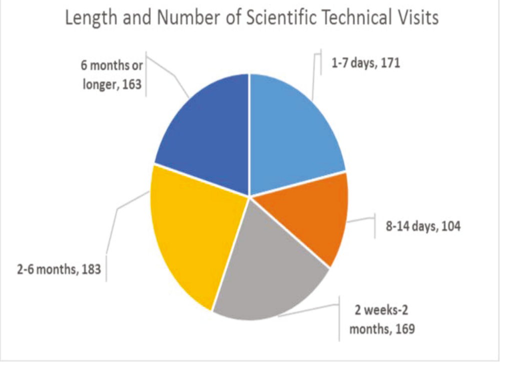
Emeritus/Emerita	Year of Appointment
Jack Calvert	2002
Rit Carbone	2016
Al Cooper	2013
James Dye	2003
Fred Eisele	2009

John Firor*	1999
Brant Foote	2017
John Gille	2015
Peter Gilman	2009
Roy Jenne*	2013
Maura Hagan	2015
Jackson Herring	1998
Richard Katz	2013
Charles Knight	2013
Joachim Kuettner*	2007
Margaret Lemone	2009
Donald Lenschow	2011
Bruce Lites	2013
Roland Madden	2002
William Mankin	2003
Annick Pouquet	2013
Art Richmond	2017
Brian Ridley	2007
Raymond Roble	2009
Bob Serafin	2001
Paul Swartztrauber*	2004
David Williamson	2014
Jim Wilson	2014

*deceased

SCIENTIFIC AND TECHNICAL VISITS TO NCAR

Date Range	Total Scientific/Technical Visits	1-7 days	8-14 days	2 weeks-2 months	2-6 months	6 months or longer
FY17	854	171	104	169	183	163



Each year students, scientists, engineers, weather forecasters, and other professionals from around the country and world receive special visitor appointments from labs and programs across NCAR to collaborate with scientific, educational, or technical staff; conduct independent research; or participate in and/or oversee a professional project. Many receive financial support for their visits and some visitors temporarily join the NCAR staff.

This year, colleagues visited NCAR 854 times and hailed from 349 institutions, located in 45 different U.S. states and 38 different countries.