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# EOS

Earth & Space Science News

100 YEARS

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# Collaboration Reveals What's Beneath the Surface

When it comes to certain fields of science, sometimes you need a tool, and sometimes you need the whole toolbox. The latter is certainly true for scientists who study Earth's interior. Coming from a spectrum of fields—analytical geochemistry, experimental petrology, global seismology—they must work together, comparing their observations and results in order to make discoveries. As we move into the second month of AGU's year-long Centennial celebrations, we want to recognize these scientists and their interdisciplinary approach to studying our planet.

In 2017, an international team made up of gas geochemists, volcanologists, physicists, engineers, and chemists traveled to Central America as the very model of collaborative research. By flying small drones into the plumes of outgassing volcanoes, they could directly measure the changes in concentrations of carbon dioxide, sulfur dioxide, and hydrogen sulfide. These data help them not only calculate the emission of volatiles from the deep Earth into the atmosphere but also study how volcanoes interact with the climate, or even help tell us when one might erupt. Read more about this supergroup of scientists on page 28.

Some groups are making tools for other scientists. On page 47, read about the team that created the latest version of the Antarctic Digital Magnetic Anomaly Project (ADMAP-2). Using one observational tool—measuring Earth's magnetic subtleties—they more than doubled the size of the Antarctic map that will be used by geologists and geophysicists studying the planet's crust. Similarly, a group from the U.S. Geological Survey recently created a catalog of 15,000 microquakes—those magnitude 3 and below—in Oklahoma to study the effects of wastewater reinjection by petroleum operations (pg. 9). That data has already allowed the team to study clusters of the tiny quakes and how they radiate out from certain locations, work that may very well lead to changes in local fracking law.

The most obvious challenge faced by scientists who study Earth's interior is simply that they can't look into it. As a result, they're forced to create more and better tools that allow them to observe and model what's happening underneath our feet. Seismologists understand this better than most. It was, after all, Inge Lehmann who studied waves traveling through the planet and discovered, in 1936, that Earth's outer core is liquid. Not-quite-as-grand observational tools can be useful too: On page 4, read about one geophysicist who is using synthetic material in a lab to create 3-D movies that model fracturing. Scientists who study these events, caused by anything from earthquakes to melting glacier ice or even plant roots pushing into rock, are rarely able to see them in real time. These new lab techniques can allow them to try to re-create and observe the process.

Finally, some of that science will have a direct impact on our lives. Our cover story this month (pg. 18) features the work of seismologists and social scientists studying the effectiveness of earthquake early warning systems in Mexico City. After a devastating *M*8.0 earthquake in 1985 killed around 10,000 people, a research and development group set about finding a way to give their neighbors some warning. When a *M*7.1 earthquake struck the nearby city of Puebla in 2017, on the anniversary of the Mexico City quake, the team was able to study the biggest test of the system since its implementation. And the wondrous part? The system is working. On 3 January, Los Angeles mayor Eric Garcetti announced that the city is the first in the U.S to have an early warning earthquake system—a phone app based in part on the research and lessons learned by the team in Mexico.

Perhaps it's sentimental to say that there's nothing we can't do if we do it together, but we don't need to say it; we can let Earth scientists show us.

**Heather Goss,** Editor in Chief





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**Christine W. McEntee, Executive Director/CEO**



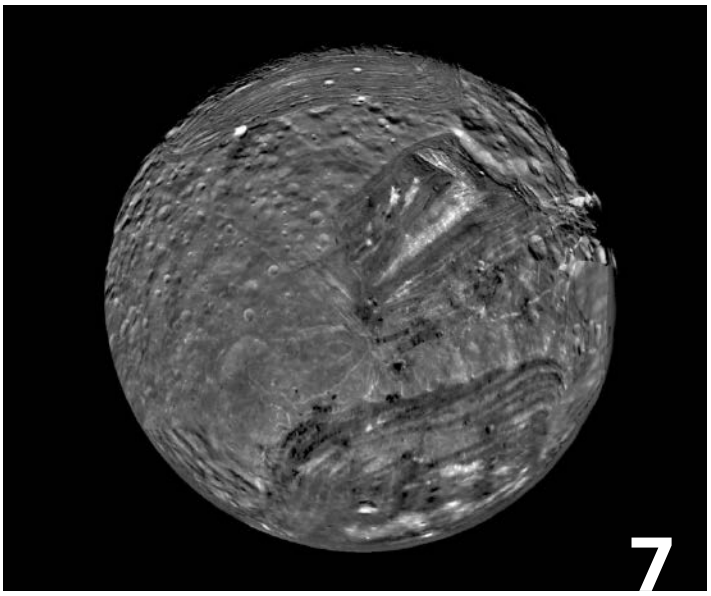

## Cover Story

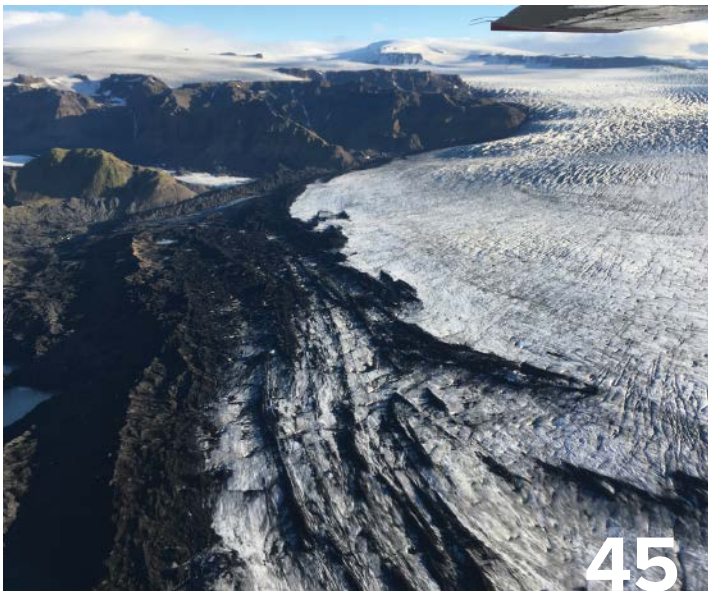


### On the Cover

Mexico City's Metropolitan Cathedral. Credit: iStock.com/bpperry

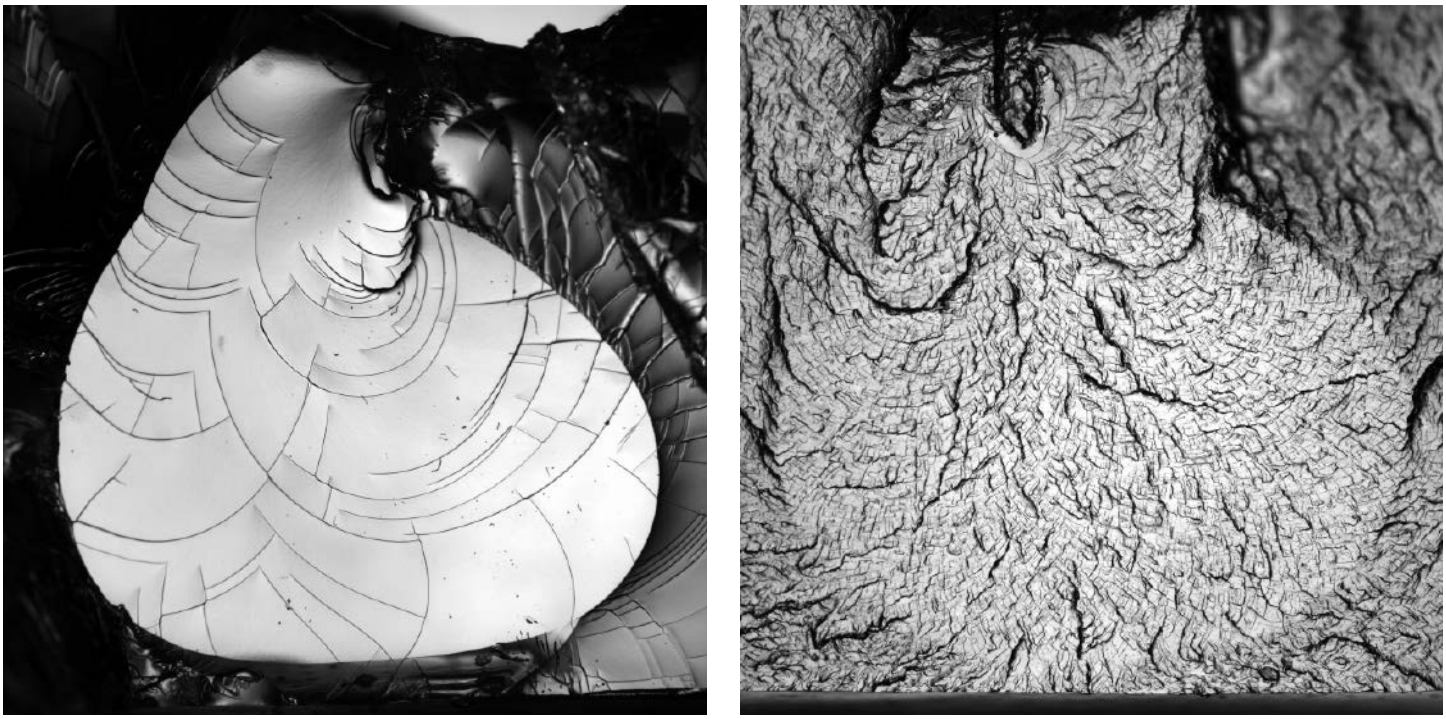
## Features




## Columns

# Modeling Fractures in 3-D



*In a Harvard University lab, researchers injected pressurized fluid into blocks of clear hydrogel, where it spread in much the same way that fractures travel through rocks or ice in the field, creating the fractures seen here. They found that a hydrogel with few flaws (left) forms long, continuous cracks, creating a smooth fracture surface. In a hydrogel sample with discontinuities created by adding glycerol or glass beads (right), the cracks that start at the discontinuities cause many more jagged step line cracks to form in the fracture surface. Credit: Will Steinhardt*

Our dynamic Earth is scattered with cracks. Earthquakes and petroleum fracking make cracks in rocks underground; melting ice forms cracks in glaciers. Freeze-thaw, roots pushing into weathered rock, the shatter from an impact—all of these processes create cracks.

The details of the fracturing process remain a mystery. Scientists know that the roughness of a rock or ice surface can affect how fluids flow across it and how fractures travel through it. But what if you had a detailed 3-D movie of fractures in the act of forming, crack by crack?

Catching an actual fracturing event as it happens is tough to do (much less figuring out how to film something underground), but one group of scientists set up and filmed a similar event in their lab using a synthetic material called a brittle hydrogel. This material, comprising mostly water, is transparent, which makes it easy to see cracks as they form.

Cracks travel through a chunk of this hydrogel in a lab similarly to the way they travel through rock or ice formations in the field. With a high-speed camera and a dye that shines under laser light, the scientists filmed a fracture traveling through a brittle hydrogel in 3-D, seen in the video at bit.ly/Eos_3d-fracture.

"I don't think anyone else has a 3-D movie of a fracture," said Will Steinhardt, a geophysicist at Harvard University. Steinhardt presented the work in December at AGU's Fall Meeting 2018 in Washington, D. C.

## Lights, Camera, Fracture

As a whole, each fracture Steinhardt studies looks almost like a flattened M&M candy or a bulging coin. Slicing an M&M-shaped fracture lengthwise gives a 2-D view of the pattern of small cracks, called step lines, in the whole fracture. Depending on how many of these smaller cracks are in the sliced area, the surface of the slice may be rough or smooth.

Steinhardt and his graduate adviser Shmuel Rubinstein, an applied physicist at Harvard, wanted to see how a fracture travels in three dimensions and how the interactions of its step lines form rough surfaces. They chose to study fractures in the transparent brittle hydrogel so they could photograph what happened inside the material as it fractured.

The researchers put a small dent in one side of a chunk of hydrogel to mimic a natural flaw where a fracture might start, like a slight tear in a sheet of paper or an existing crack in rock. They filled the small dent and a connected tube with a dyed fluid that glows under laser light.

When they applied pressure to the fluid in the tube, the hydrogel fractured, with the fluid fanning outward from the initial flaw, as seen in the pictures above.

They shone laser light into the gel to make the fluid glow and snapped photos of an area about the size of a small human fingernail with a high-speed camera at about 1,000 times per second. By combining these images into a video, the researchers captured the

changing shape of the fracture and its pattern of step lines in all their 3-D glory.

### Behind the Scenes of Fracture Patterns

The researchers found that they could make more step lines appear in the fracture—and thus create a rougher fracture surface—in one of two ways. Both involved changing properties of the hydrogel.

In the hydrogel, a network of large molecules called polyethylene glycol polymer holds the gel's water in place. Adding another chemical compound called glycerol to the hydrogel increased the total number of large molecules in the gel and made more of the small cracks appear, the scientists found.

They also tried infusing the hydrogel with tiny glass beads that were smaller than the width of a typical human hair. Adding beads also increased the number of step lines that formed in a fracture.

The researchers think that both methods may create more step lines by giving the gel more flaws—the scientists term these "discontinuities"—where the cracks can start.

From their detailed records of the small cracks forming in a fracture over time, the scientists began to figure out what patterns form when two cracks meet at a point. The shape and orientation of two cracks seem to determine whether only one crack stretches past the meeting point, for example, or whether the cracks might simply cross each other.

It's a "first step in building a comprehensive theory for roughness," Rubinstein said. By understanding what happens when two step lines meet, the researchers can start piecing together a bigger picture with many step lines interacting to create rough fracture surfaces.

"It's a new way to study this," said structural geologist Randy Williams of the University of Wisconsin–Madison. He added that he'd be interested in seeing a comparison to actual rock.

Steinhardt said that comparing their lab-made hydrogel fractures to natural rock fractures is challenging. Many factors affect surface roughness in real-world rocks, making them difficult to compare to controlled experiments. To do a similar study of the relationship between the number of discontinuities in a material and the number of step lines in a fracture, they'd need a range of rocks whose graininess is well understood.

The step to using actual rocks is something "we have wanted to do for a long time," Steinhardt explained, "but are not exactly sure how."

By **Erika K. Carlson** (erkcarls@ucsc.edu; @erikakcarlson), Science Communication Master's Program, University of California, Santa Cruz

# Lawn Sprawl Produces One Fifth of Los Angeles's $CO_2$

*A view of the Los Angeles Country Club golf course. Credit: iStock.com/trekandshoot*

The Los Angeles Basin in California, home to more than 18 million people, is often pegged as a car-centric—and, accordingly, polluted—urban sprawl. But researchers studying carbon dioxide ($CO_2$) emissions in the second-largest metropolitan area in the United States recently found a surprise: Roughly 20% of the $CO_2$ over Los Angeles derives from biogenic sources such as the decay of plant material.

What's more, the area's natural green spaces, like its grasslands and forests, probably aren't the origin of this unexpectedly large signal, the new research shows. Instead, the biogenic emissions likely derive from the region's managed landscapes like lawns and golf courses. Scientists determined this by studying seasonal variations in $CO_2$ levels over the course of 18 months.

### Old Carbon

For this study, John Miller, a carbon cycle scientist at the National Oceanic and Atmospheric Administration in Boulder, Colo., and his colleagues collected samples of air from around the Los Angeles Basin. Working in collaboration with the Megacities Carbon Project, they used accelerator mass spectrometry to analyze the carbon-14 ($^{14}C$) content of the air samples.

This isotope is present in $CO_2$ of biogenic origin like recent plant decay but not in $CO_2$ emitted by factories, power plants, and cars. That's because the carbon in coal, natural gas, and petroleum is millions of years old, said Miller. "All of the carbon-14 in them has decayed."

### A Green Surprise

Given the amount of $^{14}C$ they measured, Miller and his collaborators deduced that roughly one fifth of the carbon dioxide in the Los Angeles Basin comes from the biosphere. The remaining 80% comes from the combustion of fossil fuels.

Such a high biogenic fraction was a surprise. "We were expecting to see a more fossil fuel–dominated signal," said Miller.

Fluctuations in the $^{14}C$-containing carbon dioxide furthermore exhibited a perplexing seasonal trend: a spike in the net uptake of $^{14}C$ around July. This spike is consistent with the timing of the peak growth of the region's managed urban landscapes, like its golf courses and lawns, which receive regular watering.

> "We were expecting to see a more fossil fuel–dominated signal."

By contrast, the grasslands and forest ecosystems of Southern California, a relatively dry Mediterranean-like climate, exhibit a carbon uptake peak in early spring. These results were reported in December at AGU's Fall Meeting 2018 in Washington, D. C.

"This is a novel piece of work and is very relevant to the study of the urban carbon cycle," said Anna Karion, an atmospheric scientist at the National Institute of Standards and Technology in Gaithersburg, Md., who was not involved in the research. "More of these kinds of measurements need to be made across the country."

Miller and his colleagues are now starting to take similar measurements in the Washington, D. C./Baltimore area, and they also plan to expand their monitoring nationwide.

There's a lot more to do, Miller said. "We're just starting to learn about carbon balance in cities."

By **Katherine Kornei** (hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist

# Uranus and Neptune Should Be Top Priority, Says Report

*NASA's Voyager 2 snapped this picture of a crescent Neptune on 31 August 1989 during the spacecraft's flyby of the planet. Voyager 2 is the only mission to have visited Uranus or Neptune. Credit: NASA/JPL-Caltech/Kevin M. Gill*

Launching a small orbiter with an accompanying atmospheric probe to the solar system's ice giants, Uranus and Neptune, should be a top priority for NASA in the coming decade, say planetary scientists who conducted a review of potential missions to do so. Beyond being scientifically valuable, such a mission to each planet is technologically feasible, the team said. Voyager 2 visited the ice giants in the 1980s, the only craft ever to do so.

"It is important that the next mission to an ice giant study the entire system: the planet itself, the atmosphere, the rings, the satellites, and the magnetosphere," Mark Hofstadter, a planetary scientist at NASA's Jet Propulsion Laboratory in Pasadena, Calif., told *Eos*. Hofstadter is a coauthor of the June 2017 report that reviewed the mission potential for Uranus and Neptune. "Every component of an ice giant system challenges our understanding of planetary physics in a unique way," he said.

Here are five key questions the team wants to answer with dedicated missions to Uranus and Neptune. The team presented its findings and the state of ice giant science in December at AGU's Fall Meeting 2018 in Washington, D. C.

### 1. Why Is Neptune Too Hot and Uranus Too Cold?

Uranus and Neptune, being about the same size, should release heat leftover from planet formation at similar rates. But that's not what Voyager 2 found.

"Jupiter, Saturn, and Neptune all emit more energy than they get from the Sun," Hofstadter explained. "Uranus stands out: It's the only one that's not releasing much internal heat." It might be a result of the impact that tipped the planet onto its side, a result of differences in internal convection, or something else entirely, he speculated.

> "Every component of an ice giant system challenges our understanding of planetary physics in a unique way."

"If they're both the same type of planet… then they should be similar to each other, and why they're not makes no sense," Amy Simon, a senior scientist for planetary atmospheres research at NASA Goddard Space Flight Center in Greenbelt, Md., and a coauthor on the report, told *Eos*. "Understanding the interior structure is going to be pretty critical."

### 2. What Are Ice Giants Made Of?

Unlike Jupiter or Saturn, the ice giants "appear to be enriched in heavy materials, that is, elements heavier than hydrogen and helium," said Leigh Fletcher, a senior research fellow in planetary science at the University of Leicester in the United Kingdom who was not involved in the study. Past research has shown that the planets also contain significant amounts of ion-rich water. "How much is rocky and how much is icy is an open topic of debate. Why did they end up this way?" he asked.

Pinning down the planets' compositions would reveal where in the solar system they formed, Simon explained. It may also improve our understanding of planets of a similar size in other solar systems.

"These are the main sizes of planet that we're seeing in extrasolar planet systems," Simon said, "so the fact that we understand them so little in our own solar system is problematic for interpreting them in other solar systems."

### 3. Why Are the Rings of Ice Giants Narrow or Clumpy?

Uranus's 13 rings are narrow and densely packed, a formation that needs "shepherding moons" to keep it gravitationally stable, Hofstadter explained. Uranus seems to be missing the moons to do that. Moreover, he said, the particles in Uranus's μ ring look like those of Saturn's E ring, which is generated by the plumes of Enceladus. The moon associated with the μ ring, called Mab, lacks plumes, he said, so this ring's origin is yet unknown.

Neptune's rings raise different questions. "Before the Voyager encounter," Hofstadter said, "we didn't know Neptune had complete rings. Once we got closer and got a better look, we could see that it had complete rings but that they were very clumpy."

"Certain portions of Neptune's rings are much denser than others, and the details of

*Uranus (left) and Neptune's dark spot and bright streaks (right) imaged by NASA's Voyager 2 in 1986. Planets are not to scale. Credits: left, NASA/JPL-Caltech; right, NASA/JPL*

how and why that happens are not clear," he said.

### 4. What Is the History of Ice Giants' Moons?

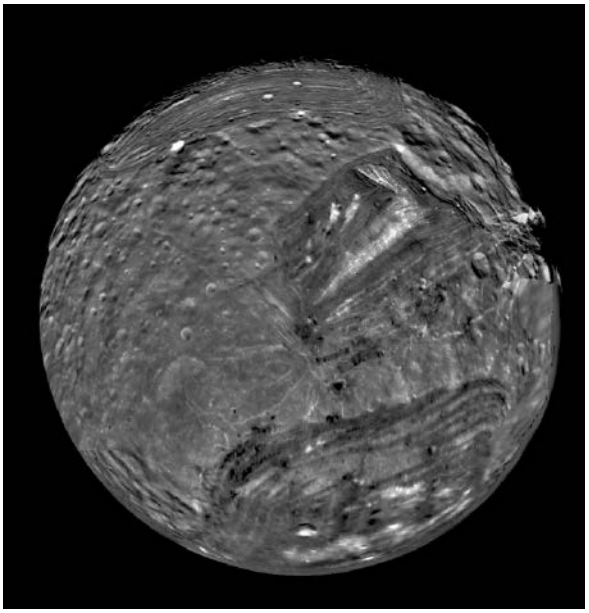
"Neptune's biggest moon, Triton, is basically a captured Pluto," Hofstadter explained. Scientists think that Triton may have formed in the Kuiper Belt beyond Neptune's orbit. Geysers and dark streaks on the moon's surface suggest that it may have a subsurface ocean similar to that of Jupiter's Europa or Saturn's Enceladus.

"We'd love to get a more careful look at Triton and see why it's active, learn about what happens when you gravitationally capture a relatively large body, and compare it to Pluto," Hofstadter said.

Regarding a possible Triton lander, Simon said that "landing on the surface of a body that we don't know much about is tough, particularly in knowing where it's safe to land." Nonetheless, "there's a lot you could learn if you could get down there."

Uranus's smallest and closest moon, Miranda, "looks like you took pieces of different puzzles and put them together," Hofstadter said. "There are blobs of very different looking regions on the surface. There's been some wild geology on this moon."

Its moon Ariel, on the other hand, might have cryovolcanism. "On these moons, water ice behaves almost like rock on the Earth, where it can be melted in the interior and flow or extrude onto the surface," he said. "There's some evidence for that kind of water volcanism on Ariel."



*The south pole of Uranus's moon Miranda, imaged by NASA's Voyager 2. Credit: NASA/JPL/USGS*

### 5. Why Are Ice Giants' Magnetic Fields So Complex?

Uranus's and Neptune's magnetic fields are relatively complex when compared with those of the gas giants, Hofstadter explained. This complexity may suggest that the deep-interior process generating the fields actually happens closer to the surface than it does on Jupiter or Saturn, he said. Sending a probe to the planets could help paint a clearer picture, he added.

"The brief Voyager flybys suggested these two planets had very irregular magnetic fields," said Fran Bagenal, a professor of astrophysical and planetary science at the Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder. Bagenal, who was not involved with this study, said that a mission to these planets is critical to understanding how the planets generate magnetic dynamos in the water layers of their deep interiors and produce such irregular magnetic fields.

Moreover, "how the solar wind couples to the ice giants' magnetic fields is very different" from any other planet in the solar system, Hofstadter said, primarily because the fields themselves are so misshapen. For example, each planet's field is severely tilted from its axis of rotation and is offset from the center of the planet. Also, "the planets' magnetic fields change their orientations relative to the solar wind in a way that no other planet does," he said. Studying these fields up close could prove to be good tests for our models of planetary magnetic fields and the solar wind, Hofstadter added, which would benefit heliophysics.

> "Is one of the ice giants more important than the other to study? Uranus or Neptune?"

### Uranus or Neptune?

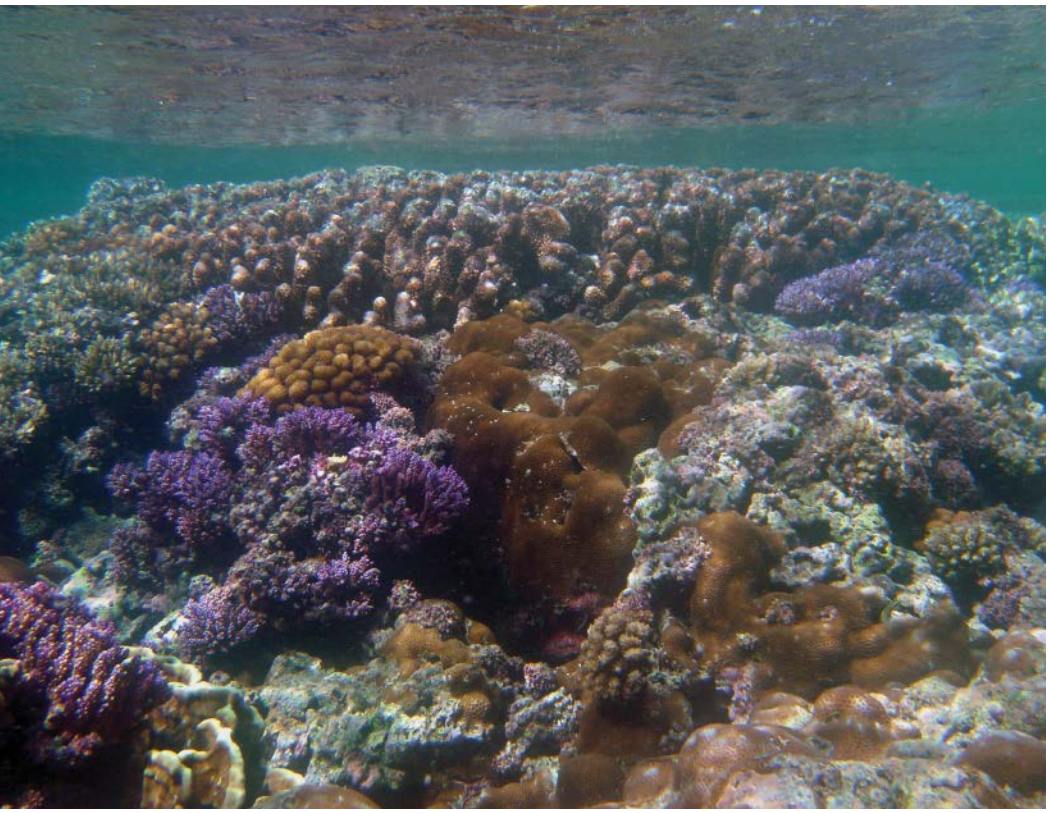
Which planet should get a mission? For all that Uranus and Neptune are grouped together into the category of ice giants, they are remarkably different worlds, Simon explained.

An ice giant mission would need to be small enough to launch in a timely fashion but not so small that it can't answer its key science questions, she said. "It's a little bit of, Do you put your eggs in multiple baskets not knowing if you get more than one basket?" she said.

"In our study," Hofstadter said, "we asked ourselves the question, Is one of the ice giants more important than the other to study? Uranus or Neptune? And we said, no. If you want to learn about an ice giant, Uranus and Neptune are equally valuable. But while they are equally valuable, they are not the same. Each can teach us things that the other cannot."

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

# Coral Reef Video Game Will Help Create Global Database



*A shallow coral reef at low tide near the Mariana Islands and Guam. Credit: NOAA, David Burdick*

An interactive video game currently in development will teach players to classify corals using satellite images of reef systems around the world. The players' results will be used to train an algorithm that will classify corals automatically and create a global data set of reefs.

"Aquatic ecosystems, particularly coral reefs, remain quantitatively misrepresented by low-resolution remote sensing," Ved Chirayath, director of the Laboratory for Advanced Sensing (LAS) and a research scientist at NASA Ames Research Center, told *Eos*. Chirayath, who leads the game development team, said that the lack of a global reef survey is largely because of how ocean waves distort and attenuate reef images taken by satellites.

Chirayath and his team are working to solve this problem with a video game for tablets called Neural Multi-Modal Observation and Training Network, or NeMO-Net. The game will allow players to identify and classify real coral reef systems around the world from satellite images. The results will train a machine learning to classify corals automatically and create a global data set of classified coral reefs.

### Peering Beneath the Waves

"For how important these ecosystems are, we know very little about where they are, what their breakdown is, and how they're changing with time," said Jarrett van den Bergh, a research scientist and graphics engineer at LAS who demonstrated the game design in December at AGU's Fall Meeting 2018 in Washington, D. C.

Results will train a machine learning to classify corals automatically and create a global data set of classified coral reefs.

Most reef systems that have been studied have been mapped in detail only with on-site field campaigns, he said, which is difficult to do for isolated reefs. Remote sensing of coral reefs by satellites or drones, which can target larger areas more quickly, is often hindered by how the ocean distorts the view of what's below, he added. New technologies, however, are helping the team get around this problem.

Chirayath pioneered one technique he calls fluid lensing. Fluid lensing removes the distorting effects of flowing water by characterizing how the water refracts light and reversing the distortion. This correction allows clear imaging of what's beneath the waves.

To expand the mapping of reef systems, the team developed a high-performance camera that applies fluid lensing to clear up remote sensing data: FluidCam. By attaching FluidCams to small drones, the team can image thousands of corals down to millimeter scales and create 3-D images of them. This technology will let the team "determine coral reef ecosystem makeup globally at unprecedented spatial and temporal scales," Chirayath said.

Currently, FluidCams are mounted on two drones that have been mapping shallow coral reef systems in the South Pacific for the past 2 years. The team combined these FluidCam data with measurements from NASA's Coral Reef Airborne Laboratory (CORAL) satellite and lower-resolution satellites to create a combination of 2-D and 3-D pictures of thousands of corals.

### Coloring Corals

The research efforts have created a wealth of images that now need to be processed. But rather than a few scientists poring over images one by one, Chirayath and colleagues had an idea. What if classification could be crowdsourced, through an interactive game?

NeMO-Net aims to do exactly that. In the game, players start on a research boat floating above a coral reef. They complete tutorials and learn to map the boundaries and textures of a coral, categorize it, and navigate around the reef. After reaching a certain

Players map the boundaries and textures of a coral, categorize it, and navigate around the reef.

accuracy threshold, they can explore the reef, classify the corals they see, and evaluate other users' coral classifications.

To classify a 2-D or 3-D image, players trace the outlines of seafloor components—rock, sand, mounding coral, or branching coral—with different colors using an in-game drawing feature controlled by touching with a finger or stylus. Once a piece of coral is classified by a player, the information is used as training data for a machine learning algorithm that will classify corals automatically.

A key behind-the-scenes aspect of the game is the frequent assessment of a player's accuracy in classifying corals, van den Bergh said. Sprinkled throughout the game are images that have already been classified by experts. Occasionally comparing a player's classification with those of experts helps the researchers weight the results on the basis of a player's accuracy. Moreover, a player needs to maintain a high level of accuracy to continue playing and progress through the game, van den Bergh explained.

A player's avatar is a reef animal. As players classify more corals and improve their accuracy, their avatar advances up the coral reef food chain, from a plankton to a clown fish and beyond. When a player levels up, old avatars are left behind to populate the reef with vibrant marine life.

### Toward a Global Coral Data Set

NeMO-Net, which is still in development, currently includes data from reefs near Guam, American Samoa, and Western Australia. Last month the team began a mapping campaign of Puerto Rico's reefs and will add those data to NeMO-Net. It plans to release NeMO-Net as an iPad game to scientists soon and to the public later this year.

Until then, you can preview one of the 3-D corals that will be included in the game in the interactive system at bit.ly/Eos_interactive-coral. You can click the image to rotate, zoom in on details, and add coloration and layers to the coral to explore it in detail.

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

# Catching Oklahoma's Tiny Tremors in the Act

*Pump jacks in Oklahoma extracting oil. Wastewater associated with this extraction gets injected back into the ground, a process that can induce earthquakes. Credit: J Pat Carter/Getty Images Sport/Getty Images*

Over the course of 1 month in the spring of 2016, scientists at the U.S. Geological Survey (USGS) detected about 15,000 tiny earthquakes in an area in northwestern Oklahoma about the size of New York City (about 800 square kilometers). These tiny earthquakes all had magnitudes of less than 3.

Many of the tremors were too small to feel, but when the scientists analyzed the quakes, they got a more detailed picture of what happens when petroleum operations dispose of their wastewater by reinjecting it into the ground. They already knew that the resulting seismic activity is the major cause of the increase in earthquakes in the central United States, but the mini earthquakes allowed them to track the seismic activity in time and space in much greater detail. Sara Dougherty, a former postdoc at the USGS who is now at the California Institute of Technology, presented these findings in December at AGU's Fall Meeting 2018 in Washington, D. C.

Oil drilling operations extract from the ground a mix of petroleum, salt water, and anything else that gets carried along. After the petroleum is filtered out, the wastewater—hundreds of millions of barrels each year—gets reinjected into the ground.

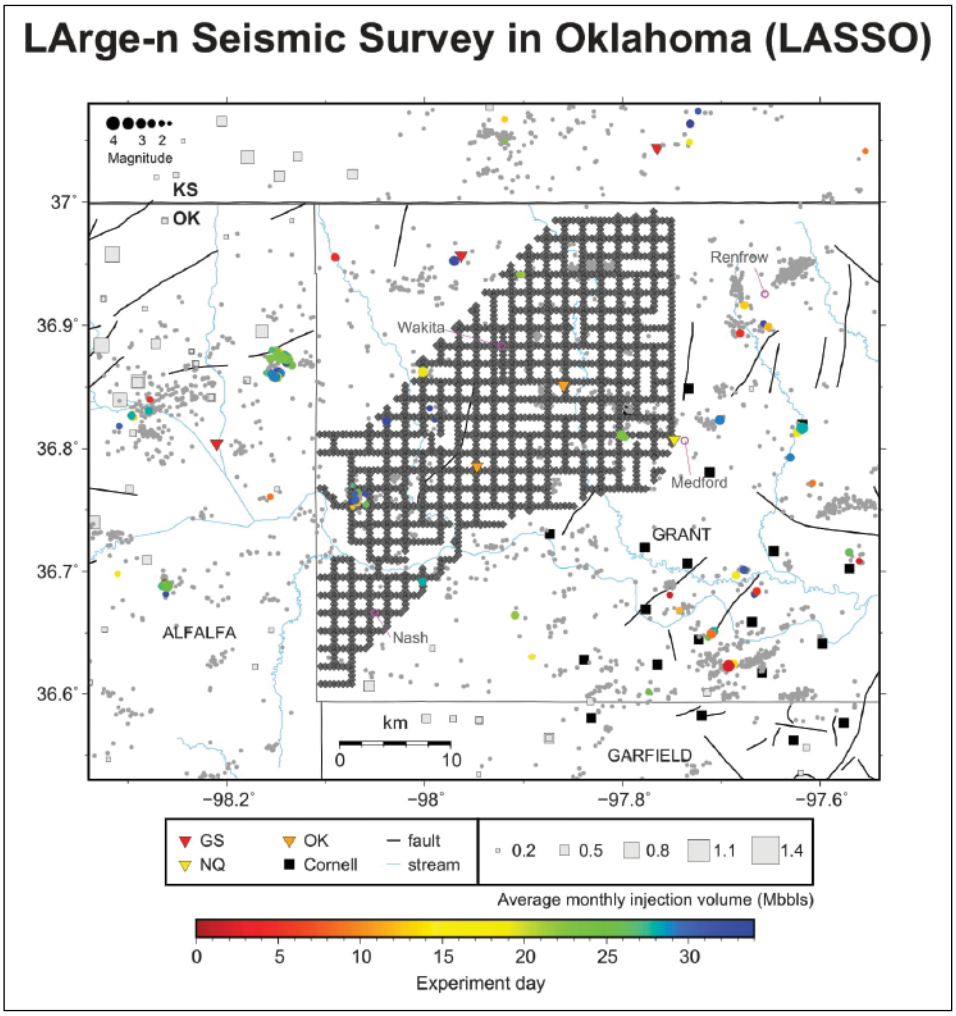
More than 10,000 reinjection wells in the state penetrate Earth's crust, reaching layers of porous rock such as limestone or sandstone. Through these wells, wastewater—salty, oily water that may contain toxic contaminants—is forced into the soft rock, causing shifts in the surrounding layers and prying apart existing faults. The latter can trigger quakes, a phenomenon known as induced seismicity.

All of this means that Oklahoma residents have been standing on increasingly shaky ground. Between 2010 and 2015, the annual number of earthquakes in Oklahoma surged from 41 to 903.

Between 2010 and 2015, the annual number of earthquakes in Oklahoma surged from 41 to 903.

### Digging into the Details

Dougherty wanted to see in more detail what seismic activity looked like after a wastewater injection event, but the existing earthquake data collected by the U.S. Geological Survey




*Researchers used a grid-shaped array of 1,800 sensors covering an area of about 800 square kilometers to record tremors that were mostly too small for people to feel. Each sensor is shown here as a gray diamond. Credit: Sara Dougherty*

recorded only earthquakes of magnitude 3 and above. A magnitude 3 quake is strong enough to rattle dishes in your kitchen cabinet but still small enough that some observers might mistake it for a truck passing by on the highway. These earthquakes definitely indicated a trend in induced seismicity, but Dougherty wanted more information about earthquakes smaller than magnitude 3.

"What we were trying to do was to get into details," she said. "We have all these really, really tiny earthquakes that no one had looked at before, so we decided to do that."

Using an array of more than 1,800 sensors laid out over street grids in Grant County, on the Oklahoma–Kansas border north of Oklahoma City, Dougherty and her coauthors created their own catalog of around 15,000 microearthquakes that rattled the area in the spring of 2016.

The sensors, white cylinders about the size of coffee cans, tracked seismic activity for a month. Normal earthquake detection systems might use fewer than 100 instruments, but the team's study used input from 1,800: *N* equals 1,800, in statistical lingo.

"Our large-*N* [sensor] array has served as a sort of test case for what can be accomplished with such a large number of sensors and what kind of data we can get out of it," Dougherty said.

With the information they gathered, the researchers were able to look in more depth at how earthquakes traveled out from a specific site and to map clusters that occurred over the month.

Zach Rosson, a graduate research assistant at the Oklahoma Geological Survey who also studies induced seismicity in Oklahoma, said that the new catalog of microearthquakes is a valuable resource for learning about earthquake behavior.

"The earthquake catalog built up in Oklahoma for the past decade has been very ad hoc," he said. "We lose out on a lot of information about small earthquakes, and small earthquakes, particularly the ones below magnitude 2, are very important to discerning how earthquakes cluster and how they evolve in space in time."

## Earthquake Sweet Spot

The researchers' data allowed them to track waves of tiny quakes as they radiated out from certain points. These, Dougherty said, might be wastewater disposal sites or just small fault lines.

During a microearthquake cluster, quakes started out at shallower depths and then moved deeper into Earth. Over the next 24 hours, they also migrated farther away from the site. The following 24 hours were generally quiet. Then quakes started up again.

"You have this 24-hour sweet spot—a burst of activity in 24 hours followed by a 24-hour pause, then another burst of activity in 24 hours—and then it goes back to the background rate," she said.

During the experimental period, there were no recorded hydraulic fracturing events—the petroleum companies were not injecting fluids into the ground to extract oil or gas. This means that these results are most likely tied to wastewater disposal. The next steps, she said, are to see whether the tiny quakes are, in fact, the direct result of wastewater injection.

"One thing we're focusing on now is identifying any characteristic patterns to the sequences of earthquakes that we've identified and exploring if these patterns can be correlated to any specific wastewater injection or oil and gas production behavior," she said.

## Changing Policies

In 2016, after studies revealed the extent of the human activity–induced earthquakes in Oklahoma, policy changed to tighten regulations on wastewater injections. Still, seismicity levels remained high.

Dougherty said that the new level of detail achieved in the team's research could further influence oil and gas regulations in the area. For example, she noted, the work can help pinpoint wells that trigger high rates of microearthquakes.

"We were able to find new pockets of seismicity that [the USGS] was not able to pick up on the regular network," she said. "They may not know that these wells are also causing earthquakes; [they] are just not big enough. So maybe it's something they should watch more closely."

By **Eva Frederick** (evaf@mit.edu), Science Writing Student, Massachusetts Institute of Technology, Cambridge

# Arctic Undergoing Transition Unprecedented in Human History

*The Arctic Report Card outlines vast changes taking place in the region. Pictured, the icebreaker USCGC* Healy *heads through ice in the Arctic Ocean. Credit: Devin Powell, NOAA*

The Arctic continues to undergo dramatic change due to atmospheric and ocean warming, and the region "is no longer returning to the extensively frozen region of recent past decades," according to the 2018 Arctic Report Card, issued by the National Oceanic and Atmospheric Administration (NOAA) at AGU's Fall Meeting 2018 in December.

"The Arctic is experiencing the most unprecedented transition in human history," said Emily Osborne, lead author of the report and manager of NOAA's Arctic Research Program. "In 2018, the effects of persistent Arctic warming continue to mount. Warming air and ocean temperatures continue to drive broad, long-term change across the region, pushing the Arctic into uncharted territory."

The report states that "new and rapidly emerging threats are taking form and highlighting the level of uncertainty in the breadth of environmental change that is to come."

Programs to conduct long-term monitoring "are critical to understanding baseline conditions and the magnitude and frequency of the changes that are being delivered to the Arctic," the report continues. "Such understanding is central to the livelihood of communities that call the Arctic home as well as the rest of the globe which is already experiencing the changes and implications of a warming and melting Arctic."

> Older sea ice declined by 95% between March 1985 and March 2018.

Here are some of the main findings in the report:

- In 2018, surface air temperatures in the Arctic continued to warm at more than twice the rate of the rest of the globe. The year 2018 was the second warmest year on record in the Arctic since 1900; its temperature of 1.7°C above the long-term average of 1981–2010 is second only to 2016. Arctic air temperatures for the past 5 years—2014–2018—have exceeded all previous records since 1900.
- Arctic sea ice cover, which reached a winter maximum value extent of 14.48 million square kilometers on 17 March 2018, was the second-lowest maximum extent in the 39-year record, following 2017. The 2018 extent was 7.3% below the 1981–2010 average, and the past 4 years—2015–2018—are the four lowest maximums in the satellite record.
- Older sea ice, which tends to be thicker and more resilient to changes in atmospheric and oceanic heat content compared with younger and thinner ice, declined by 95% between March 1985 and March 2018. In 1985, ice 4 or more years old composed 16% of the Arctic ice pack (2.54 million square kilometers); in March 2018 the older ice composed 0.9% of the ice pack (0.13 million square kilometers).
- For nearly all of the 2017–2018 Bering Sea ice season, the ice extent was at a record low. With reduced sea ice coverage and early breakup of ice, the effect on ocean primary productivity was profound, and productivity levels in the Bering Sea region sometimes were 500% higher than normal.
- The warming Arctic Ocean may be experiencing an increase in the extent and magnitude of toxic algal blooms, which pose threats to human and ecosystem health.
- Increased atmospheric warmth in the Arctic "results in a sluggish and unusually wavy jet-stream that coincided with abnormal weather events in both the Arctic and mid-latitudes." Extreme weather events coincident with deep waves in the jet stream include the heat wave at the North Pole in autumn 2017, severe winter storms in the eastern United States in 2018, and an extreme cold outbreak in Europe in March 2018.
- Although some impacts of climate change on extreme weather are clear—more severe heat waves, more frequent heavy-precipitation events, and more intense droughts—the understanding of other less direct influences is less clear. "The role of a rapidly warming and melting Arctic is one of these factors that challenges present computer modeling capabilities and understanding of atmospheric dynamics," the report states. "Exactly how the northern meltdown will 'play ball' with other changes and natural fluctuations in the system presents many questions that will keep scientists busy for

*A Teshekpuk caribou in the National Petroleum Reserve in Alaska. The report card states that the abundance of herds of migratory caribou and wild reindeer in circum-Arctic tundra areas has declined by 56% in the past 2 decades. Credit: Bob Wick, BLM*

years to come, but it's becoming ice-crystal-clear that change in the far north will increasingly affect us all."

- The report card calls marine microplastics an "emerging threat" in the Arctic, and it notes that a recent global survey shows that the Arctic Ocean has higher concentrations of microplastics than any other ocean basin in the world.
- The abundance of herds of migratory caribou and wild reindeer in circum-Arctic tundra areas has declined by 56% in the past 2 decades, dropping from 4.7 million to 2.1 million animals. Five herds in the Alaska-Canada region have declined by more than 90% and show no signs of recovery. This decline threatens the food security and culture of indigenous people, according to the report. Although it is normal for herd numbers to vary over decades, some herds currently have all-time low populations since reliable record keeping began, the report states.

The report card, which also looks at trends in terrestrial snow cover, the Greenland ice sheet, and tundra greenness, among other environmental changes, is a peer-reviewed report that was compiled from research by 81 scientists working for governments and academia in 12 countries.

The report card calls marine microplastics an "emerging threat" in the Arctic.

### Briefing President Trump?

NOAA acting director Tim Gallaudet said at the briefing that "the report card summarizes some very significant changes." In response to a reporter's question, however, Gallaudet acknowledged that despite concerns about the Arctic, neither he nor any other senior NOAA official had briefed President Donald Trump about climate change or the changes in the Arctic since Trump took office on 20 January 2017.

By **Randy Showstack** (@RandyShowstack), Staff Writer

# Preparing Graduate Students for STEM Careers Outside Academia

*EMPOWER NRT faculty member Chris Junium shows students how to test water quality in Fayetteville Green Lake near Syracuse, N.Y., during a domestic field course on water and energy. Credit: D. McCay*

Current graduate programs in science, technology, engineering, and mathematics (STEM) prepare students for a career that most of them will never find themselves in. These graduate programs have traditionally been apprenticeships that prepare students to become researchers at academic institutions [*Hancock and Walsh,* 2016]. However, more than 50% of all doctoral degree holders do not work in academia or even do research as their primary job (Figure 1).

Given these trends, a new report by the National Academies of Sciences, Engineering, and Medicine recommends adjusting our mind-set to recognize that many of our most talented graduates will such enter career sectors as industry and government [*National Academies of Sciences, Engineering, and Medicine,* 2018]. Ideally, programs should encourage students to explore such diverse career options by allocating the time and resources needed to pursue course offerings designed for career exploration, as well as seminars, internships, and real-life professional experiences.

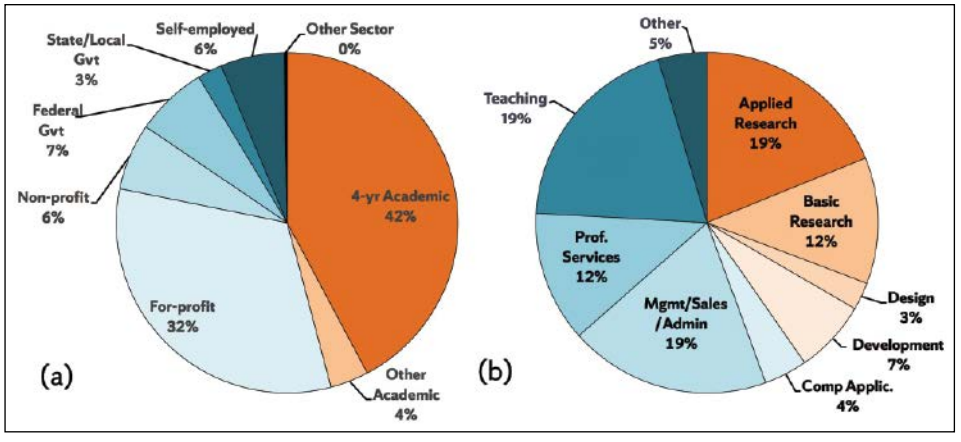



*Fig. 1. The percentages of employed doctoral degree holders in all fields of science and engineering that (a) work in different sectors and (b) engage in different primary work activities* [NSF, *2013b*].

With this report as a backdrop, we offer recommendations that have worked in our experience to build a program that prepares students for diverse careers after graduating. Our recommendations are derived from experience developing the Education Model Program on Water-Energy Research (EMPOWER), one program in the first cohort of National Science Foundation Research Traineeship (NRT) programs at Syracuse University.

## Employment Trends and Opportunities

A 2013 study by the National Science Foundation (NSF) suggests a disconnect between skills desired by employers and professional development provided in graduate programs [*National Science Foundation (NSF),* 2013a]. Employers from diverse sectors expect STEM doctoral degree holders to have expert content knowledge, strong communication skills, a multidisciplinary focus, entrepreneurial and project management skills, a sense of professionalism, and the ability to apply knowledge across a broad context [*Council of Graduate Schools and Educational Testing Service,* 2012]. Despite employer expectations, the NSF study indicates that today's STEM graduate programs still leave critical gaps in skills focused on science communication, preparation for nonacademic careers, broadening the societal relevance of research (e.g., engaging nonscience audiences, policy makers, and stakeholders through outreach), and entrepreneurship.

To help fill these gaps, NRT has funded more than 50 programs since 2014 that emphasize interdisciplinary research and are uniquely focused on producing STEM professionals prepared for research-related careers within and outside of academia. Our program addresses the connections between hydrocarbon energy production, use, and effects and water systems.

Within water and energy fields, many careers outside of academia require advanced research-based degrees, and employment trends are typical of trends across science and engineering. Fewer than half of geoscience doctoral graduates are hired by universities; most work in oil and gas (22%), research institutes (21%), and the federal government (14%) [*American Geosciences Institute,* 2014].

We know that STEM Ph.D. graduates explore for natural resources, advise policy makers, run industry labs, manage environmental restoration efforts, and more. With


*Fig. 2. Sequence of training elements that are integrated with traditional, research-based graduate degree programs to prepare students for multiple career pathways in STEM.*

this in mind, how do we help students develop the skills they need to navigate the diverse career paths they eventually may take?

## Principles for Developing Graduate Programs for Multiple Career Pathways

Pulling from our NRT experience, we suggest five guiding principles for adapting research-based STEM graduate programs to address training gaps.

*1. Allow programs to be student designed and highly individualized.* There is no one-size-fits-all program that meets the needs of all students. Career opportunities are simply too diverse. Rather, students need to design their program to meet their anticipated needs. Through the process of identifying and evaluating available career trajectories, students take ownership of their career preparation [*St. Clair et al.*, 2017].

*2. Provide exposure to careers in STEM early and often.* As one NRT student noted at a recent career seminar, "It's not that I don't know what I want to do—it's that I don't know what I can do." Programs need to develop mechanisms to improve student awareness of career pathways in their field. It is critical to expose students to the full spectrum of possibilities early in their program to maximize the time and opportunities for skills training.

*3. Create a program culture that values professional development.* It is essential to weave professional development into the start of a student's graduate program. Emphasis on science communication, interdisciplinarity, negotiation, professionalism, and the ability to apply disciplinary knowledge across a broad context cannot begin too early. Students learn the value of such training when they have time and opportunities to integrate professional development and career path experiences into their program of study. Institutions can demonstrate the importance they place on such training by providing assistantship support during internships, offering seed grants for networking events, and hosting professional development workshops. With strong program support, students can be more effective in their career development and job search process [*St. Clair et al.*, 2017].

*4. Build a strong sense of community.* As soon as a graduate student group has been established, it is imperative to bring students together often. Programs should foster continuity across disciplinary boundaries and between cohorts of students (i.e., incoming and senior). Community building is the first stage of professional network development and a critical component of establishing a culture that values career preparation and student-centered programming.

*EMPOWER NRT students Changcheng Pu and Robin Glas at work in the program's foundational seminar. Credit: D. McCay*

*5. Don't reinvent the wheel.* STEM graduate programs can leverage a wealth of existing resources. Many campuses have programs designed to support career planning and professional development. We have found that participation in these programs fosters student awareness of the myriad of campus resources available. Such programming provides the foundation for students to seek and tailor resources available to support their individual career interests [*St. Clair et al.*, 2017]. Programming should facilitate personal connections between the students and the campus services available to meet their needs.

## A Model Test Bed of Best Practices

We developed the above guiding principles on the basis of experience creating a graduate program for students to study the water-energy nexus and prepare for a range of careers. The program has many elements, but the three fundamental components include a foundational seminar, individualized professional development coursework, and a capstone career path experience (Figure 2).

### Foundational Seminar

We found that a required semester-long foundational seminar course that brings together the student cohort every week is a critical component of changing program culture, establishing a sense of community, and developing student ownership and agency. The foundational seminar involves students from multiple disciplines and is required in the first four semesters for Ph.D. students (two semesters for master's students). Students must participate continuously, which integrates multiple cohorts of students at multiple stages in their program. These cohorts pass down and advance institutional knowledge and program culture.

Programming should facilitate personal connections between the students and the campus services available to meet their needs.

The foundational seminar serves as an "interdisciplinary discussion space" [*Hancock and Walsh*, 2016], and it allows professional development, career discussion, and exposure to campus resources to begin early and be repeated throughout a student's graduate pro-

gram. We feature different career options by hosting nonacademic speakers, offering career panels, and discussing the future of STEM careers in relevant disciplines.

Our program provides training in the scientific enterprise through experiential learning around peer review, grant proposal review, and data visualization. We also invite on-campus professionals to the seminar for targeted training and to establish one-on-one connections with students. We regularly solicit student feedback, enabling students to take ownership of the seminar program and ensuring that the seminar meets the needs of each cohort. There is no formulaic structure for the seminar that works every semester or for every student, so the format and content are constantly changing in response to the dynamic student group.

*EMPOWER NRT students Amanda Campbell, Alaina Hickey, and Kyle Blaha collect water samples on Fayetteville Green Lake, during a regional field course on water and energy. Credit: D. McCay*

### Professional Training Specialization

Building on the seminar, students pursue individualized professional training for their careers of interest. By self-selecting coursework in some combination of communication, policy, business, entrepreneurship, law, information technology, and education, students can explore different fields, develop soft skills, and grow their professional network.

We have collaborated with professional schools at Syracuse University to identify appropriate coursework for STEM graduate students that may count toward degree requirements. The coursework is analogous to certificates of advanced study (CAS), although it is highly individualized. Alternatively, students can complete existing CAS programs, such as one in sustainable enterprise (bit.ly/Eos_casse).

### Capstone Career Path Experience

Students are required to obtain experience in career sectors through internships, collaborative site visits at research labs, study abroad, or other opportunities designed to foster scientific knowledge outside of the university [*Hancock and Walsh,* 2016]. Although internships are routinely referenced in this context, we emphasize that career experiences cannot be formulaic or overly prescribed.

We advise that programs not place students in career experiences but, rather, support students as they seek out such experiences via their professional network, career knowledge, and interests. We have integrated professional network building into the program through visiting professional speakers, work with campus career services, workshops, conferences, seed grant opportunities, and coursework.

A number of funding models support career experiences, including supplemental awards from NSF (e.g., the Graduate Research Internship Program, Graduate Student Preparedness Opportunity, and Non-Academic Research Internships for Graduate Students (INTERN), as well as fellowships available through national organizations. Some employers fund internships or paid professional experiences. Our students have pursued career path experiences with the U.S. Geological Survey, The Nature Conservancy, local nonprofits, and academic institutions. Funding, for 1 month to an entire year, provides students the flexibility to pursue career experiences.

### Showing STEM Graduates a Multitude of Career Options

STEM graduate programs have many strengths, but recent data and employment trends suggest a disconnect between graduate training and the skills desired by employers outside of academia. Programs addressing these gaps in career preparation take different approaches, and ongoing evaluation will assess their effectiveness [*Feldon et al.,* 2010]. Our model is to adapt STEM programs through program design to try to meet the needs of today's students and allow for student ownership of their career preparation.

> Programs should support students as they seek out career experiences via their professional network, career knowledge, and interests.

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# Earth's Rich Textures, Seen by Satellite

Have you ever been up in an airplane and looked out the window as you were flying across a mountain range or along a coastline or at night above a major city? These sights can bestow a feeling of wonder and enchantment at the beauty of the world we live in and a sense of awe at how small we are in comparison.

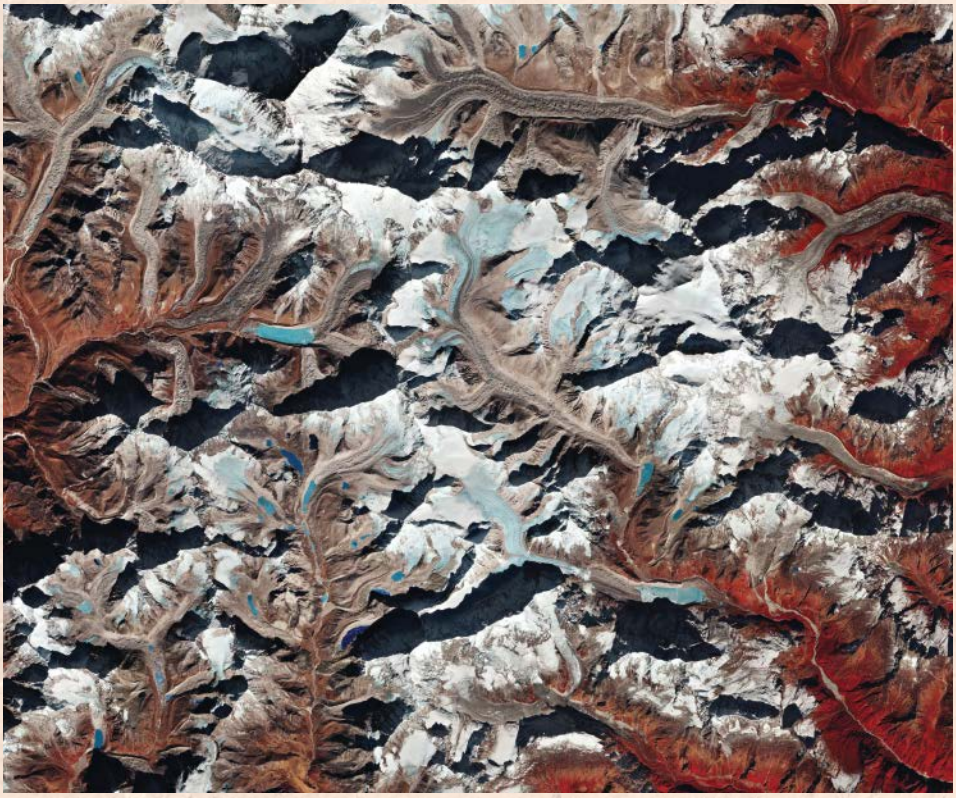
Dozens of Earth-observing satellites capture such views for us to marvel at each and every day. They also gather weather and atmospheric data, report surface changes due to natural disasters, track changes to coastlines and glaciers due to climate change, and monitor pollution levels around the globe.

Here we highlight seven stunning views of Earth taken by satellites in visible or infrared light. These photos do more than showcase the incredible diversity and beauty of planet Earth. They remind us of why we got into geoscience in the first place.

Images like these mesmerize, catching our eye with their subjects' roughness, smoothness, scope, depth, or brilliance of hue. They inspire wonder at what we're seeing, prompt us to question how it formed, and make us yearn to reach out a finger and touch.

See for yourself!

## Mount Makalu and the Himalaya





When seen from above, the soaring peaks of the Himalaya don't seem as towering but are no less breathtaking. This false-color infrared image from Copernicus Sentinel-2B on 9 December 2017 is centered on Mount Makalu, an 8,485-meter-tall mountain nestled on the border between Nepal and China. To find Makalu in this image, locate the deep gray valley near the center and find the pyramid-shaped peak to its right capped with blue-white snow. Earth's tallest peak, Mount Everest, sits 19 kilometers northwest of Makalu and can be seen at top left in the image. Mount Makalu may be the fifth-tallest mountain in the world, but it is considered an extremely difficult climb because of its steep and isolated ridges, which leave climbers exposed to the elements.

## Ribbons of Icy Eddies in Greenland



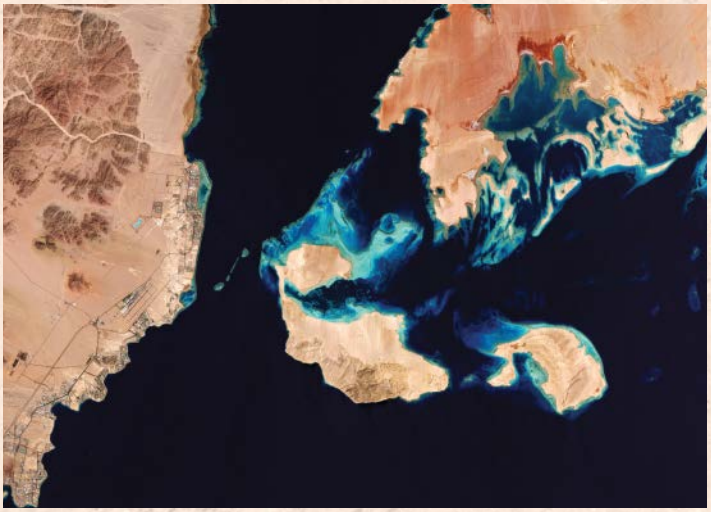
Near Greenland's coast, wind and ocean currents twist floating sea ice along eddies that dance atop the near-frozen waters. One such ribbonlike ice eddy, seen above, was imaged by ESA's Copernicus Sentinel-3B satellite on 7 May 2018 in broadband visible light. This photo captures not only the ocean eddy but also the featherlike texture of Greenland's icy shoreline and the wispy and bumpy clouds that hover high above.

## Mountains, Glaciers, and Kettle Holes in Iceland

Contains modified Copernicus Sentinel data (2017); processed by ESA, CC BY-SA 3.0 IGO (bit.ly/ccbysaigo3-0)

Glaciers, mountains, and curious green pockmarks decorate the landscape near Iceland's capital of Reykjavík, seen in this true-color image from ESA's Sentinel-2A satellite on 1 November 2017. Green speckles within the reddish-brown region toward the top of the image mark formations known as kettle holes, which form when buried chunks of glacier ice melt and leave holes waiting to be filled by water. South of the kettle holes are Mount Esja (center) and Reykjavík (bottom center), which stands out in metropolitan gray amid vivid greens, reds, and ocean blues.

## Coastal Waters in the Gulf of Aqaba



Contains modified Copernicus Sentinel data (2017); processed by ESA, CC BY-SA 3.0 IGO (bit.ly/ccbysaigo3-0)

This true-color image taken by the European Space Agency's (ESA) Copernicus Sentinel-2 satellite on 11 April 2017 captures the colorful coasts of the southern Sinai Peninsula. The Gulf of Aqaba lightens from deep blue to brilliant turquoise off the coasts of Tiran Island and Sanafir Island. Coral reefs appear as slightly darker patches among blue-green waters. Egypt's Sharm El Sheikh, a popular resort area, is seen along the leftward coast. The sands of mainland Saudi Arabia, seen at top right, range from moist reddish browns to salt-rich whites.

## The Zambezi River Delta in Mozambique

Contains modified Copernicus Sentinel data (2016); processed by ESA, CC BY-SA 3.0 IGO (bit.ly/ccbysaigo3-0)

Swamps, grasslands, woods, and vast mangroves highlight the diversity of the Zambezi River delta on the coast of Mozambique, seen in this satellite image. The 3,000 square kilometers of lush delta are protected land. The Zambezi River delta is known for its vast array of wildlife, diverse and healthy ecosystems, use as a local food source, and protection against coastal flooding. This image, packed with vivid green meanders where river waters nourish verdant banks in their natural colors, was taken by ESA's Copernicus Sentinel-2A satellite on 28 September 2016.

## Swirling Algae in the Gulf of Finland

NASA/Landsat 8

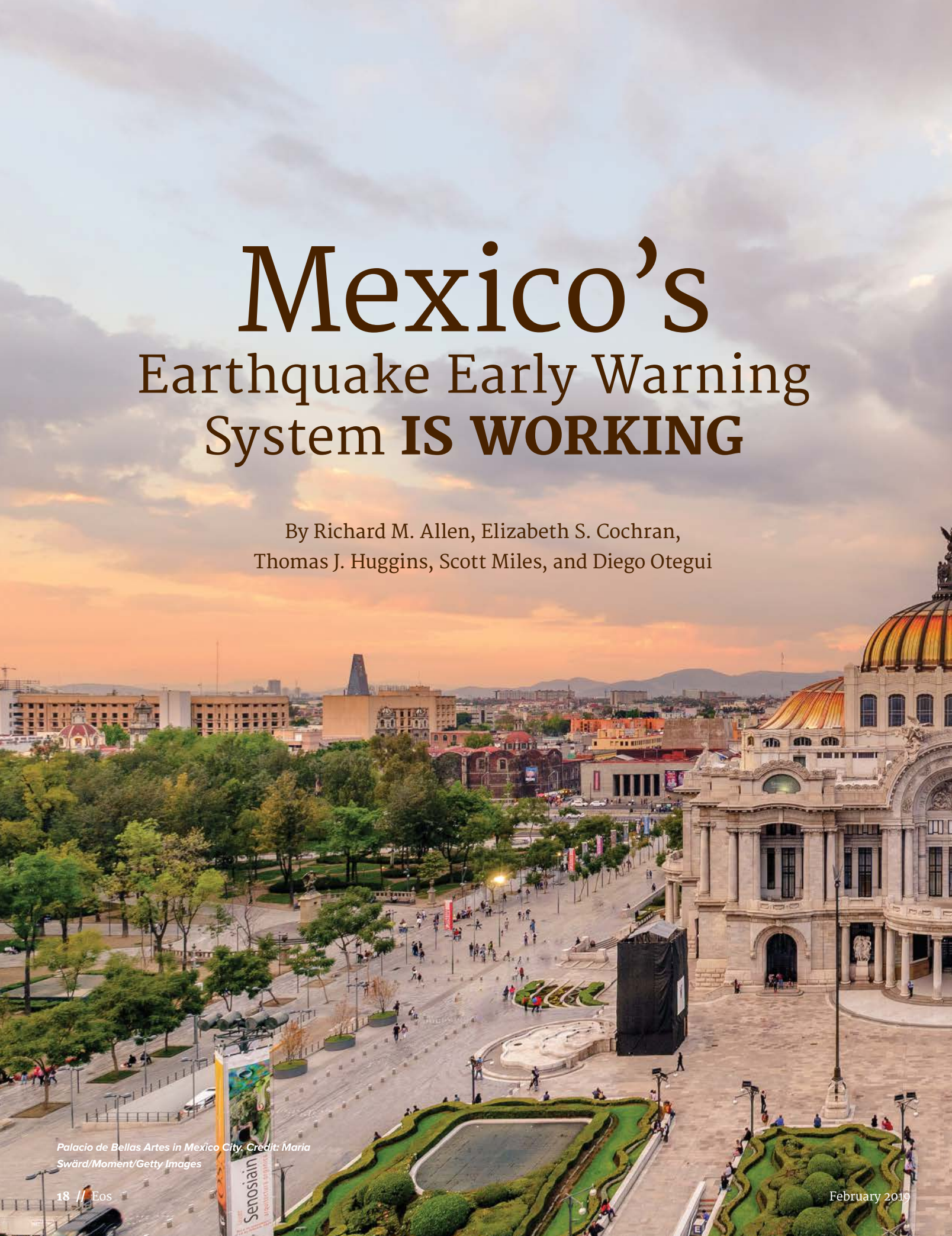
Spirals of teal green phytoplankton decorated the Baltic Sea last summer in the Gulf of Finland. This natural-color image, taken by NASA's Landsat 8 satellite on 18 July 2018, features swirls of what the Finnish Environment Institute found to be cyanobacteria. The vortexlike spiral at the center is more than 25 kilometers across and is one of many algae blooms that blossomed in Scandinavian waters last summer.

Have you seen a stunning image of our planet taken by a satellite? Share it with us by contacting the author or tweeting @AGU_Eos with the hashtag #EarthSatPics.

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

# Mexico's Earthquake Early Warning System **IS WORKING**

By Richard M. Allen, Elizabeth S. Cochran, Thomas J. Huggins, Scott Miles, and Diego Otegui



*Palacio de Bellas Artes in Mexico City. Credit: Maria Swärd/Moment/Getty Images*

# The devastating 2017 Puebla quake provided an opportunity to assess how citizens react to an alert.

On 19 September 2017, an earthquake shook Mexico City with an intensity not felt since the same day 32 years before, when the 1985 magnitude 8.1 Michoacán earthquake killed more than 9,000 people and left more than 100,000 homeless.

The September 2017 magnitude 7.1 Puebla earthquake was part of a sequence of seismic events that included a magnitude 8.2 earthquake offshore of Chiapas, Mexico, and a magnitude 6.0 aftershock to that event. After the losses resulting from the 1985 Michoacán earthquake [*Espinosa-Aranda et al.*, 2009], the Centro de Instrumentación y Registro Sísmico (CIRES) developed an earthquake early warning system with the hope of providing a 60-second warning for earthquakes initiating along the subduction zone [*Espinosa-Aranda et al.*, 1995].

The system has provided warnings for several small to moderate events since its implementation in 1991. However, the September 2017 sequence is the most significant test of Mexico's early warning system to date. For this reason, the Earthquake Engineering Research Institute (EERI) dispatched a reconnaissance research team of seismologists and social scientists to Mexico City from 1 to 6 October 2017. The team met with people from a wide variety of backgrounds and interests in earthquake early warning, including those responsible for generating alerts and activating sirens, local government organizations, university scientists, and members of the public. The objective of the

reconnaissance research was to understand performance and public perception of the early warning system in the immediate aftermath of a devastating earthquake to draw initial lessons for early warning systems around the world.

The lessons learned from observing Mexico's earthquake early warning system, public attitudes, and responses to earthquake alerts are informing similar efforts in the United States, including implementation of the ShakeAlert early warning system, which began its public rollout in Los Angeles, California last month.

## History of Early Warning Systems in Mexico City

Mexico City started to receive earthquake alerts from the earthquake early warning system in 1991 [*Espinosa-Aranda et al.*, 1995; *Goltz and Flores*, 1997]. At the time, the system was set up to detect earthquakes occurring along the Guerrero Gap portion of the subduction zone located 300 kilometers from the city. The Guerrero Gap was considered to be the source most likely to generate future events with the potential to affect Mexico City.

The system works like this: Special radio receivers in schools, government offices, and TV and radio stations receive radio broadcast alerts that provide warning of imminent shaking [*Suarez et al.,* 2009]. The system was initially designed to issue an alert that would provide about 1 minute of warning before residents of Mexico City would begin to feel an earthquake (corresponding to about magnitude 5 or larger in the Guerrero Gap portion of the subduction zone [*Espinosa-Aranda et al.*, 1995]).

From its inception through September 2017, the system issued a total of 33 alerts about earthquakes with estimated magnitudes of 6 or larger and 70 alerts for earthquakes with estimated magnitudes between 5 and 6 [*Centro de Instrumentación y Registro Sísmico*, 2018]. In one case, an alert was issued because of a technical error and was not associated with any known earthquake. A more detailed evaluation of the system performance is given by *Suarez et al.* [2009].

Since its implementation, CIRES has deployed additional sensors inland and along much of the subduction zone along the western coast of Mexico [*Espinosa-Aranda et al.*, 2009; *Cuéllar et al.*, 2017]. With a larger seismic network, the system—currently called the Mexican Seismic Alert System (SASMEX)—is now able to provide alerts in other cities across Mexico.

SASMEX's alert message indicates only that an earthquake likely to be felt has been detected. The alert does not provide an estimate of the time until shaking starts or shaking intensity, which can vary widely.

At present, several channels provide SASMEX alerts in Mexico City: Specially adapted National Oceanic and Atmospheric Administration weather radios provide alerts in thousands of schools and critical facilities; 12,000 pole-mounted speakers can sound a characteristic siren and verbal notice that is intended to be heard across the city. SASMEX also posts alerts to a dedicated Twitter account (@SASMEX).

## A Busy Month for Earthquakes in Mexico City

September 2017 was a trying month for the population of Mexico City—the city's 12,000 sirens signaled a total of five earthquake alerts. A technician working on the sirens accidentally triggered the first alert on 6 September, but this alert was not associated with an earthquake.

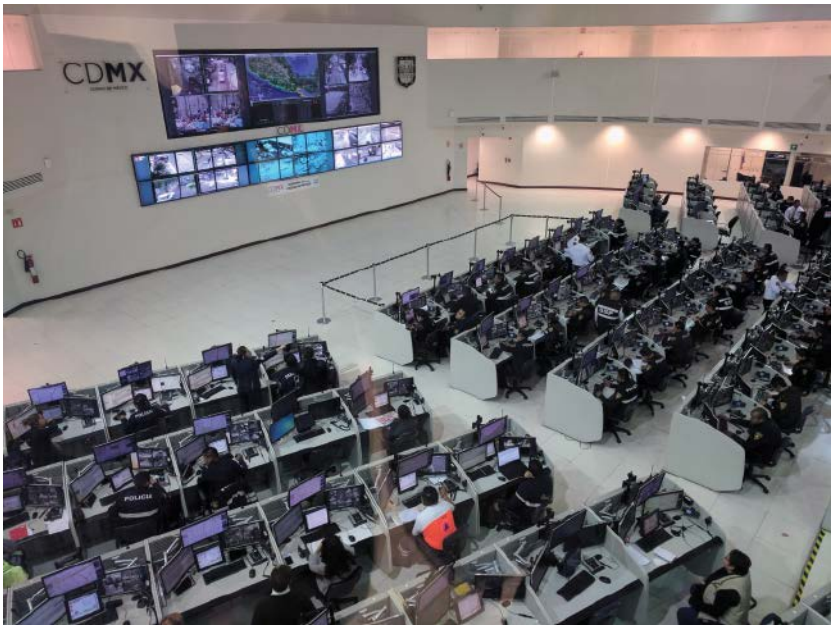
On 7 September, the magnitude 8.2 Chiapas main shock triggered the system. Sirens sounded across Mexico City 2 minutes before the start of the shaking. Although people across the city felt the shaking, it caused relatively little damage because of the large distance (more than 700 kilometers) between the source and the city. On 19 September at 11:00 a.m., the anniversary of the 1985 Michoacán earthquake, the sirens sounded for the annual earthquake drill. About 2 hours later, the sirens sounded again, triggered by the *M*7.1 Puebla earthquake. This earthquake was relatively close to Mexico City (120 kilometers away), so the SASMEX alert was issued only about 5 seconds after the primary (*P*) wave arrival and approximately 20 seconds before the secondary (*S*) wave arrival.

*This apartment building in Mexico City was damaged during the M7.1 Puebla earthquake on 19 September 2017. One of the 12,000 pole-mounted sirens used to issue SASMEX warnings is visible in front of the building. Credit: Elizabeth Cochran*

The *P* waves caused strong shaking across the city that rendered the alert somewhat redundant: Residents began initiating responses when they felt the *P* wave arrival. In response to the shaking, some people evacuated structures while others sheltered in place. We visited a school where students and personnel had regularly practiced evacuating to designated safe areas outside of buildings as the planned response to earthquake shaking or an alert. However, during the

*M*7.1 Puebla earthquake, the strength of the early shaking forced students and teachers to shelter in place rather than evacuate the buildings.

On 23 September, the system was triggered again, this time by the magnitude 6.0 aftershock of the 7 September Chiapas earthquake. Most people in Mexico City, however, did not feel shaking from this event.




*Ciudad de Mexico's (CDMX) emergency operations center broadcasts earthquake early warnings to 12,000 pole-mounted speakers across the city. Credit: Elizabeth Cochran*

## Public Perceptions of the Earthquake Early Warning System

Our interviews with people across Mexico City indicated that their attitude toward SASMEX was generally positive following the September 2017 events. People appeared to see value in having an alert system to take protective action, even when they may receive an alert without feeling or otherwise being aware of shaking. In fact, it appeared that Mexico City residents consider an alert to be "false" only if there was no earthquake at all, even if they did not personally feel shaking at their location.

In other words, there seems to be general acceptance of the technical limitations of the early warning system in exchange for some measure of peace of mind, for fostering the general awareness of earthquake hazards, and for promoting protective behaviors such as evacuation from buildings that may be prone to collapse. We noted that people were much more accepting of alerts from smaller events with no perceptible shaking or even no event at all than of not receiving a timely warning (i.e., a missed alert).

We note that it is possible, and perhaps likely, that the perception of the system may change, depending on how recently the alerts and earthquakes have occurred. For example, the perception of the system may be more positive right after a damaging earthquake, but support can wane with increasing time since the last significant earthquake. These questions will require additional follow-up studies to answer.

In Mexico City, we found that having the earthquake early warning can contribute to a certain "culture of prevention" that cultivates hazard awareness and certain response behaviors [*Goltz and Flores*, 1997]. For example, we spoke with the chief financial officer of a major company who felt that 30 minutes of lost work for a drill or a "false alert" every 2 months would be an acceptable exchange for receiving an alert when strong shaking did occur, and he was considering buying an earthquake early warning receiver for the company's building.

## Early Warning Messaging and Information

Developers of earthquake early warning systems and seismologists have sometimes proposed that alerts should provide an estimate of the expected shaking intensity at the user's location and the expected time until shaking. We learned in Mexico City that the challenges associated with this approach are unlikely to be overcome.

For example, educating the public about any warning message other than simply warning of imminent shaking poses substantial difficulties. Members of the general public are usually familiar with only earthquake magnitude. They do not appreciate the difference between magnitude (the size of the earthquake source) and shaking intensity (which decreases with distance from the source). Thus, it is unlikely that untrained users of early warning systems would correctly interpret an intensity estimate, especially when the information must be interpreted and implemented within seconds.

In addition, it is technically difficult to accurately determine the time when shaking will start at each alerted location. Typically, earthquake early warning systems, including SASMEX, estimate performance by using the time until the arrival of an *S* wave, which is usually associated with stronger shaking [*Espinosa-Aranda et al.*, 1995; *Allen et al.*, 2009]. However, in the 19 September *M*7.1 Puebla earthquake, residents across the city felt the *P* wave strongly. Communicating an estimate of *S* wave arrival time to the public would have been meaningless because most people began taking protective action soon after they felt the shaking from the *P* wave.

## Communication Channels for Earthquake Early Warnings

Mexico City is unusual in having a preexisting public loudspeaker system that could be leveraged to sound earthquake alarms. Even so, many residents want to receive alerts on their smartphones. Indeed, at least two private companies operate their own independent earthquake


*Emergency placards from several buildings in Mexico City provide a wide array of suggestions for taking protective actions during an earthquake. Credit: Elizabeth Cochran*

detection and warning systems in Mexico, with the goal of pushing alerts to Internet-connected devices.

However, it remains unclear how quickly an alert can be pushed to millions of smartphones running an app. This uncertainty creates a potential mismatch between how people want to receive earthquake warnings and the technical challenges associated with push notifications to smartphone apps.

Cell broadcast is one possible solution for getting alerts to cell phones. This approach has been implemented for distributing earthquake alerts in Japan, but it has yet to be implemented in Mexico.

### Effective Warnings, Prompt Responses

From our reconnaissance, we have drawn several initial conclusions. First, an earthquake early warning system should provide an initial alert that is as simple as possible for technological and protective action purposes. The alert should simply indicate "earthquake" to prompt immediate protective actions. More complex alert information is not necessarily helpful for public warnings.

Second, follow-up information is needed in the seconds and minutes after an alert is issued. The immediate follow-up information can be as simple as indicating that an earthquake did occur and possibly an estimate of its size. This information may help people take further mitigating action, such as safe sheltering, or may avoid frustrating individuals who did not feel shaking. Follow-up information should be delivered through a large range of media channels to ensure that it reaches the maximum number of people. In Mexico City, social media served as an important source of postwarning information for people.

Third, it is important that the warning information and messaging provided by early warning systems be consistent and distributed as widely as possible.

Last, any warning system is only as good as the action taken by users to reduce harm to themselves and others. In Mexico City, we realized that there is considerable confusion about what action to take when an earthquake alert is issued. The official recommendation from Civil Protection, Mexico's federal emergency management agency, is to move to a safe space, such as near a structural column, which is often designated to be within a building.

Signage indicating the recommendation is required for many categories of building occupancy, but most people we talked to said they had been told to evacuate and did actually evacuate after receiving an alert. This highlights how messages from an earthquake early warning system can match the capacity for recommended protective actions. Nonetheless, making sure that these protective actions are both feasible and effective means closely pairing earthquake early warning systems with disaster preparedness research, education, planning, and policy.

### ShakeAlert and Early Warning in the United States

The public's perception of Mexico's earthquake early warning system may help inform the strategy for the United States' earthquake early warning system. This system, called ShakeAlert, recently released its first app, in

Apple and Android versions, that will warn users with some notice—at least seconds, perhaps tens of seconds—when an earthquake *M*5.0 or greater occurs in Los Angeles County.

A significant lesson from Mexico is to simplify this messaging for public alerting. The short time that people have to act prior to the arrival of shaking likely precludes effective interpretation of a large amount of information or updated information as the earthquake (and expected shaking) grows. People are likely to ignore or be confused by detailed or updated information that is not effectively tied to feasible protective action.

In the United States, the current recommended protective action when people feel strong shaking is for them to drop to their hands and knees, cover their head and neck with an arm, seek shelter under a table or near an interior wall if possible, and hold on to their shelter (when shelter is available). This protective action is commonly referred to as "drop, cover, and hold on" and typically takes a few seconds to perform.

"Drop, cover, and hold on" is widely communicated as a part of the popular annual Great ShakeOut earthquake drill, as well as of many U.S. state and local emergency management public education campaigns. Thus, it is hoped that warnings issued on ShakeAlert will result in people taking the protective action recommended in the United States to keep them safe. This pairing of recommended action and early warning, in turn, is likely to be more effective in further reducing future injuries than having no early warning. Aligning the public's expectations for ShakeAlert's performance and messaging with the capabilities, design, and track record of the system is the best way to facilitate an effective response to future earthquakes.

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*Visitors to the Oregon Museum of Science and Industry can check out the Invisible Mars Science on a Sphere exhibit, part of an effort by NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission team to bring Mars research to the public. Credit: OMSI*

# ENGAGING IN SCIENCE WITH **MAGNETIC MARS**

A NASA team has developed resources to intrigue the public with the discoveries from its Mars Atmosphere and Volatile Evolution (MAVEN) mission. Here are four tips for communicating that science.

By Christine Shupla, Karin Hauck, Tom Mason, and Bruce Jakosky

For a cold little planet, Mars remains a hot topic: The public wants to know more about this alien world and hear from the scientists who study it. Recent findings that highlight tantalizing clues to Mars's wetter past have piqued this interest still further.

For example, because Mars lacks a global magnetic field, the planet has lost much of its ancient, thicker atmosphere, and much of its carbon dioxide has been lost to space. How habitable was the Red Planet, and what does its history tell us about habitability of other alien worlds?

The public engagement team for NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission has developed a series of resources that use current findings from this mission to engage nonscientists in the world of Mars research. These resources have been used successfully by formal and informal educators, museum docents, and planetarium guides to captivate their respective audiences and connect them to a variety of Mars-related science topics.

Scientists can adopt and extend many of these resources to reach another set of potential Mars science enthusiasts.

## What Is MAVEN? A Window to Mars

Without the benefit of a global magnetic field to protect it, the solar wind and the Sun's radiation are wearing away the Martian atmosphere through a variety of mechanisms. MAVEN seeks to understand these mechanisms.

Since entering Mars orbit in September 2014, MAVEN has measured the effects of the Sun's radiation and particles on Mars's atmosphere and the rates at which particles are escaping into space. This mission is continuing to refine our understanding of how planets evolve over time.

The mission has determined that the erosion of Mars's atmosphere was great enough to account for a significant change in the planet's climate. The spacecraft is now examining how seasonal cycles and the solar cycle affect this system. The most recent results and publications from the mission can be found on the MAVEN website (bit.ly/Eos_Maven).

## Sharing MAVEN's Science

All of this research can be used to tell the story of Mars's evolution to different audiences. In particular, the research gives the public a window into three key concepts:

- Planets change over time.
- The Sun's particles and radiation can affect planetary atmospheres and climate.
- Earth's magnetic field and atmosphere have played critical roles in maintaining our habitable environment.

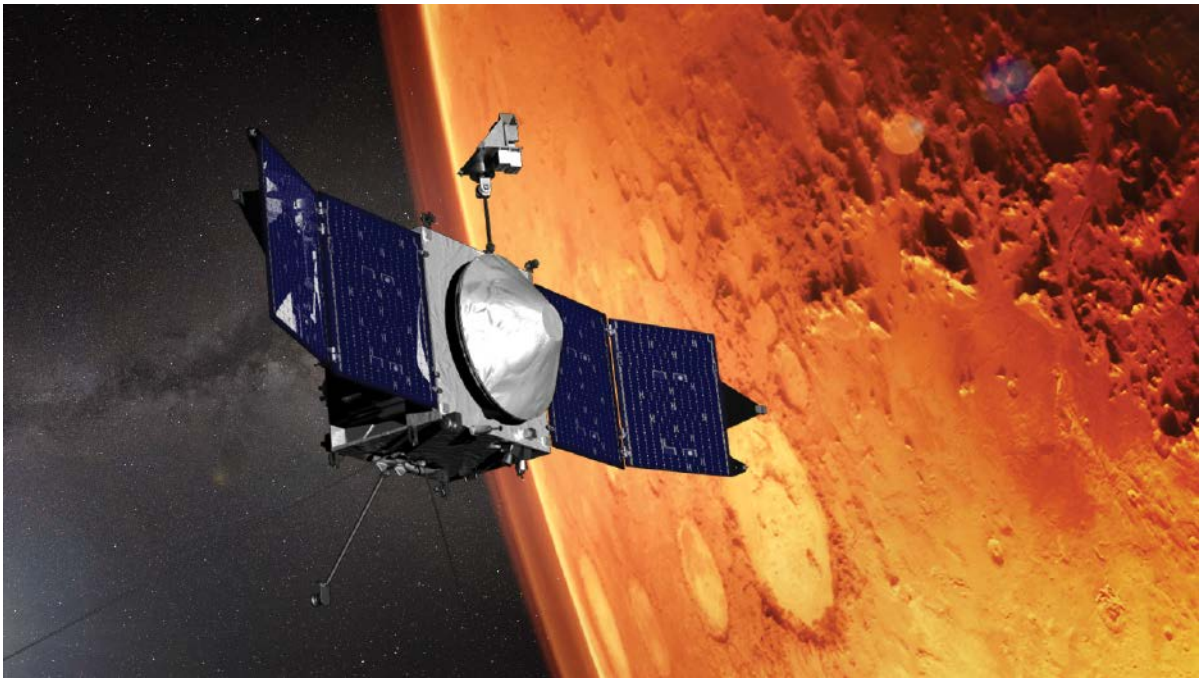
To help communicate these key concepts and share the story of Mars's changing climate, MAVEN's public engagement team has worked out a variety of tips and resources.

*This artist's conception, based on Mars's current topography, shows an early, wetter Mars with a thicker atmosphere. Credit: USRA/LPI*

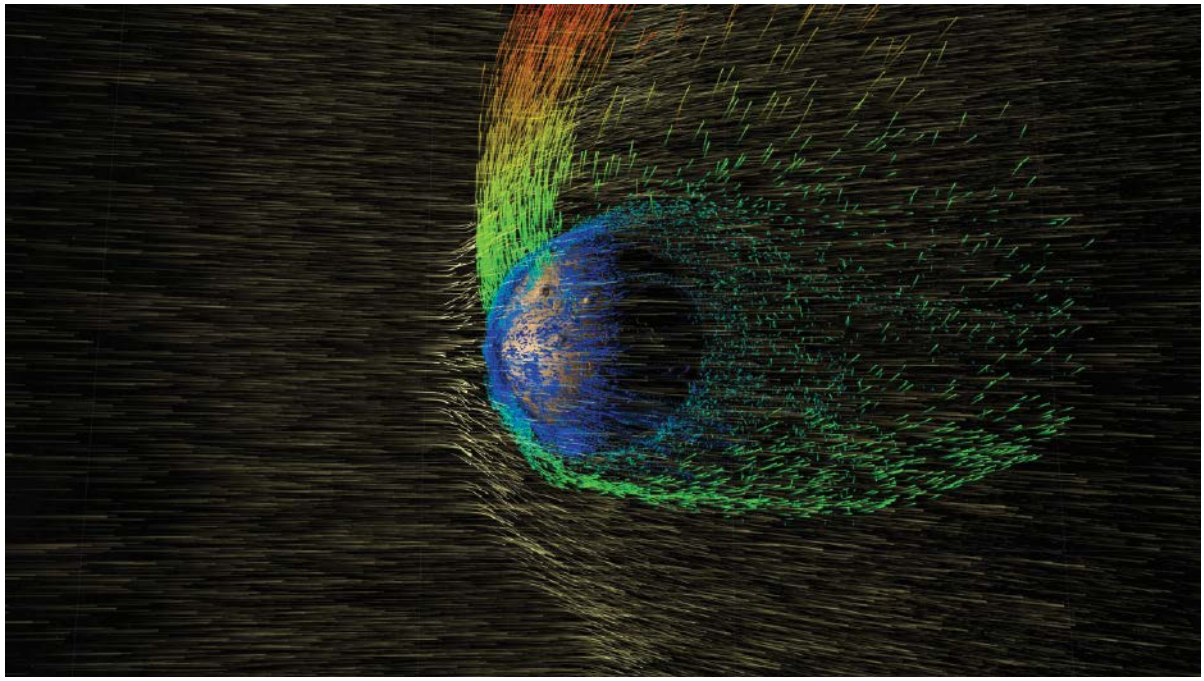
### 1. Use Strong Visuals

The MAVEN public engagement team has created a Science on a Sphere (SOS) presentation, *Invisible Mars* (bit.ly/Eos_Invisible-Mars), for use in presenting this story to general audiences. An SOS presentation is designed and scripted for a spherical projector, an effective way of demonstrating planetary features with compelling visuals.

A shorter PowerPoint version is also available, which can be modified for presentations. In addition, presenters can include a variety of videos produced by the NASA Goddard Scientific Visualization Studio (bit.ly/Eos_Maven-Video).



*In this artist's conception, the MAVEN spacecraft is orbiting Mars. Credit: NASA/GSFC*



*The solar wind strips electrically charged oxygen ions from Mars's atmosphere. The most energetic ions (red) accelerate in a plume above Mars, whereas most escaping ions (green) are lost along the "tail" region. Credit: NASA/GSFC*

One of these videos, "Martian Atmosphere Loss Explained," explains how MAVEN is measuring solar wind erosion at Mars, observing ions in the upper atmosphere as they pick up energy from the electric field of the solar wind and escape to space.

### 2. Get Personal

Scientists are encouraged to add their own personal stories to more deeply connect with their audiences. Many students and adults appreciate the opportunity to get to know scientists as people and hearing about their experiences, including failures and successes. Scientists can share their stories with live audiences, or they can make videos or podcasts to extend their reach still further.

Sharing how Mars (or evolving planetary atmospheres and solar interactions) has inspired your interests and career would provide your audience with another connection to your topic.

### 3. Be Hands-On

To increase interest of younger audiences, consider incorporating some hands-on models and activities (available on MAVEN's website):

- Red Planet lessons were created for the elementary classroom, but some activities could be useful models to include in presentations. For instance, "Atmospheric Pressure on Mars" uses a vacuum pump and marshmallows to demonstrate the effects of low atmospheric pressure on objects.
- Girls Go to Mars is a set of hands-on activities designed to engage middle school girls, but many of the activities can be easily adapted to use with other audiences. In the activity "How Do Atmospheres Change Over Time: The Role of Magnetosphere and Solar Wind," participants build a simple model to demonstrate that the underlying magnetic field protects charged particles in the atmosphere from being carried away by the Sun's magnetic field.
- MAVEN lessons and interactives include "Planet Designer," an online program in which audiences change features of a model of the planet to explore how the changes affect temperature and habitability.

### 4. Tell the Story of How Scientists Do Science

Audiences may be interested in how MAVEN discoveries might affect future human exploration of Mars and how they relate to the future of our own planet. Scientists may also want to discuss how the solar wind and storms affect our own atmosphere and interact with Earth's magnetic field.

Scientists don't have to be prepared to answer any and all questions related to these topics. It is more important that audiences learn how we conduct science, that investigations uncover additional questions, and that what we learn about other planets often helps us understand our own world.

Please contact the MAVEN public engagement team (epomail@lasp.colorado.edu) for further information and recommendations for specific audiences.

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# HOVERING IN THE PLUME

By Fiona D'Arcy, John Stix, J. Maarten de Moor, Julian Rüdiger, Jorge Andres Diaz, Alfred Alan, and Ernesto Corrales

## Volcanologists, chemists, physicists, and engineers test drone techniques at Central America's two largest degassing volcanoes.

Volcanic gases are important eruption forecasting tools often used in volcano monitoring. However, collecting gas samples requires scientists to enter high-risk volcanic areas.

This is where drones come in. Drones are the perfect tools for volcanologists to access these danger zones. Although they're rapidly becoming popular among the scientific community for photography and aerial mapping, few studies have attempted to quantitatively measure gas emissions with drones [e.g., *McGonigle et al.*, 2008; *Mori et al.*, 2016].

A drone, or unmanned aerial vehicle (UAV), is a remote-controlled device that allows a pilot to remain a safe distance from an active crater while the drone is maneuvered to the site of interest. Drones can be piloted manually or with an autonomous navigation sys-

*The Turriabla volcano in Costa Rica belches ash and gases in 2017. Credit: Fiona D'Arcy*

*Researchers make final adjustments to a drone equipped with compact gas instrumentation. The drone will carry the instruments through the gas plume emitted by Turrialba volcano, seen here behind the researchers. Credit: Fiona D'Arcy*

tem. Compact gas sensors can be mounted onto the drone that take measurements while the drone is in the air.

Last year, a team of researchers gathered in Central America for a 2-week excursion to test a variety of instrument and drone combinations. Their number included gas geochemists, volcanologists, physicists, engineers, and chemists from four institutions across Canada, Germany, and Costa Rica. Most, of course, doubled as drone pilots.

### Why Measure These Gases?

Scientists measure volcanic gases for three main reasons.

First, changes in the ratios of certain gases can indicate an imminent eruption. The concentrations of carbon dioxide ($CO_2$), sulfur dioxide ($SO_2$), and hydrogen sulfide ($H_2S$) can be measured by flying the drone right into the plume of gas as it emerges from the volcano.

Second, researchers need to know which reactive species are coming out of the volcano so that the interactions between volcanoes, climate, and ozone can be better understood. These compounds contain such halogens as chlorine and bromine, and a drone hovering directly in the gas at varying distances from the source can help scientists determine how the compounds change as the plume ages.

Third, the total amount of gas being emitted can be used to calculate the exchange of volatiles between the deep Earth and the atmosphere. The emission amount can also be used to monitor volcanic activity. This is done by flying transects under the entire width of the gas plume to measure the output, or flux, of $SO_2$.

**The amount of gas emitted can be used to calculate the exchange of volatiles between the deep Earth and the atmosphere.**

Usually a researcher drives or walks under the width of the plume to collect the needed transects, but limited road access and obstructions at ground level often prevent or curtail surveying such transects. The drone bypasses these problems, is faster, and can even directly measure wind speed at plume height, which is a key variable for the flux calculation.

By combining gas concentration ratios and $SO_2$ flux measurements, scientists can also calculate the $CO_2$ flux.

### Gas Giants

Turrialba in Costa Rica and Masaya in Nicaragua are Central America's largest degassing volcanoes, each having emitted well more than 4 million tons of $SO_2$, among other gases, over the past 20 years alone (calculations are based on data from *de Moor et al.* [2016] and *Martin et al.* [2010]).


*A researcher pilots an octocopter toward a gas plume at Turrialba volcano. Credit: Fiona D'Arcy*

Both of these gas giants lie dangerously close to major cities, making them key locations to test new measurement techniques.

Turrialba was sculpted by a series of violent eruptions during the past 10,000 years, but all activity came to a halt in 1866. Then, in 1996, the volcano sprang to life again.

More than 20 years later, explosive bursts of ash frequently rise several hundred meters above the summit, causing havoc at the international airport in San José, Costa Rica's capital. The opening of new vents and the escape of magmatic gas from intruding magma are the main drivers of the ongoing volcanic activity, and a small lava lake has been spotted forming at the bottom of the crater.

Masaya is a different kind of volcano altogether. It is composed of a large caldera complex that formed 2,500 years ago, with volcanic cones rising from the floor of the caldera. One of the craters atop the largest cone hosts a vigorously bubbling lava lake that has attracted a multitude of tourists in recent years.


*The location of Masaya and Turrialba volcanoes. Credit: Fiona D'Arcy*

Unlike Turrialba, Masaya has been persistently active throughout the past several hundred years, with a long-standing history of degassing from the surface of the lava lakes that have come and gone for centuries.

The extraordinary degassing at these two volcanoes makes them ideal locations to test new drone-mounted instrumentation thereby improving hazard assessments.

## Building Compact Instrumentation

For measuring concentrations of $CO_2$, $SO_2$, and $H_2S$, we designed two compact variations of multiple-gas analyzers (Multi-GAS) for drone flights. Multi-GAS instruments are typically

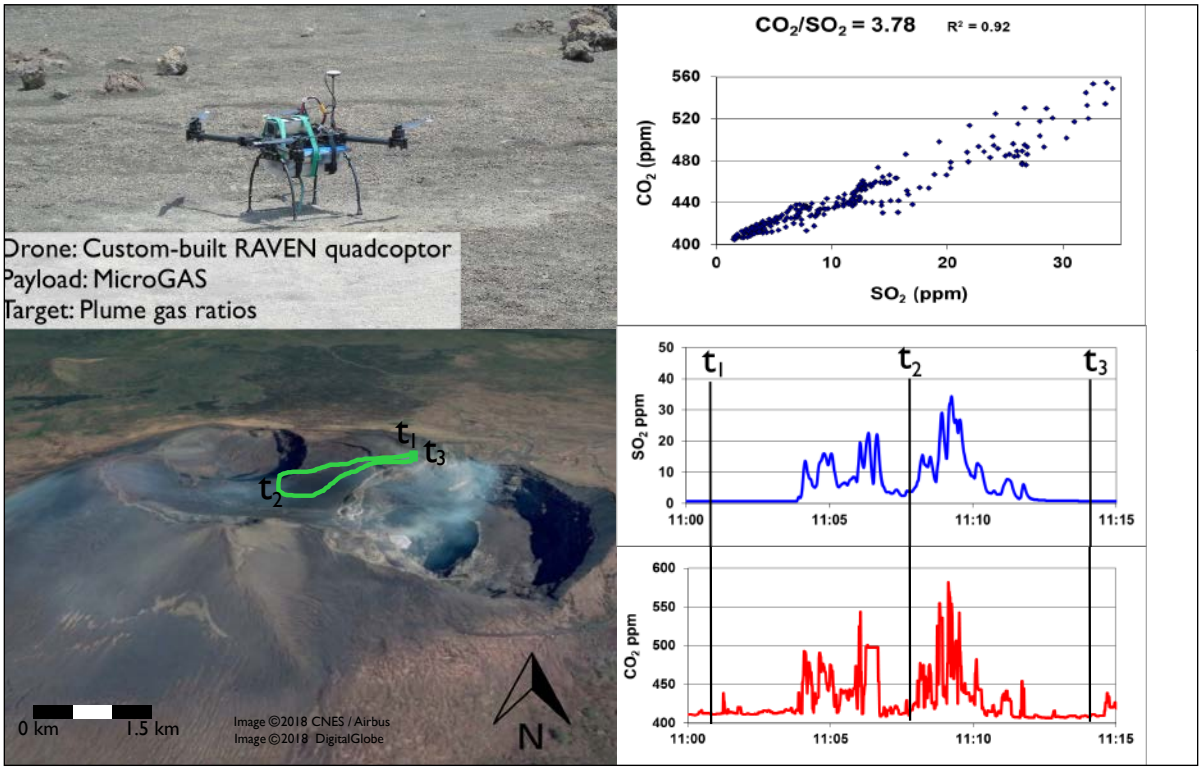


*Fig. 1. Sample flight mission showing the carbon dioxide/sulfur dioxide ($CO_2/SO_2$) ratio measured in the plume of Masaya volcano. At $t_1$, the drone takes off from the edge of the crater. At $t_2$, the drone passes through the plume and turns around for the return journey through the plume again. At $t_3$, the drone lands back at the start location.*

the size of a toaster, require heavy batteries and a case, and are meant for long-term measurements atop a volcano. We created miniaturized versions weighing under 1.5 kilograms, around the size of a football.

We named the two instruments MiniGAS and MicroGAS. MicroGAS was designed by the volcanology group at McGill University, and MiniGAS was designed by GasLab of the Universidad de Costa Rica. Both have varying sensor ranges, but both consist of a pump, electrochemical sensors, and onboard data loggers to store the data or, in the case of MiniGAS, transmit it by telemetry.

We also deployed a lightweight gas diffusion sampling device to measure halogen species and their compositional variations. This device uses a pump and glass tubes with reactive coatings, called denuders, designed to collect the desired halogen compounds. An $SO_2$ sensor and additional wiring that connects to the drone telemetry system allow the pilot to remotely start the sampling once high $SO_2$ levels are reached, signaling that the drone is in the plume.

In addition, we built a drone-mounted miniaturized differential optical absorption spectrometer (DROAS) to make $SO_2$ flux measurements. Typical instruments are also toaster-sized and weigh roughly 2–4 kilograms, plus they require a large battery and a computer connection; the DROAS weighs roughly 950 grams and contains a telescope, an ultraviolet spectrometer, and a microcomputer running the data collection program.

## Choosing the Right Drone

We used two octocopters and two quadcopters for this expedition, which was conducted in late April 2017. The drones were flown in combination with different types of compact sensors and spectrometers. What drones we chose depended on the goals of the particular flight in question.

For example, if the goal was to perform a DROAS traverse, which requires covering a large distance (a kilometer or more) beyond the line of sight, then a sturdy octocopter with autonomous flying capability was ideal.

If the goal was to fly straight up until the gas plume was reached and then hover there as long as the battery allowed, a manual flight by a lightweight quadcopter was best suited to the mission.

The team discovered the suitability and limitations of each drone and created an effective protocol for assessing when and where it was useful or too dangerous to fly each type. A preflight checklist was used to ensure that wind, fog, and other hazards were taken into consideration and that any bystanders in the area were in a safe viewing location.

## Flying High

We flew a dozen missions at Turrialba and Masaya from the crater rim, from the base, and downwind from the plume at each volcano. Each of the instruments was deployed, sometimes in tandem, on at least one drone.

During these flights, we successfully entered the volcanic plume to measure $SO_2$ and $CO_2$ concentrations. We also

conducted several flight transects to estimate $SO_2$ flux values. Examples of these missions can be seen in Figure 1 and in the video at bit.ly/Eos_carta-mission.

## Soaring into the Future

We demonstrated an array of drone and sensor capabilities in volcanic gas plumes during 2 weeks of field testing in Costa Rica and Nicaragua. At the same time, we learned countless lessons about the adaptability and preparedness needed to undertake such a task. In addition to acquiring permits, customs letters, plane-approved batteries, and spare parts prior to travel, coordinating with local authorities proved vital to dealing with the surprises that abounded at every stage of the fieldwork.

With proper safety measures and permissions in place, this kind of work could revolutionize volcanic gas measurements made at volcanoes without ever putting the researchers in danger. New ash deposits and crater lakes could be sampled during eruptive periods. Instrumentation could be deployed in craters by drones. The possibilities are endless.


## Acknowledgments

We thank the Observatorio Vulcanológico y Sismológico de Costa Rica (OVSICORI) and the Instituto Nicaragüense de Estudios Territoriales (INETER) for their aid during the field campaign. We also thank José Pinell and the Instituto Nicaragüense de Aeronáutica Civil (INAC) for their assistance in Nicaragua and the Vicerrectoría de Investigación and Centro de Investigación en Ciencias Atómicas, Nucleares y Moleculares (CICANUM) from the Universidad de Costa Rica for their support on the CARTA-UAV research project.


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# Awardees and Prize Winners Honored at 2018 AGU Fall Meeting

## Jobbágy, Lopes, and Reddy Receive 2018 Ambassador Awards

*Esteban G. Jobbágy, Rosaly M. C. Lopes, and Christopher M. Reddy received the 2018 Ambassador Award at the AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award is in recognition of "outstanding contributions to one or more of the following area(s): societal impact, service to the Earth and space community, scientific leadership, and promotion of talent/career pool."*

Esteban G. Jobbágy

### *Citation Esteban G. Jobbágy*

Dr. Esteban Jobbágy drives positive change in the world as an ambassador of science, bringing rigor to environmental decision-making and fostering the growth of the next generation of environmental leaders.

Esteban has uncovered important ecohydrologic mechanisms by which land use change and human activities alter ecosystems. His seminal work on eucalyptus plantations in Argentina demonstrated a disruption of the natural water balance through an increase in evapotranspiration and an induced hydrologic transfer from surrounding grasslands to plantations. Hydrologic alteration between patches laterally redistributes nutrients and salts, initiating vegetation feedbacks and in some cases, adverse impacts on soil fertility. He advocates systems that integrate trees into grassland as more sustainable alternatives to single-species plantations.

However, Esteban is not content merely to publish peer-reviewed articles; he works with farmers and foresters to improve best practices and spreads his message to those who can effect change. In the documentary film *Gran Chaco,* Esteban highlighted the deforestation of the second-largest forest in South America. The changes to the dry forest ecosystem, biodiversity, hydrology, economy, and culture of the region that have occurred in the past 15 years cannot be overstated. Similarly, in Rio Nuevo, Esteban's narration provides a riveting story of the ecohydrologic feedbacks by which land use change on the Argentinian plains has led to water excess and the surprising formation of new rivers. The documentaries featuring Esteban are raising awareness of socioenvironmental cascades that previously received little global attention.

Esteban has worked tirelessly with Argentinian government agencies, local growers associations, and agricultural corporations. He organizes workshops and two-way interactions to combine the collective wisdom of hundreds of farmers and the scientific community to develop decision support tools. Cultivating and maintaining these personal relationships has been key to translating Dr. Jobbágy's research into measurable impacts across South America, leading to a more sustainable balance between food production, flooding, the economy, and the environment. For his efforts, Dr. Jobbágy was honored with the Bernardo Houssay Award by Argentinian president Cristina Fernández de Kirchner for contributions by a scientist under 45 years of age.

Dr. Jobbágy's tremendously creative and pragmatic research style has led to major discoveries on the imprint of vegetation on hydrologic and biogeochemical processes. His work has had, and will continue to have, a sustained impact on environmental decision-making in South America. Through his passionate advocacy, communication, and stakeholder outreach, his legacy will be preserved in the work he has done and the students he has trained.

**—Steven P. Loheide III**, *University of Wisconsin–Madison*

### *Response*

It is a warm and encouraging surprise to receive the AGU Ambassador Award for my work connecting science with real-life problems in the plains of southern South America. I especially thank AGU and my nominators and supporters, Steve Loheide, Ying Fan, and Rob Jackson. Their enthusiasm in nominating me is the best gift I am receiving.

This award invites me to reflect upon the beginning of my career at the Agronomy School of the University of Buenos Aires 30 years ago. There, lively discussions with fellow students about the imprint of farming on nature pushed me to learn more about the vagaries of nutrient and water cycles. After a decadelong immersion into pure biogeochemical and ecohydrological quests at labs in the United States and Argentina (and at many mind-blowing AGU events), I started to contact an amazing community of sharp and curious farmers. These people, like me, were full of questions about nature. We all wanted to know the causes of the widespread hydrological transformations of the Argentine Pampas, to understand the mysterious "dialogue" between shallow groundwater and crops that we were cluelessly observing, to make sense of the confusing effects that cutting or planting forests had on soil and water salinity. Slowly, this vibrant community brought me back to my agronomic start, engaging me in an amazing collaborative exchange of observations, hard fieldwork, and, once again, lively discussions about the imprint of farming on nature.

Argentina hosts one of the last agricultural frontiers of our modern world. Its brutal expansion over natural grasslands and forests has offered a unique experimental setting to study how ecosystems shape water cycling, nutrient distributions, and soil carbon stocks. With unexpected success, I attracted colleagues from all over the world to embark on that adventure, together with some of the best students I could possibly have dreamed to advise. I am deeply indebted to all these good friends, and they own a substantial part of this award.

The same land use changes that opened unique scientific opportunities are posing urgent environmental and social challenges to my country. Staying away from the controversies that arise from them has been impossible for me, and thanks to that, I discovered a whole new world in the exchange with county- to national-level policy makers. I have witnessed science and farming shape each other. So far, being part of this reciprocal transformation has been the biggest joy.

**—Esteban G. Jobbágy**, *Universidad Nacional de San Luis, San Luis, Argentina; and Conseja Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina*

Rosaly M. C. Lopes

### *Citation for Rosaly M. C. Lopes*

Dr. Rosaly Lopes is one of the world's leading planetary geologists, particularly in the area of volcanic processes relevant to satellites of the outer planets. In addition to her prolific scientific output on volcanic and resurfacing processes on Io and the geology of Mars and Titan, she has been an outstanding science ambassador throughout her career. For this she receives the 2018 AGU Ambassador Award.

A native of Brazil, she is considered a role model for Latinas, in particular, and an inspiration for numerous students from Brazil and other countries. Her outreach efforts have reached students and the public nationally and internationally and have been recognized by NASA and the American Astronomical Society, among others. Throughout her career, she has given many hundreds of interviews to media all over the world, appearing in some 20 television documentaries produced in the United States, the United Kingdom, Canada, and Brazil, and has presented outreach lectures on every continent, including Antarctica (at McMurdo Station). She has been extremely active in giving public and school talks throughout California and the United States, as well as in Brazil, Mexico, Morocco, Portugal, Singapore, and several other countries.

She has authored eight books, five at a popular level, and 28 articles in magazines such as *Astronomy* and *Sky and Telescope*. She has been recognized for her public outreach work by the American Astronomical Society's Division for Planetary Sciences Carl Sagan Medal in 2005, awarded to "recognize and honor outstanding communication by an active planetary scientist to the general public." NASA awarded her the Exceptional Service Medal in 2007 with a citation "for providing planetary exploration knowledge to the public, leading an active volcanology research program, and providing a positive role model for women and minorities in science." She often participates in events aimed at encouraging young women to pursue careers in science and was used by Sally Ride Science as a role model for her school materials, such as the book and poster *What Do You Want to Be?* She is featured in several other books aimed at school-

children and young people, such as Scholastic's *Extreme Science Jobs,* as well as at the public, such as *A World of Her Own: 24 Amazing Women Explorers and Adventurers* by M. E. Ross (Chicago Review Press, 2014). For her consistent public outreach effort throughout her scientific research career, Rosaly Lopes receives the 2018 AGU Ambassador Award.

**—Susan W. Kieffer**, *University of Illinois at Urbana-Champaign*

### *Response*

I am deeply grateful to AGU for this great honor, to Dr. Susan Kieffer for nominating me, and to colleagues who wrote supporting letters. I also wish to acknowledge the Jet Propulsion Laboratory and Caltech for being supportive of my education, outreach, and community service activities. It has been my honor to serve AGU and other scientific societies and to help advocate for our community.

Inspiring future generations should be the goal of every scientist. Whatever science we do, we should encourage future generations of scientists to surpass it. Our work is a stepping-stone for others to reach farther. For this reason, I remain deeply committed to helping students and early-career people in their own journey and to inspiring young people to follow their passion. An essential part of this commitment is public outreach. I make time to talk to the media, because there may be a young person somewhere who will be inspired by something they read in a newspaper, like I was, or see on television or online. I make time to carefully answer questions from schoolchildren, because they need to know that we value their curiosity. I love the science that I work on and the incredibly smart colleagues who surround me, and it is a pleasure to share knowledge with the younger generation. I realize how lucky I am to have a career in science and wish to help others achieve the same. Per audacia ad astra.

**—Rosaly M. C. Lopes**, *Jet Propulsion Laboratory, California Institute of Technology, Pasadena*

Christopher M. Reddy

### *Citation for Christopher M. Reddy*

Dr. Christopher Reddy embodies the concept of a scientific ambassador through his tireless efforts to represent, promote, and translate science to a diverse range of groups outside the ivory tower.

Chris's confidence as an ambassador stems from his deep scientific expertise in environmental chemistry, which draws him into myriad real-world events. With over 200 publications, Chris has developed a niche of studying emerging issues by developing and applying new technologies, simultaneously creating knowledge while answering questions of societal importance. But what makes Chris such an effective ambassador is his persistence in seeking out those who will benefit from his knowledge and then actively engaging them.

Chris constantly reaches out to policy makers, industry representatives, media, spill responders, and the mythical entity known as the general public. As a result, when it comes to the issue of ocean contamination, Chris has become a first point of contact among academic scientists—our ambassador. On any given day, he could be counseling members of Congress, military admirals, corporate executives, reporters, foreign officials, or high school students working on a science fair project. Chris's special blend of rigor and clear communication has engendered trust among those whose interests intersect with his expertise, which has in turn provided him an exceptional platform from which he can further engage. For example, Chris is one of few academic scientists to develop a level of trust among federal response officials such that he is welcomed into the Unified Command structure during major events. Chris is simply voracious in his appetite to engage for the benefit of science.

Another theme that pervades Chris's activities is that he challenges everyone—scientists, reporters, congressional representatives—to improve their communication and their use of science. He challenged all scientists to serve as ambassadors in his *Science* editorial "Scientist Citizens"; he challenged a frenzied media to get their information right in his CNN op-ed "How Reporters Mangle Science on Gulf Oil"; he challenged the disciplinary vernacular that pervades AGU meetings in his *Eos* editorial "Dude, You Are Speaking Romulan"; and he challenged popular perception of chemical dispersant use in a CNN op-ed we coauthored, "A Frightening Tool to Fight Oil Spills?" Not only is Chris a consummate ambassador for science, but also he pushes all of us to do our equal part. We would do well to heed his advice.

**—David Valentine**, *University of California, Santa Barbara*

### *Response*

I thank AGU for the Ambassador Award and Prof. David L. Valentine (University of California, Santa Barbara) for his citation. It is a humbling yet inspiring honor. It cements my resolve to continue my efforts to communicate the culture and function of science beyond the ivory tower. These are challenging times for science, but I believe that fostering a sense of trust and openness is critical to building new and more effective science ambassadors.

In his 2014 book *American Ambassadors,* Dennis Jett wrote that "Diplomacy, like politics, can be described as the art of the possible." To me, science diplomacy is very much the art of the possible. Academia often creates more challenges for itself than necessary by relying on terms and customs that are foreign to many. By improving and ultimately delivering the information that the lay public, media, and elected officials need, researchers are engaging in a very concrete and visible example of the art of the possible.

I once asked Bill Rugh what makes a successful diplomat. Rugh, who was stationed in the Middle East from the 1960s to the 1990s and was U.S. ambassador to both Yemen and the United Arab Emirates, emphasized the importance of appreciating his hosts' culture to understand what is important to them, of meeting with them to develop a sense of honesty and mutual trust, and of mentoring those junior to him. Ambassador Rugh just as easily could have been describing what is important to any scientist attempting to explain his or her work to a journalist, a congressperson, or a grade-school classroom.

I have been lucky to have had many mentors through my career and been afforded the luxuries of many life experiences that have contributed to my growth as a scientist and a person. Learning from my mistakes while continuing to hone my skills has been crucial to that growth. At the same time, training opportunities through the Aldo Leopold Leadership Program, the Alan Alda Center for Communicating Science, Harvard's Kennedy School of Government, and MIT's Sloan School of Management allowed me to learn from leaders in business, diplomacy, and the military. These courses also taught me that understanding the cultures of those who value the knowledge that science offers them to make the most well informed decisions possible is the cornerstone to being a successful science ambassador.

**—Christopher M. Reddy**, *Woods Hole Oceanographic Institution, Woods Hole, Mass.*

## Hooper Receives 2018 Edward A. Flinn III Award

*Richard P. Hooper received the Edward A. Flinn III Award at the AGU Fall Meeting 2018 Honors Ceremony, held 12 December in Washington, D. C. The award is given annually to "an individual or small group who personifies the Union's motto of 'unselfish cooperation in research' through their facilitating, coordinating, and implementing activities."*

Richard P. Hooper

### *Citation*

Dr. Richard P. Hooper is being recognized for his dedicated service to the hydrologic sciences community as founding executive director of the Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI). The realization that emerging water science research challenges cannot be addressed through traditional single-investigator projects led to the creation of CUAHSI, the first community research consortium for hydrologists. Hooper served as the consortium's executive director and president for nearly its entire history, from 2003 just after CUAHSI was incorporated until his retirement in 2017. Under his leadership, the consortium grew from a few dozen members to more than 130 U.S. universities and international water science organizations, a full professional staff, and a wide range of programs supporting hydrologic science.

Hooper worked with the board of directors and university scientists to develop the first strategic plan and to secure base funding from the National Science Foundation's Geosciences Directorate. He tirelessly advocated for CUAHSI in pursuit of opportunities with national and international collaborators for the benefit of the broad hydrologic community. This led not only to significant increases in CUAHSI's budget but also, more important, to transformative services for hydrologic science. One notable example is the collaboration with the National Oceanic and Atmospheric Administration to engage the next generation of scientists through the annual summer institute for graduate students at the National Water Center.

Where Hooper has personally had a significant impact upon the community is in the area of hydroinformatics. He had a deep understanding of data services and cyberinfrastructure based on his pre-CUAHSI experience with the U.S. Geological Survey as director of the National Stream Quality Accounting Network and co–principal investigator of the Panola Mountain Research Watershed. As CUAHSI's executive director, Hooper built upon that understanding to coordinate hydrology and information technology activities that have transformed prototypes developed in research projects like the Hydrologic Information System and HydroShare into full-scale CUAHSI services that benefit the entire hydrologic sciences community.

There are few scientists who would dedicate the majority of their productive career to helping the broader community develop research infrastructure and graduate student education and training programs. CUAHSI is now internationally recognized as the place for community hydrology. Hooper is that unique person who embodies the spirit of the Edward A. Flinn III Award as an individual "who personifies the Union's motto of 'unselfish cooperation in research' through their facilitating, coordinating, and implementing activities."

**—Albert J. Valocchi,** *University of Illinois at Urbana-Champaign and* **David Hyndman,** *Michigan State University, East Lansing*

### *Response*

I am honored to receive the Flinn Award. I hope that the community's efforts in developing CUAHSI will yield continuing benefits in the years to come. It has been a privilege to work with many of the leading scientists in hydrologic science over the past decade in crafting a community approach to complement and to support the research of individual scientists. I particularly want to recognize the efforts of the various chairs who have served CUAHSI, as well as the contributions of David Maidment and David Tarboton in advancing hydroinformatics. We are just now beginning to get a sense of the dividends that that work might bring with the emergence of continental-scale hydrologic modeling.

I have learned so much over the years at CUAHSI and believe that we have a strong foundation to continue the advancement of hydrologic science.

**—Richard P. Hooper,** *Tufts University, Medford, Mass.*

## Montanari Receives 2018 William Kaula Award

*Alberto Montanari received the William Kaula Award at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award honors an individual "for unselfish service to the scientific community through extraordinary dedication to, and exceptional efforts on behalf of, the Union's publications program."*

Alberto Montanari

### *Citation*

As editor in chief of *Water Resources Research* (*WRR*) from 2013 to 2017, Prof. Alberto Montanari transformed *WRR* into a truly international go-to journal for premier interdisciplinary publications spanning a wide range of disciplines concerning the natural and social sciences of fresh water and its management.

Almost immediately after his appointment began, Dr. Montanari laid out the Editorial Board's vision for *WRR* ("address with fervor issues related to the interaction and feedbacks between water and society") and initiated a special fiftieth-anniversary collection of manuscripts. The result was 57 superb papers, with titles reflecting a broad and enduring perspective. Dr. Montanari played a special role in framing the collection and attracting high-quality manuscripts.

To encourage a broader pool of reviewers, Dr. Montanari initiated an annual listing of all reviewers who served in the previous year.

To stimulate discussion and awareness on relevant and timely research issues on water resources and related disciplines, Dr. Montanari initiated a series of debates on the big issues. Two collections of papers have been published in Debates on Water Resources: "The Future of Hydrological Sciences: A (Common) Path Forward?" and "Perspectives on Socio-Hydrology."

To encourage submissions from both the AGU and European Geosciences Union (EGU) communities, Alberto consistently reached out to potential authors and held "Meet the Editor" sessions at AGU and EGU meetings.

Dr. Montanari clearly expanded the international reach of *WRR*, adding two other European scientists and a Chinese scientist to the *WRR* Editorial Board. He visited China to attract more quality manuscripts from Asia and encouraged submissions from the European community through his roles as past president of the Hydrology section of EGU, as an officer of EGU, as president of the International Commission on Water Resources Systems of the International Association of Hydrological Sciences (IAHS), and as first chair of the 2013–2022 scientific decade "Panta Rhei" of IAHS.

Given this exemplary activity building *WRR* as the premier journal for water resources research, it is notable that these efforts yielded a substantial increase in the impact factor of *WRR*.

In summary, Prof. Alberto Montanari has initiated creative and effective innovations that have led to demonstrable increases in the impact of *Water Resources Research*. His extraordinary efforts in serving the scientific community on behalf of the AGU publications program have inspired other editors to implement his ideas. For these significant contributions to advancing AGU publications, he is recognized by the William Kaula Award.

**—Steven Ghan,** *Pacific Northwest National Laboratory, Richland, Wash.*

### *Response*

I am extremely thankful to AGU for awarding me the Kaula Award. I feel profoundly humbled to join the ranks of previous recipients, whom I deeply admire as role models for their dedication to the scientific community. To be the editor of a prominent scientific journal is an enormous privilege that gives one the opportunity to know very interesting people. From every author, reviewer, and editorial assistant, I have gained inspiring ideas and advice. Above all, they shared with me a positive attitude and bright-eyed enthusiasm, as research is a peaceful source of inspiration and faith in humanity and its future.

*Water Resources Research* is the AGU journal I had the privilege to handle. It deals with water science. Together with air, fire, and earth, water is one of the classical elements that in ancient Greece were proposed to explain the complexity of nature. Indeed, water is a synonym for life. I believe that the water cycle still holds fascinating mysteries. Gaining a better understanding of water processes is essential for the sustainable development of environment and humanity.

During my editorial activity, I learned the value of diversity. I did all that was in my power to give voice to all scientists, no matter their personal history or opinion. In fact, I learned that diversity of views is essential for the development of science and society.

I am extremely grateful to the editors who worked with me on *Water Resources Research* and the editors of the other AGU journals. I wish to thank the associate editors and the thousands of reviewers I had the fortune to work with. The amount of energy, passion, and working hours that scientists voluntarily dedicate to refereeing is really amazing. I am indebted to the AGU Publications Committee and the staff of AGU publications for their professional support and their friendship. Working with AGU was one of my best professional experiences. I am thankful to my nominator, Steven Ghan, whom I was privileged to meet at AGU, and my supporters Günter Blöschl, Ximing Cai, and Amilcare Porporato. I am also indebted to the editors of *Water Resources Research* who handled the journal before and after me. I learned a lot from them. Finally, I am grateful to my wife, Flavia, and my son, Nicolò, for their love and their patience during the evenings and nights I spend reviewing papers.

**—Alberto Montanari,** *University of Bologna, Bologna, Italy*

## Miller Receives 2018 Waldo E. Smith Award

*M. Meghan Miller received the Waldo E. Smith Award at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award honors an individual "for extraordinary service to geophysics."*

M. Meghan Miller

### Citation

Dr. Meghan Miller's scientific contributions to geodesy and the growth of the geodetic community and her interest in education, diversity, and fostering the next generation have provided extraordinary service to geophysics. Under her technical and managerial leadership as the president of UNAVCO since 2008, the geodetic community has been transformed into a vibrant and growing organization. UNAVCO is home to the National Science Foundation's geodetic capabilities that serve scientific advances on every continent. Geodesy, in support of geophysics, has flourished under Meghan's leadership. Since Dr. Miller came to UNAVCO, the national and international geodesy community has published 1,653 peer-reviewed contributions supported by UNAVCO services.

Meghan Miller received her Ph.D. in geology from Stanford University in 1987 after receiving a B.S. in geology and geophysics from Yale in 1979. By the 1990s, Meghan had realized the value of geodetic measurements for addressing geologic and geophysical tectonic problems, publishing on GPS determination of Pacific–North American plate motion. In the late 1990s, Meghan transitioned to understanding coseismic motions using GPS with application to the Landers and Hector Mine earthquakes and the eastern California shear zone. In 1991, she joined the faculty of Central Washington University (CWU), taking her geodetic expertise with her and expanding into studying the Cascadia subduction zone. She participated in the first discoveries of slow-slip events along the subduction zone, publishing the results in *Science* (2002) and AGU's *Journal of Geophysical Research* (2004). Following these key scientific contributions and having demonstrated the value of geodetic data to understanding plate tectonics, crustal deformation, and fault and subduction zone processes, Meghan worked to establish the Pacific Northwest Geodetic Array, which later became part of EarthScope's Plate Boundary Observatory.

Throughout her 27 years of exceptional leadership, Dr. Miller's interest in education and fostering the next generation has never flagged. In lockstep with carrying out scientific research and leading the geodesy community, Meghan has improved education and outreach. Dr. Miller transformed the geology program at CWU while advancing our scientific understanding of tectonic processes. She served as dean of the College of Sciences from 2002 to 2008. During this time, she established a master's program at CWU, supervised eight master's theses, held two editorships, and produced 11 field trip guides, geologic maps, book reviews, and invited papers! Meghan Miller has been truly exceptional in her scientific contributions and in serving the entire geodetic community ranging from early students to senior researchers.

**—Andrea Donnellan,** *Jet Propulsion Laboratory, California Institute of Technology, Pasadena*

### Response

I am humbled and honored to be recognized with the Waldo E. Smith Award for extraordinary service to geophysics. I am grateful to Dr. Andrea Donnellan for leading the nomination and to my colleagues who supported it, Roger Bilham, Jeff Freymueller, and Bill Holt. Thank you! I am thrilled to have found a career path that I love, one that has been rich in serendipity and opportunities to advance geophysics research and education for the benefit of science and society. Among my greatest pleasures is the community of talented geodesists I work with; collectively they have driven a geophysics renaissance by the creative application of the emerging GPS/Global Navigation Satellite System (GNSS), interferometric synthetic aperture radar (InSAR), and lidar technologies that we collectively call geodesy.

My path has been circuitous. My early career focused on the geology of active tectonic plate margins, particularly the Klamath Mountains, the eastern California shear zone, and the Cascadia subduction zone. As a postdoc at the Jet Propulsion Laboratory, I got lucky with early GPS campaign observations in the Mojave Desert and Baja California (NASA) and was able to "capture" the Landers earthquake the year after an initial GPS campaign. Then Central Washington University took a chance on me.... Working with Canadian and U.S. Geological Survey (USGS) colleagues, we built the first international Cascadia GPS network—PANGA (National Science Foundation, the Canadian Geological Survey, and USGS)—and established continuous GPS stations near historical tide gauges in coastal California and the U.S. portion of Cascadia (with NASA support).

But the work I love most is with students: running GPS campaigns and building networks, cultivating the next generation of scientists, building a student-centered geology faculty, initiating the CWU master's program, and watching students fledge to advance their own dreams.

At UNAVCO, I am lucky to serve an international science community that studies the Earth and its fluid envelopes at a spectrum of temporal and spatial scales, from individual fault or volcano systems to continent-scale geodynamics, and the storage and cycling of water through solid Earth, surface reservoirs, and the atmosphere.

Little of this was the path I meant to follow; it was simply the path that presented! But serendipity has created so many opportunities to serve geophysics, in ways that didn't even exist when I was a student! I am deeply honored to receive the Waldo E. Smith Award for extraordinary service to geophysics.

**—M. Meghan Miller,** *UNAVCO, Boulder, Colo.*

## Neumann Receives 2018 Charles S. Falkenberg Award

*Rebecca B. Neumann received the Charles S. Falkenberg Award at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award honors "an early- to middle-career scientist who has contributed to the quality of life, economic opportunities, and stewardship of the planet through the use of Earth science information and to the public awareness of the importance of understanding our planet."*

Rebecca B. Neumann

### Citation

From her early career, Becca has been passionate about combining fieldwork with laboratory analyses, Earth science data, and models to discover insights into large-scale societal problems, such as arsenic contamination of groundwater in Asia, methane emission from peatlands of the Arctic, and food quality challenges in a changing climate. She has always dared to tackle wicked problems by traveling around the world and has put herself in difficult situations.

As a graduate student at the Massachusetts Institute of Technology (MIT), Becca focused on the large-scale problem of arsenic contamination in groundwater in Bangladesh. Her work advanced understanding of how land surface modifications related to water resources management and agricultural development could affect groundwater arsenic concentrations by altering water and carbon fluxes through the soil and aquifer. By focusing on fundamental physical and biogeochemical processes, her research resulted in a number of concrete suggestions for policy makers and land use planners, including approaches for reducing agricultural water use, providing the area with arsenic-free drinking water, and minimizing future arsenic contamination.

After MIT, Becca's continued work in Bangladesh demonstrated that current irrigation practices can actually result in more methane gas being released into the atmosphere from pumping methane-rich groundwater than what paddy fields normally release through the slower decomposition processes. This archaic irrigation practice by millions of farmers who actually feed nations is in urgent need of improvement to meet the challenges of the 21st century. Becca responded to this need, publishing a study demonstrating that the simple act of sealing the boundaries of rice fields can save a large amount of irrigation water and unnecessary emissions of methane.

In more recent times, Becca has articulated the risk of legacy arsenic in Puget Sound lakes to aquatic ecosystems and human health via fish. She has developed a mechanistic understanding of how arsenic uptake by rice will change with warming temperatures in rice-producing countries. She is also investigating how dam development on the Mekong may alter rice production and grain quality in Tonle Sap Lake of Cambodia. Because of her recognized expertise in these areas, she was asked to review the California Environmental Protection Agency's draft scientific document titled "Proposed Naturally Occurring Concentrations of Inorganic Arsenic in White and Brown Rice" in 2017. A little farther north of her workplace in Seattle, Becca has been engaged in fieldwork in the Arctic to understand how warming may change greenhouse gas concentrations as permafrost melts.

I am thrilled that AGU has bestowed on Becca the Falkenberg Award for 2018.

**—Faisal Hossain**, *University of Washington, Seattle*

### *Response*

I entered environmental research because I wanted to protect human and environmental health globally, and I believed that through research I could generate the knowledge and understanding needed to create sound policy and management strategies. While I feel that there is always more to achieve, receiving the Charles S. Falkenberg Award is recognition that my work so far has had a positive impact and, quoting the award criteria, "contributed to the quality of life, economic opportunities, and stewardship of the planet." I feel fortunate to have a career that gives me the freedom to pursue these ideals, tackling societally relevant problems in a multifaceted and cross-disciplinary way.

I want to thank Faisal Hossain for recognizing the impact of my efforts and nominating me for the award. I am awed by his apparently bottomless reservoir of energy and encouragement. I am also grateful to those who, in addition to supporting my nomination, have mentored and guided me in my research career: Charles Harvey, Zoe Cardon, Borhan Badruzzaman, Roger Beckie, and Jim Gawel. Acknowledgment is also due AGU, the Earth Science Information Partners (ESIP) federation, and the Falkenberg Award review committee.

I did not know Charles Falkenberg, but from his legacy it is clear that he was committed to involving the public in Earth science. Moving scientific knowledge beyond the ivory tower is a difficult and daunting task, but it is an important endeavor. I am energized by recent efforts of AGU, my home institution (University of Washington), and other organizations to provide scientists with the communication and networking skills needed to make their science actionable. I am actively taking advantage of these opportunities and building skills to better realize my goal of translating research results into policy and management strategies that protect human and environmental health. I am optimistic that as a scientific community, we will only get more proficient at navigating the science–public interface. At the University of Washington, I am surrounded by energetic undergraduates, graduate students, and postdoctoral researchers who are truly motivated to make positive change in the world and already have the soft skills needed to engage the public, policy makers, and journalists.

It is an honor to be part of Charles Falkenberg's legacy. I am inspired to continue moving the findings of my own research program into the public and policy spheres and supporting others with this important undertaking.

**—Rebecca B. Neumann**, *Civil and Environmental Engineering, University of Washington, Seattle*

## Young Receives 2018 Athelstan Spilhaus Award

*C. Alex Young received the Athelstan Spilhaus Award at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award honors an individual for the "enhancement of the public engagement with Earth and space sciences."*

C. Alex Young

### *Citation*

The Athelstan Spilhaus Award recognizes exceptional skill, dedication, and success in informing the public of the value, beauty, and excitement of Earth and space science research. Dr. Alex Young embodies these virtues as an outstanding communicator and a national asset to the space science community.

As an enthusiastic and effective communicator, Alex has made extraordinary contributions to enhancing the public's understanding of space science. He has contributed to half a dozen science documentaries; given hundreds of live interviews to news media for NASA; responded to journalists from local to international levels; and reached thousands of children and adults via classrooms, museums, libraries, clubs, professional societies, and science fiction events across the country. These activities led him to become the associate director for science in the NASA Goddard Space Flight Center's Heliophysics Science Division, where he developed and continues to lead a national education program for space science through the NASA Science Mission Directorate.

Alex's leadership as the program manager of NASA's 2017 total solar eclipse national education and outreach effort exemplifies his dedication and impact. He led efforts in the largest, most complex, most inclusive, and most impactful public engagement program ever executed by NASA. These successful efforts encapsulate the unique combination of vision, strategic planning, team leadership, and intense personal energy that he applies toward his ultimate goal: widespread and lasting public engagement with space science. Alex did not stop at leading the efforts; he was in the trenches as the primary spokesperson for NASA. He made more than 50 presentations leading up to the eclipse to promote NASA science activities and especially safe solar viewing. These presentations happened coast to coast, from the Library of Congress and professional society meetings to a local county library in an underserved region of Delaware. On any given day, Alex was responding to multiple journalists, interviewing with the *New York Times,* and creating videos with the *Washington Post.* He gave over 60 interviews spread over four separate live-shot events through the NASA Goddard television studio. Dr. Young also served as a subject matter expert for the NASA associate administrator for science during a NASA preeclipse press conference and a posteclipse House and Senate subcommittee hearing on the eclipse.

The eclipse program was only Alex's latest achievement among many over the past decade and more. He has more than demonstrated that he is a most deserving recipient of AGU's 2018 Athelstan Spilhaus Award.

**—Holly Robin Gilbert**, *NASA Goddard Space Flight Center, Greenbelt, Md.*

### *Response*

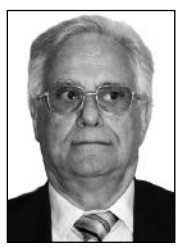
It is amazing to be noted for doing one's passion, so I am deeply honored to be recognized with the Athelstan Spilhaus Award by AGU. Sharing the thrill and wonder of the universe with friends and strangers through communicating the excitement of space science is a personal joy. But even more so is knowing that I have the support and understanding of my peers, mentors, family, and friends. Whether it be a TV broadcast from the top of a mountain, under the shadow of an eclipse, or sitting with a roomful of children, sharing nature's glory and seeing the awe inspired in someone's eyes are themselves beautiful to behold. And I believe that bringing the complexity and wonder of the world and beyond to a single person and maybe even to society is a critical part of science at its best.

No one gets there on their own. Thank you to all my colleagues, who not only have helped me to learn and share my own science but also have given me the breadth of their knowledge to bring to others. Without their love and drive for science, this grand adventure would not be possible. I especially thank my teachers and mentors, in particular, Holly Gilbert, Michael Hesse, Joe Gurman, Kristen Erickson, Jim Ryan, and Dawn Meredith and my team. They have believed in me and supported me through a winding career. Thank you to my parents for their foundation. And a special thank you to my wife, Linda, my Sun, Moon, and stars, who inspires and pushes me to new heights.

**—C. Alex Young**, *NASA Goddard Space Flight Center, Greenbelt, Md.*

## Panza Receives 2018 International Award

*Giuliano Francesco Panza received the International Award at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award honors an individual "for making an outstanding contribution to furthering the Earth and space sciences and using science for the benefit of society in developing nations."*



Giuliano Francesco Panza

### *Citation*

I was able to follow the international scientific and teaching activity of G. F. Panza for more than 30 years.

At the beginning of the 1990s, Prof. Panza, together with strong support from Prof. Keilis-Borok (of Russia), created, in the framework of the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, two new biennial workshops on seismology for young geophysicists from third world countries. One of the workshops was dedicated to the genesis and prediction of earthquakes, as well as to related tectonic problems; the other was dedicated to the generation, propagation, and interpretation of three-dimensional seismic waves.

These regular workshops attracted young seismologists from countries in Asia, Africa, South America, and elsewhere who were able to listen to lectures from internationally distinguished scientists and have personal contact with

them, as well as to learn modern techniques for computer-based analysis of observations. These workshops, under the continuous control and leadership of Prof. Panza, continued for 2 decades, up to 2010, and had a significant effect on the development of seismology in third world countries. Many of the participants continued to be in close contact with Prof. Panza and relied on his advice for their Ph.D. theses in seismology and obtained leading positions in geophysical institutions in their countries. Prof. Panza's tireless support in raising money to fund these workshops, even in economically difficult times, as well as persuading leading scientists to participate, was impressive. The quality of these workshops became so high that both the U.S. National Science Foundation and the European Union each funded 12 graduate students to participate twice in the early 2000s. Several participants of the workshops became professors in the United States and other developed countries.

I therefore consider Prof. Panza ideally suited to receive AGU's International Award.

**—Anatoli L. Levshin**, *University of Colorado Boulder*

### *Response*

Heartfelt thanks, Tolya, for your generous citation for the 2018 AGU International Award, notification of which was a total surprise! Knowing that such famous scientists as Shamita Das, Yuntai Chen, Anatoli Levshin, and Francis Wu nominated me makes this award very special. In gratitude, I thank my mentors as well: Markus Båth, Michele Caputo, Vladimir Keilis-Borok, Leon Knopoff, Anatoly Levshin, Stephan Mueller, Fred Schwab, and Nobel laureate Abdus Salam, who signified ICTP's golden age.

On a 12 December, I married Rita, who has always accepted my frequent and sometimes prolonged absences, making possible my focus on international training and scientific cooperation; on a 4 December, I earned a doctorate in physics from Bologna University; and on a 6–9 December I gave my first overseas presentation at an AGU Fall Meeting.

One could draw the conclusion that December is a recurring month, albo lapillo dingus, and even more so, 12 December, dies albo signando lapillo, since December marks very important events for me. These conclusions, based on scarce data, are invalid! The problem of invalid conclusions is not alien in science. I have invested career-long scientific training efforts to show how chimeric (fanciful) the concept of earthquake "return period" can be, as universally applied in earthquake engineering. Certainly, it does not apply to the following recognition chronology: April, EGU Gutenberg Medal, and July and March, nomination in Accademia dei Lincei and the Russian Academy, respectively.

Our 1980 Europe model of the lithosphere–asthenosphere system (in the Alpine domain; subduction is not limited to the oceanic lithosphere but also affects the continental lithosphere) contributed to furthering the Earth sciences, leading to the 2012 Polarized Plate Tectonics model, wherein tidal forces contribute significantly to plate motion.

The award also recognizes the "advent of the paradigm" I introduced in *Advanced Earthquake Hazard Assessment,* even while encountering opinionated and stubborn resistance. Hopefully, it will have some influence on national seismic codes.

The by now well-known neo-deterministic seismic hazard assessment (NDSHA), mostly developed since the 1980s by the ICTP-SAND group and published in 2000, exemplifies the use of science for societal benefit. NDSHA, validated by the main earthquakes occurring in Italy after 1997, is now widely applied in Europe and developing nations.

When combined with intermediate-term and middle-range earthquake prediction algorithms, NDSHA allows for improved time-dependent hazard assessment.

Many thanks to the International Award Committee for this tangible recognition, not a chimera, of the work I have done during my long international academic career, always with commitment to improved public safety against earthquakes!

**—Giuliano Francesco Panza**, *Accademia dei Lincei and Accademia dei XL, Rome, Italy*

## Chandler Receives 2018 Excellence in Earth and Space Science Education Award

*Mark A. Chandler received the Excellence in Earth and Space Science Education Award at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award honors a team, individual, or group "for a sustained commitment to excellence in geophysical education."*

*Mark A. Chandler*

### *Citation*

It gives me great pleasure to cite Mark Chandler for the Excellence in Earth and Space Science Education Award. Mark's dedication to ensuring that students have the tools to effectively learn about the Earth system can be seen in the development history of the Educational Global Climate Model (EdGCM). Mark's inspiration for creating EdGCM came from working at NASA Goddard Institute for Space Studies with summer institute students who wanted to run climate model experiments themselves, despite not always having access to NASA's programmers and supercomputers. Mark wanted something that would give students hands-on experience with a global climate model and also teach them the steps of the scientific process that climate modelers follow in conducting their research. Moreover, he believed that this would help demystify the role of modeling in climate science at a time when skepticism of complex models was growing, something that has important ramifications for a public needing to make and understand policy decisions aimed at mitigating climate change.

Mark began work on the project with some talented high school students in the mid-1990s but received initial funding in 2003, when the National Science Foundation's Paleoclimate Program saw the potential impact of the idea. NASA's High-Performance Computing Program followed, and EdGCM was released publicly in January 2005. To keep EdGCM sustainable, the project partially transitioned to a license-based distribution system, a necessity when NASA's Global Climate Change Education Program funded nine projects that all planned to use EdGCM.

While enthusiasm for EdGCM grew, feedback from high school teachers indicated that it remained too difficult to manage, especially given classroom time constraints and the proliferation of tablets and Chromebooks. Mark responded with a browser-based tool called EzGCM for the K–12 community, which is now in use by the American Museum of Natural History and is being piloted in Lincoln, Neb., public schools, together with a curriculum developed with the University of Nebraska.

There have been >40,000 downloads of EdGCM and so far over 3,000 users of EzGCM. The software has seen use on seven continents and at nearly 200 institutions, covering subjects that include atmospheric science, climate change and impacts, environmental science, engineering, geography, and physics. Mark has personally given over 100 presentations and workshops since 2000.

For his unwavering dedication to the development and support of EdGCM and its effective use in teaching secondary and postsecondary students, Mark Chandler clearly deserves the AGU Excellence in Earth and Space Science Education Award.

**—Tamara Shapiro Ledley**, *Independent STEM Education Consultant, Earth and Climate Scientist, Needham, Mass.*

### *Response*

I am honored to receive the 2018 Excellence in Earth and Space Science Education Award. It gives me special satisfaction to accept the award for the team of the Educational Global Climate Model (EdGCM) project. There are few scientific endeavors that take a more sustained team effort than developing a GCM, and the fact that EdGCM exists at all is a testament to the talented scientists and programmers at NASA Goddard Institute for Space Studies. They have had open doors and given invaluable advice, and I'm immensely grateful. My other team, who spent 7 years developing EdGCM, consisted almost exclusively of high schoolers and undergraduates who were hardworking, creative, excited just to be at NASA, and like most youth, adept at doing things others said shouldn't be done. While part of me is amazed that EdGCM even exists and is used by so many, I think my students knew then that teachers needed such tools to engage and convince their own emerging skeptical generation. In 2018, when skepticism seems to be rising faster than atmospheric $CO_2$ levels, the need for educational support of authentic classroom research has become an imperative. And if climate scientists will create great modeling tools that not just work for researchers but also allow students to participate in the process, I'm certain we won't spend so much time trying to convince people of the efficacy or urgency of our findings. In 1996, climate scientist David Randall wrote, "GCMs will begin running on workstations in high schools, and possibly elementary schools. They may even be running in the offices of congressmen." I believed him then (he's an AGU Fellow, after all), but I just didn't realize I'd still be trying to make it happen 22 years later. I wish we'd made more progress, but the next 22 years look promising.

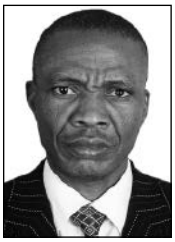
I thank NASA and the National Science Foundation for supporting EdGCM, the concept behind it, and the people

who use it. I thank my dedicated team (all two of them) who work hard to support EdGCM's users. Finally, I thank all educators who take on the role of teaching climate science and using climate models despite the obstacles placed by administrators, politicians, budget cuts, and bugs in EdGCM. I hope that together we will provide even better learning experiences under the Next Generation Science Standards and give next-generation science students the tools and opportunities they deserve to solve the problems we have bequeathed to them.

**—Mark A. Chandler**, *NASA Goddard Institute for Space Studies, Columbia University, New York*

## Aizebeokhai Receives 2018 Africa Award for Research Excellence in Earth Sciences

*Ahzegbobor Philips Aizebeokhai received the Africa Award for Research Excellence in Earth Sciences at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award recognizes an early career scientist from the African continent "for completing significant work that shows the focus and promise of making outstanding contributions to research in Earth sciences."*



*Ahzegbobor Philips Aizebeokhai*

### *Citation*

Carrying out innovative research in an environment without adequate infrastructure, ranging from electricity and Internet access to research equipment, could be challenging and demotivating. This has often been the story for most young geoscientists who studied and worked in Nigeria or most other sub-Saharan African countries. They have had to quit research, resolve to do only "desktop research" and teaching, or emigrate to a developed country. This, however, has not been the case with Dr. Ahzegbobor Philips Aizebeokhai. In spite of having studied in and currently working in Nigeria, he has chosen to defy the setbacks due to the lack of research facilities and resolved to work hard making use of available resources, mining collaborative opportunities when possible, and, above all, maximizing available learning opportunities. Dr. Aizebeokhai's recognition with AGU's Africa Award for Research Excellence in Earth Sciences for his contributions in applying hydrogeophysical methods to solving groundwater and environmental challenges in Nigeria is highly deserved and serves as motivation not only for him but also for other young scientists defying the odds and tasking their innovation to solve societal challenges, mostly in sub-Saharan Africa.

Dr. Aizebeokhai obtained his M.Sc. and Ph.D. degrees in applied geophysics from the University of Ibadan and Covenant University, respectively, in Nigeria. During his doctoral research, he worked closely with Prof. Olayinka of the University of Ibadan and Dr. Singh at the Groundwater Research Group of the National Geophysical Research Institute in Hyderabad, India, where he developed 2-D and 3-D field electrical resistivity designs for groundwater investigations in southwestern Nigeria. Since completing his Ph.D. in 2010, he has remained committed to his research on applying geophysical methods for hydrogeological, engineering, and other environmental investigations and has published over 30 scientific papers in both local and international journals. In addition to his research, he is deeply committed to teaching and capacity development for young geoscientists.

In recognition of his research excellence, demonstration of high self-motivation, and commitment to teaching, he was recently promoted from the position of a senior lecturer to a full professor at Covenant University. Prof. Aizebeokhai's research, teaching, and service contributions show great potential for contributing to effective management of water and environmental resources in sub-Saharan Africa.

**—Kennedy O. Doro**, *Science for Development Research and Teaching Initiative, Lagos, Nigeria*

### *Response*

I express my profound gratitude to AGU's Honors and Recognition Committee for finding me worthy of the AGU Africa Award for Research Excellence in Earth Sciences. My sincere appreciation goes to my mentors, Prof. A. I. Olayinka of the University of Ibadan, Ibadan, Nigeria, and Dr. V. S. Singh, Scientist Emeritus of the National Geophysical Research Institute (NGRI), Hyderabad, India. They are the giants on whose shoulders I stand tall and strong; they taught me the art and science of near-surface geophysics. I thank Covenant University for giving me the platform to teach and conduct research in near-surface geophysics. I thank my students, who have always assisted in the field survey. I am grateful to my wife, Uyoyo Anita Aizebeokhai, for her encouragement and support over the years.

Each time I attend a Society of Exploration Geophysicists (SEG) Annual Meeting, when I consider the volume and quality of research work presented by geoscientists across the globe, my heart bleeds because only a handful of the presentations are from Africa. At the 2016 SEG Annual Meeting, for example, out of the several thousands of papers scheduled for presentation, I was the only Nigerian living in Nigeria who made a presentation; the other Nigerians who presented at that conference are living in the United States, Canada, or Europe. The situation is the same in most geoscience international conferences. This shows that Africa is not contributing much in terms of research output to the geoscience world. This may be due to a number of constraints that characterize the research climate in Africa; the most important constraints include inadequate research infrastructure, poor training in the art and science of research, lack of motivation due to poor research incentives from government and institutions, and poor funding. Most researchers in Africa either are not aware of existing funding opportunities or are unable to write competitive research grant proposals to fund research.

I have been faced with all of these challenges; apart from the fact that I was lucky to win a TWAS-CSIR Postgraduate Fellowship at NGRI in 2008 and an SEG Foundation Travel Grant in 2009, I have practically been funding my research from my salary. This naturally poses limitations to the kind of research I am able to conduct. My main motivation for research is born of a strong desire to help raise a new generation of geoscientists with the right paradigm in Africa.

**—Ahzegbobor Philips Aizebeokhai**, *Covenant University, Ota, Ogun State, Nigeria*

## Ouattara Receives 2018 Africa Award for Research Excellence in Space Science

*Frédéric Ouattara received the Africa Award for Research Excellence in Space Science at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award recognizes an early career scientist from the African continent "for completing significant work that shows the focus and promise of making outstanding contributions to research in space science."*

*Frédéric Ouattara*

### *Citation*

After a first thesis about the thermodynamics of African homes, Dr. Frédéric Ouattara chose in 2006 to focus his studies on the relationships between the Earth and the Sun. He participated in the International Heliophysical Year project and defended his state thesis in 2009 on the basis of six articles published in rank-A journals. He currently has 30 publications in well-known journals, such as *Journal of Atmospheric and Solar-Terrestrial Physics, Annales Geophysicae, Journal of Space Weather and Space Climate, Journal of Geophysical Research,* and *Advances in Space Research.*

His thesis was titled "Contribution to the study of the relations between the two components of the solar magnetic field and the equatorial ionosphere." It was defended at the Université Cheikh Anta Diop, Dakar, in October 2009.

This is the first thesis linking the poloidal and toroidal components of the solar magnetic field to the critical frequency of the F region of the ionosphere, with a direct impact on high-frequency propagation. He trained a team of six researchers in Burkina Faso and is currently developing the University of Koudougou, where he is vice president.

**—Jean Lilensten**, *Institut de Planétologie et d'Astrophysique de Grenoble, Saint-Martin-d'Hères, France*

### *Response*

It's a great pleasure and honor for me to receive the 2018 edition of the AGU Africa Award for Research Excellence in Space Science. I am grateful to the selection committee for appointing me, a modest Burkinabe scientist from West Africa, for such a distinction. I also show my deep gratefulness to Sunanda Basu for having the bright idea to establish this prize since 2015. I would also thank the present AGU award committee for the necessary measures they took to enable me to participate in the unfolding and famous ceremony. I am indebted to Drs. J. Lilensten from the Planetology Laboratory of Grenoble, A. Elias from the National University of Tucumán, and Le Huy Minh from the Institute of Geophysics of Hanoi, who invested themselves so as to help me apply for this prize, for their precious contributions, suggestions, and recommendations.

I defended my Ph.D. oriented on the study of the components of the solar magnetic field and their effects on ionosphere variability at Université Cheikh Anta Diop (Senegal) in 2009 under the scientific direction of Prof. G. Sissoko. I thank the late Dr. O. Fambitakoye, who encouraged me to study space sciences at the school of Abidjan in 1995. After this Ph.D. defense, I created the Energetic and Space Weather Research Laboratory at Université Norbert Zongo. I led a research team at this university on the West African equatorial ionosphere variability. Let me take the opportunity here to thank sincerely the Fulbright Scholar Program for granting me in 2012 a 9-month enriching and beneficial stay at the High Altitude Observatory. I am grateful to the director of this institute as well as to all my collaborators who did their best to make this scientific exchange a real success. I am particularly indebted to Drs. A. Richmond and A. Maute.

My acknowledgments are especially directed toward Prof. C. A. Mazaudier, who supervised my dissertation. I thank Dr. R. Fleury for his collaboration, training, and the ionospheric data. I would like to thank Drs. J. P. Legrand and P. N. Mayaud for our exciting scientific discussions during my stay in Paris.

I cannot end my speech without showing my love to my beloved wife and my paternal love to my children and let them know that the present prize is the fruit of their different sacrifice and understanding.

Glory to the Almighty Good, the Provider.

**—Frédéric Ouattara**, *Université Norbert Zongo, Koudougou, Burkina Faso*

## Davis Receives 2018 Science for Solutions Award

*Kyle Frankel Davis received the Science for Solutions Award at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award recognizes a student or postdoctoral scientist "for significant contributions in the application and use of the Earth and space sciences to solve societal problems."*

*Kyle Frankel Davis*

### *Citation*

Dr. Davis's research addresses questions in the general area of global crop production, water and food security, environmental sustainability, and the food–water–energy nexus. His early work evaluated the extent to which agricultural intensification would be able to meet the increasing food demand of human societies under a variety of dietary and land use change conditions. His research quantitatively demonstrated how—under suitable diet moderation and agricultural intensification scenarios—enough water and food would be available to feed the growing global population until the end of the century. He also evaluated the "hydrologic feasibility" of yield gap closure scenarios.

His research has also investigated ongoing changes in livestock production and quantified the relative importance of feed-fed and grass-fed production in different regions of the world and the associated impacts on the water footprint of the livestock. He identified patterns of virtual water flow associated with the animal feed trade and documented the ongoing "livestock transition" resulting from the increasing reliance on less resource intensive livestock types.

One of the effects of the recent food crises has been the increase in transnational investments in agriculture by agribusiness corporations. Kyle's research has evaluated the role of climate change in this phenomenon and quantified the impact of large-scale land acquisitions on rural livelihoods and the environment. His work focused on the impact of large-scale land acquisitions on land use change and demonstrated how the ongoing land rush is contributing to deforestation in Cambodia.

Some of his research work is investigating alternative models of agricultural development that would allow for an increase in yields without requiring massive investments in modern irrigation technology that local farmers in the developing world would not be able to afford. For instance, by planting more suitable crops in the "right place," it would be possible to increase food production while reducing water consumption.

Collectively, these contributions demonstrate his ability to identify important societal problems and develop a research agenda that can provide the basis for effective solutions. Through fieldwork in Mozambique, Nigeria, and India, he is filling the gap traditionally existing between science and the solution of societal problems by means of interactions with local farmers, communities, and policy makers in some of the areas of the world that are most in need. Kyle has a unique intellectual curiosity, a diverse range of interests, and a strong personal motivation to contribute to a better world with his work and studies.

**—Maria Cristina Rulli**, *Politecnico di Milano, Milan, Italy*

### *Response*

I am greatly humbled and honored to be receiving the 2018 Science for Solutions Award. I am deeply grateful to Cristina Rulli for leading my nomination, to the award committee for their time and effort during the selection process, and to AGU for its continued support of early-career scientists.

As with many of us, I was originally drawn to Earth and environmental sciences by a fascination with nature and the excitement of scientific discovery. While the role of such scientific curiosity and of basic science will always be vital to what we do, there is a growing need for research that pursues direct benefits to societal challenges. Processes like globalization and climate change mean that the issues facing decision makers are increasingly complex. As scientists, we have a critical role to play in understanding these interconnections and in providing evidence and information that are readily comprehendible beyond our scientific community. Developing relationships with stakeholders and decision makers will be essential for bridging the gap between our science and the policies that it can ultimately help to inform. AGU's efforts at improving the ability of its members to effectively interact and communicate with the public and policy makers—for example, through its Science Policy and Sharing Science initiatives—are recognition that these skills and connections are becoming increasingly important for researchers and for young scientists in particular.

All of my work continues to be possible due in large part to the guidance, support, and collaborative efforts of a great many people. I am especially indebted to my Ph.D. and postdoctoral advisors, Paolo D'Odorico and Ruth DeFries, who have encouraged me to think big, to be creative, and to pursue solutions that benefit people and the environment. I am also grateful to Cristina Rulli and Brian Richter for the invaluable roles they have played in nurturing my scientific interests and for showing me that my work can potentially play a part in tackling some of today's grand societal challenges. I would also like to thank The Nature Conservancy and Columbia University's Earth Institute and Data Science Institute for their support of my work.

Thank you again for this award. I am excited to be part of the next generation of international scientists with profound and far-reaching opportunities for (and challenges to) realizing positive change for people and the planet.

**—Kyle Frankel Davis**, *Columbia University, New York*

## Fox Receives 2018 Walter Sullivan Award for Excellence in Science Journalism–Features

*Douglas Fox received the Walter Sullivan Award for Excellence in Science Journalism–Features at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December in Washington, D. C. The award "is presented annually to a journalist for a feature story or series in any medium except books that makes information about the Earth and space sciences accessible and interesting to the general public."*

Douglas Fox

### Citation

Douglas Fox has spent much of the past 11 years writing about ice: how microscopic dust grains spawn high-altitude ice crystals that lead to rain, how the ice crystals that compose the rings of Saturn led scientists to discover a potential habitat for life deep inside one of Saturn's moons, and the surprising role that ice may have played as a cradle for the origin of life on Earth 4 billion years ago.

But it was pure serendipity that piqued Doug's interest in ice's elemental opposite. While researching a story on climate change in 2015, he happened to speak with a wildfire scientist who told him how little we actually know about the inner workings of a flame.

Whether a single burning match or a roaring forest inferno, a fire's essence is its rising column of hot, buoyant gases. The smoke plume that billows thousands of feet above a wildfire drives its intake of fresh oxygen and, ultimately, its dangerous behavior on the ground. Doug loved the idea of writing about the ephemeral and unexplored heart of a wildfire, in a story about nothing more than hot air. The topic may seem small and mundane from the outside yet turns out to be vast and expansive on the inside. Doug spent over a year working on his feature story "Firestorm" (*High Country News,* 3 April 2017), which won the Walter Sullivan Award.

His story traces the unlikely roots of our knowledge on extreme fire behavior, from the incendiary bombing raids of World War II to studies that were performed during the Cold War to predict the impact of nuclear explosions on American suburban neighborhoods. The story reveals the surprisingly destructive power of seemingly trivial forces: the condensation of water vapor exhaled from combustion, a physiologic trait shared by both humans and wildfires. Most important, his story illuminates an archetypal theme in science: how an invisible force, be it magnetism, radiation, or pathogenic microbes, finally became visible to humans for the first time. This story, in other words, helps us see the world in a brand-new light: the light of a burning flame.

**—Brian Calvert**, High Country News, *Paonia, Colo.*

### Response

It's a tremendous honor to earn the Walter Sullivan Award, and I want to thank AGU for supporting journalism.

I am especially happy to see the honor go to this particular story ("Firestorm") because of the recognition that it brings to a number of other people who greatly deserve it.

*High Country News,* which published the story, has shown such a commitment to the accurate and nuanced telling of complicated stories—a commitment to storytelling not just as a service to the public but also as an art form. No story can live up to its full potential without a proper investment in time, money, space on the page, and the meticulous attention of editors, and Brian Calvert, the magazine's editor in chief, has seen to it that *High Country News* accomplishes this again and again.

I am especially grateful to Sarah Gilman, who was my editor on this story and who was a joy to work with, for so many reasons. She was unfailingly excited about this story—seemingly every bit as excited as I was—from the moment that I first approached her with the idea, in September 2015, to the day that it was finally published, in April 2017. She has a deep interest in storytelling—a true talent for it and a perceptive eye—and as she and I partnered on revising this piece, she constantly challenged me to think clearly about the grand arc of the story, the analogies and metaphors that would shape the reader's understanding, the rhythm of scenes and explanation, and the precise placement of images and details, from the biggest mushroom cloud to the tiniest flicker of a flame. Not every story lives up to its full potential—but I believe that this one did—and I give her equal credit for making that happen. It was hard work but enjoyable and rewarding. Thank you so much, Sarah!

**—Douglas Fox**, High Country News

## Hall Receives 2018 David Perlman Award for Excellence in Science Journalism–News

*Shannon Hall received the David Perlman Award for Excellence in Science Journalism–News at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The award recognizes a journalist for "excellence in science news reporting, defined as work prepared with a deadline of one week or less."*

Shannon Hall

### Citation

Many of the best science stories start as hidden gems, overlooked by the crowd and encrusted in layers of equations, jargon, and other obfuscating material. It takes determination, imagination, and a very high level of craft to unearth them and polish them to a sparkle.

Shannon Hall knows where to look and what to do. For as long as I've known her (she was my student in 2014–2015), she's always had the ability to transform dense science into shiny narratives that audiences treasure as both entertainment and information.

Shannon is a trained astronomer, with undergraduate and master's degrees in the discipline (and a master's in science journalism too). But I like to think that it's her other undergraduate major, in philosophy, that says the most about what propels her work today. Shannon is mission driven, and her mission is to help lay audiences understand and even cherish the centrality of science and scientific thinking in their daily lives. She finds ignorance intolerable, so she pushes herself to find creative ways to make her stories fresh and appealing—and accurate, always scrupulously accurate.

It's why you can pick up the *New York Times* on a steamy midsummer day and find a story by Shannon enthusiastically explaining the weirdness of Earth's orbit and why the distance to the Sun has nothing to do with seasonality. It's also why you can find her patiently sparring online with readers who just can't quite understand why the discovery of a "supervolcano" beneath Yellowstone National Park does not mean the apocalypse is nigh.

Shannon's prizewinning story for *Scientific American* about plate tectonics on exoplanets beautifully illustrates her process. She came up with the idea one morning while scanning primary source material, in this case the arXiv preprint server of about-to-be-published papers. The study she found was both opaque and highly speculative, because our ability to assess the composition of distant worlds is still severely constrained. Most reporters, even astrophysics specialists like Shannon, gave it a pass. But the vision of volcanoes, earthquakes, oceans, and continents churning on planets trillions of miles away fired Shannon's always-smoldering imagination.

She quickly pitched her idea to *Scientific American,* got the approval she needed, and plunged into the work, reading and reporting intensely through the weekend and turning around a very complicated feature story in just 5 days. The result was a timely story that not only got readers excited about the nascent field of exogeology, but also, and probably more important, gave them a fresh appreciation for the unusually lively tectonics of our home world and for the life that almost certainly could not have evolved without it.

**—Dan Fagin**, *New York University, New York*

### Response

It is a dream come true to receive the David Perlman Award, both because David carved a legendary career and because so many other inspiring journalists won this award before me.

I'd like to share credit for this story with Clara Moskowitz, my editor at *Scientific American,* who accepted my pitch, provided guidance, and edited the story in a smart and thoughtful manner. She even said yes when I begged her for a slightly longer word count.

Needless to say, the story would not have been possible without Clara or the generous help of the scientists I interviewed. I am so appreciative of the geologists who talked to me—even providing background that was not ultimately quoted in the story. And there was a lot of background!

I have never taken a formal class in the Earth sciences. But geologists have welcomed me into their labs and invited me to join their fieldwork. They have gone out of their way to talk to me, often calling me during their holidays and emailing me from the field. Although many past award winners have spoken of this incredible generosity, I think it is worth reiterating,

in part because I would like to ask scientists to keep this chain of communication open. Today it is more crucial than ever.

More broadly, I'm grateful to Dan Fagin, the director of NYU's Science, Health and Environmental Reporting Program, for his kind words here—and in the past. He has long supported me (and so many others) by providing feedback, a push when necessary, and constant advice. It was Dan who first encouraged me to write about topics beyond astronomy, a nudge that ultimately helped me widen my lens to include our pale blue dot and the awe-inspiring processes that shape it.

And finally, I'd like to thank my husband. With this news story, I found myself facing a fast approaching deadline, but my husband immediately carved time out of our busy lives so that I could work. This is something he has done time and time again, allowing me to hit so many deadlines that seemed insurmountable—and without him, they probably would have been.

So it is with deep gratitude that I accept this award. Thank you.

**—Shannon Hall**, *Freelance Science Journalist, Boulder, Colo.*

## Dugan Receives 2018 Asahiko Taira International Scientific Ocean Drilling Research Prize

*Brandon Dugan received the Asahiko Taira International Scientific Ocean Drilling Research Prize at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The prize recognizes an individual "for outstanding transdisciplinary research accomplishment in ocean drilling."*

Brandon Dugan

### *Citation*

Brandon Dugan's transdisciplinary contributions, which couple pore pressure, fluid flow, and the evolution of sediment properties, are a crucial pillar of the geohazard research highlighted in the International Ocean Discovery Program (IODP) science plan. His novel approaches shed light on the fundamental physical processes operating at granular to regional scales by combining field experiments with robust and experimentally validated models.

Brandon's early work laid the theoretical foundation tested on IODP Expedition 308, "Gulf of Mexico Hydrogeology." The mechanism for overpressure generation and slope failure that he pioneered has since been adopted elsewhere and continues to guide research in this arena. As part of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), he sailed on Expedition 322, served as the hydrogeology planning group leader for NanTroSEIZE Stage 2, and was co–chief scientist for Expedition 338. Through these projects, Brandon showed how sediment fabric, porosity, and permeability evolve during consolidation and provided basic information to support models of fluid flow, overpressure development, and slope stability. In 2016, Brandon coled Expedition 362 and in a collaborative effort with members of the science party, documented complete dehydration of silicates before plate subduction, expanding on prevailing models of subduction seismogenesis. Processes such as these, which take place outboard of the deformation front, are key to understanding the behavior of plate boundary seismogenesis and tsunami generation.

Brandon's research has been expanding beyond slope stability and seismogenic themes to multiple directions that encompass both observation and theory. For example, the integration of numerical modeling and IODP data toward understanding gas hydrate dynamics in Hydrate Ridge and the Kumano basin has important linkages to carbon cycling. He recently spearheaded an integrated offshore–onshore drilling program to understand freshwater resources along the New England continental shelf that will address how glacial dynamics, sea level variations, and groundwater flow have emplaced large volumes of fresh water in offshore sediments. This pioneering research has direct and immediate societal relevance, as traditional freshwater resources are declining due to overexploitation and climate change.

Brandon has made extraordinary contributions to the ocean drilling program. He has served the IODP community in many advisory capacities, including as a long-term member of the Environmental Protection and Safety Panel and as a leader or steering committee member of various workshops. Noteworthy is the workshop Engaging Early Career Scientists in Future Scientific Ocean Drilling, which illustrates Brandon's commitment to engage, train, and motivate early-career scientists to take an active role in IODP, a key effort to ensuring the success and long-term vitality of the program.

**—Marta E. Torres**, *Oregon State University, Corvallis*

### *Response*

I am honored to receive the Taira Prize, and I thank AGU, Japan Geoscience Union, and IODP for establishing it. I also thank Marta Torres for her kind citation. My path to ocean drilling started at the University of Minnesota, where Mark Person introduced me to integrating mathematical modeling and Earth science research. An internship at Oak Ridge National Laboratory exposed me to working with wells. Most influential, however, was a handwritten note from Michelle Markley on a structural geology homework that said, "use your imagination." This led to a Ph.D. at Penn State blending engineering and geosciences. Peter Flemings, my advisor, set me loose on data from Leg 174A. Under his guidance, I started linking fluid flow and slope stability. Peter's mentorship was invaluable. He encouraged me and pushed me to understand and to explain. This inspired me to sail on Leg 194, where I experienced the grind and the joys of working at sea and, even as a young graduate student, was treated as an equal while being mentored. I loved the environment that mixed hard work, cutting-edge science, and engineering. On Expedition 308, we tested models that I developed, and we advanced in situ pressure analyses. Here I realized the true value of working with a diverse group of scientists all looking at the same problem. In addition, I became aware of all that the technicians and crew do so we can focus on science. This blossomed into other projects looking at fluid–rock interactions, like NanTroSEIZE, where I sailed as a scientist (Expedition 322) and a co–chief scientist (Expedition 338). This leadership opportunity helped me grow as a scientist and as a mentor and pushed me to integrate across disciplines. Since then I have had other great experiences as a co–chief scientist studying inputs to the Sumatra subduction zone (Expedition 362) and as a logging scientist studying landslides and slow-slip earthquakes (Expedition 372). Every project has amazed me, and I am proud to be part of this community—working together, testing hypotheses, and solving problems at sea. Within this community, many scientists have inspired me, but a few who have had the biggest impacts are Peter Flemings, Lisa McNeill, Casey Moore, Greg Moore, Demian Saffer, Marta Torres, and Mike Underwood. I thank them. Most of all, I thank my family, wife, and children, who support me as I chase my dreams.

**—Brandon Dugan**, *Colorado School of Mines, Golden*

## Mann Receives 2018 Climate Communication Prize

*Michael E. Mann received the Climate Communication Prize at the 2018 AGU Fall Meeting Honors Ceremony, held 12 December 2018 in Washington, D. C. The prize recognizes an individual "for the communication of climate science."*

Michael E. Mann

### *Citation*

Michael Mann not only is one of the most distinguished scholars in the field of climate science but also is unparalleled in the depth, diversity, and sheer volume of his communication about climate science and its implications for society. His firm grounding in scholarship at the highest levels of climate science underlies all of his climate communication efforts and makes him effective in engaging his peers as well as members of the public in nuanced, fact-based discussions about climate science, its uncertainties, and its implications for our future.

Mike's efforts to communicate climate science stretch back more than 20 years; include the use of virtually every communication platform; and exemplify a mastery born of dedicated, sustained, and repeated engagement. He and several colleagues founded the seminal, award-winning

science blog *RealClimate* to engage the public in fact-based discussions about the climate issues of the moment. It quickly became a trusted repository of fact-based discussion about peer-reviewed climate science that is frequently cited, even to this day. He has also written a number of popular science books aimed at engaging and informing science enthusiasts and, most recently, young children about climate change. He has given hundreds of interviews for traditional media outlets, as well as given an equally impressive number of public talks, participated in documentaries, written countless op-eds for prestigious newspaper outlets, and, perhaps most notable of all, is engaged in what appears to be a 24/7 stream of exchanges with his huge social media followings. Of particular note, he has regularly appeared to testify before Congress about climate science, knowing that such appearances will bring him under withering, partisan-fueled attacks.

In the past decade, Mike has been an unflinching and courageous defender of the principles of free and open scientific investigation and the urgency of combating misinformation with the scientific facts of climate change. He has done so at great personal cost, persevering through terrifying death threats, organized smear campaigns, and protracted lawsuits. Long before "alternative facts" became a household phrase, Mike was sounding alarm bells about efforts to undermine climate science findings and their role in shaping evidence-based policy. His courage, his resilience, and his tireless pursuit of truth in the public discourse around climate change have had a lasting impact on an entire generation of geoscientists and the public. Every day, Mike reminds us that communicating science lies at the heart of scientific practice, with untold benefits to society.

**—Kim M. Cobb**, *Georgia Institute of Technology, Atlanta*

### *Response*

I am humbled to receive this prize. I thank my citationist, Kim Cobb, for her support and her kind words. They mean a lot coming from Kim, she herself being an unusually gifted communicator.

I didn't choose to enter the world of science communication. Public engagement was the furthest thing from my mind when I double-majored in applied math and physics in college, when I went on to pursue graduate studies in theoretical physics, and when I completed my Ph.D. in geology and geophysics. What drove those pursuits was a love of problem solving and a fascination with the use of computational approaches to modeling physical phenomena.

My Ph.D. thesis involved modeling the coupled ocean–atmosphere system to better understand long-term natural climate cycles. Because the instrumental climate record is so short, I turned to longer-term paleoclimate "proxy" data in an attempt to validate results from the modeling. My analysis of those data eventually led to the now-iconic "hockey stick" curve, coauthored with Ray Bradley and Malcolm Hughes. Though I couldn't have known it at the time, my career and life path were fundamentally altered with the publication of that graph in the late 1990s.

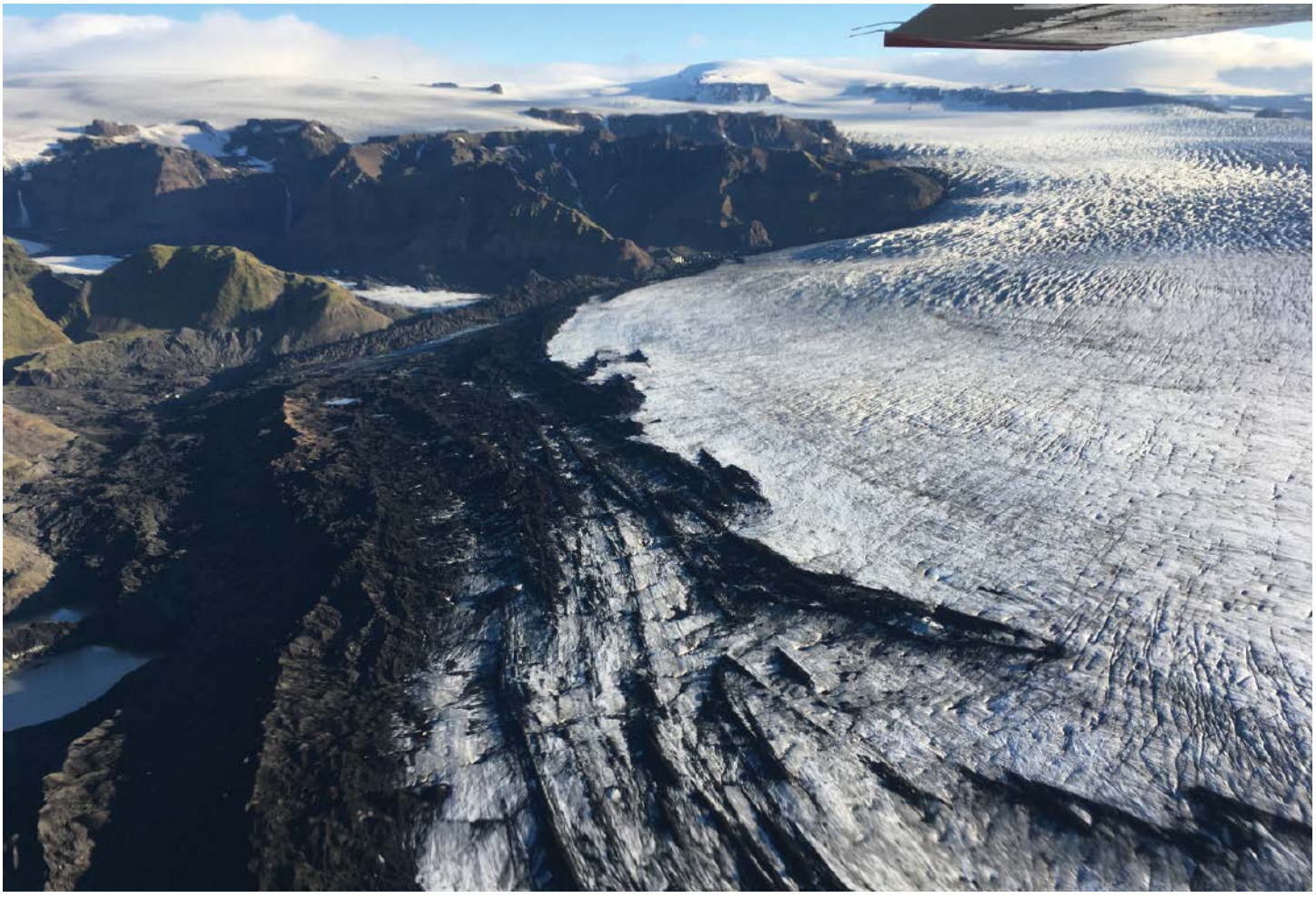
The hockey stick was perceived as a threat by groups opposed to climate action because it spoke a simple truth, conveying the unprecedented nature of human-caused warming in easily understood terms. Still a young postdoc, I would find myself subject to a decades-long campaign of intimidation and vilification by those seeking to discredit our findings, as detailed in my book *The Hockey Stick and the Climate Wars*.

Initially reluctant to be at the center of the fractious public debate over human-caused climate change, I've ultimately come to embrace that role. I feel privileged to be in a position to influence the societal discourse over what may well be the greatest challenge we face as a civilization.

I am honored to be recognized for those efforts. At the same time, I am acutely aware that too few AGU awards have gone to women scientists in recent years. We need a diversity of scientific voices that reflect the diversity of society itself. I have a 12-year-old daughter who loves mathematics. I want her to grow up in a world that encourages and rewards women in science, technology, engineering, and mathematics (STEM), a world that is replete with female role models. We would all benefit from a more inclusive approach to recognition.

**—Michael E. Mann**, *Pennsylvania State University, University Park*

# Volcano in Iceland Is One of the Largest Sources of Volcanic $CO_2$



*An airborne view of the massive glacier (600 square kilometers and up to 700 meters thick) that covers Katla, one of Iceland's most active and hazardous volcanoes. Credit: Evgenia Ilyinskaya*

The emission rate of carbon dioxide ($CO_2$) is one of the less obvious—but nevertheless significant—measures of volcanic activity. Volcanic $CO_2$ emissions are also important for understanding the preindustrial climate balance. To date, estimates of global volcanic $CO_2$ emissions have been extrapolated primarily from measurements collected at a small number of active sources. Ice-covered volcanic centers are prevalent, but they are often difficult to access and their vents are difficult to discern, so they are rarely included in these calculations.

To address this gap, *Ilyinskaya et al.* recorded the first atmospheric gas emission rate measurements from Katla, one of Iceland's largest active volcanoes. This massive ice-covered caldera, which last erupted a century ago, was previously assumed to be a relatively minor emitter of $CO_2$, but the new results suggest otherwise.

The team detected $CO_2$ emitted by Katla by analyzing airborne gas emission measurements made in October 2016 and October 2017. These observations were combined with gas dispersion modeling to calculate the volcano's total emissions. The results indicate that Katla emits 12–24 kilotons of $CO_2$ per day, which is more than double previous estimates of the emission rate of $CO_2$ from all volcanic and geothermal sources in Iceland combined (2.7–5.8 kilotons per day). Although the large $CO_2$ emission rate may suggest the presence of magma in the roots of Katla volcano, regular monitoring is needed to establish whether there is a link between the $CO_2$ emission and any future eruptions.

These findings suggest that subglacial volcanoes—the emissions of which have not been considered in much detail, historically—may be major emitters of carbon dioxide. Because of this, their contributions to the global volcanic $CO_2$ budget may have been underestimated. Future work will determine whether Katla is representative of other ice-covered volcanoes. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL079096, 2018) **—Terri Cook, Freelance Writer**

# Insect Infestations Alter Forest Carbon Cycles

*Insect outbreaks have killed healthy hemlock trees like these in the Coweeta Hydrologic Laboratory in western North Carolina, and they also change how carbon is stored in the forest. Credit: Corinne Muldoon*

Forests are generally recognized as carbon sinks, meaning that they absorb more carbon from the atmosphere than they release, and soils store between 25% and 45% of the carbon in the ecosystem. Forests around the world are changing, however. As living ecosystems, they are undergoing alterations due to land use changes, warming temperatures, fire, and insect and disease infestations. As these forces reshape landscapes, they also alter the role of forests in atmospheric carbon dioxide concentrations.

However, mixed results in past research have caused disagreement in the scientific community over exactly how forest carbon cycles respond to widespread tree mortality.

In a new study, *Fraterrigo et al.* examine how insect infestations, a significant driver of tree mortality, shaped the storage and transformation of soil carbon in a southern Appalachian forest. The researchers framed the study around an outbreak of hemlock woolly adelgid at the Coweeta Hydrologic Laboratory, a U.S. Forest Service experimental forest in the Nantahala Mountain Range in western North Carolina. The insects attacked eastern hemlocks, a codominant species in riparian forests. To mimic the disturbance, the researchers girdled hemlocks at separate study plots to accelerate tree mortality. They visited the plots annually from 2004 to 2014.

After a decade of monitoring, the team found that the soil carbon storage capacity was not reduced by the disturbance. Although tree mortality did not trigger a release of stored carbon to the atmosphere, it did affect how and where it was stored.

The results indicate that soil carbon pools near the surface moved deeper underground in response to the hemlock mortality. As soil microbe organic matter consumption increased, the carbon pools bound to small soil minerals increased as the larger organic matter particles decomposed. These changes to the carbon cycle happened more quickly in the girdled plots and offered a preview of what insect-infested sites will look like in the future.

These conclusions differ from those of similar studies that found that increased tree mortality led to the release of soil carbon to the atmosphere, which may relate to differences in how undisturbed vegetation picks up the slack in the carbon cycle across ecosystems. Deeper, mineral-bound carbon is believed to be more persistent in the ecosystem, but it remains unclear what spurred the transition of carbon from surface to subsurface pools. (*Journal of Geophysical Research: Biogeosciences,* https://doi.org/10.1029/2018JG004431, 2018) **—Aaron Sidder, Freelance Writer**

# Plasma Activity Around Sunspots May Foreshadow Solar Storms

In a new study, Attie et al. describe a series of observations captured from 1 to 3 September 2017 that foreshadowed heightened solar and space weather activity. Looking in solar active region AR12673, the researchers noticed disturbances to the moat flow surrounding the region's main sunspot several hours before the telltale magnetic flux that spawns solar storms. Moat flow is an outward flow of plasma that encircles a sunspot and forms a sooty shadow around its darkened core. The flow moves away from the center of the sunspot, like pancake batter expanding and flattening on a frying pan.

Using data from the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory and an automated algorithm applied for the first time, the researchers reported breaks in the moat boundary as its radius expanded prior to magnetic fluctuations around the sunspot. In some local instances, the moat radius expanded by 20%–35%. The expanding moat boundary was also accompanied by a reduction in the velocity of escaping plasma. In the study's focal zone, the changes to the moat boundary occurred between 2 and 12 hours before the magnetic disturbances.

These promising—but still exploratory—findings suggest that the topology of the moat may serve as a compass that points to regions of emerging magnetic flux. The authors were keen to note that they examined only one active region and that their hypothesis is still speculative. (*Space Weather,* https://doi.org/10.1029/2018SW001939, 2018) **—Aaron Sidder, Freelance Writer**

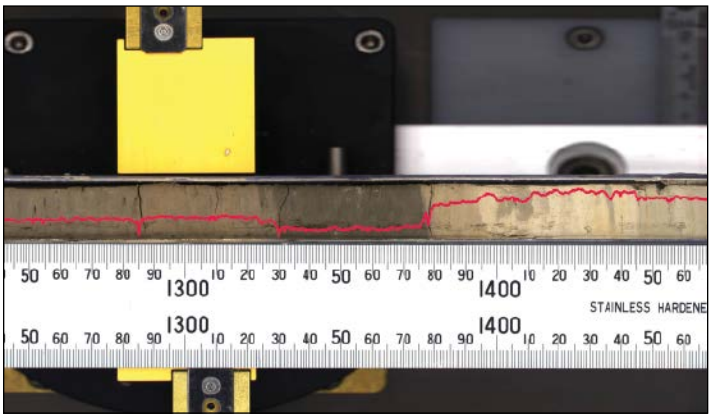
# Tiny Marine Shells Reveal Past Patterns in Ocean Dynamics

The Gulf Stream carries warm water across the Atlantic Ocean, north from the tropics, across the equator, and into the upper latitudes, where it cools, sinks, and flows back toward the tropics. This pattern is known as the Atlantic Meridional Overturning Circulation (AMOC), one element of the global ocean circulation commonly referred to as the ocean conveyor belt. The AMOC is closely tied to the climate in the North Atlantic and may be susceptible to global warming.

A new study by *Gottschalk et al.* explores the link between AMOC dynamics and calcium carbonate saturation in the Atlantic Ocean, a measure of how corrosive water masses are for calcareous shells of marine organisms at the seafloor. Their carbonate remains may accumulate in marine sediments when they sink to the ocean floor. Burial and preservation of carbonate are essential components in the global carbon cycle and are closely tied to ocean circulation reorganizations and atmospheric carbon dioxide levels.

The researchers used sediment cores from the Cape Basin, located west of South Africa, to reconstruct changes in carbonate preservation over the past 400,000 years, which covers the last four glacial–interglacial cycles. The researchers used millimeter-scale X-ray fluorescence to analyze calcium/titanium ratios (Ca/Ti) in the sediment cores. The Ca/Ti ratio corresponds closely to carbonate weight percentages in the sediment samples and serves as a proxy for the carbonate saturation of deep water masses in the South Atlantic.

The study found that fluctuations in carbonate preservation reflect abrupt changes in the AMOC, which are linked to past global climate changes. AMOC changes redistribute carbonate ions, and the patterns showed, for example, that carbonate preservation peaks were associated with Northern Hemisphere warm intervals (both long and strong as well as short and weak) during the past four glacial periods. The authors suggest that abrupt changes in carbonate preservation in the South Atlantic hint at an oceanic mechanism linking North Atlantic climate anomalies and variations of the global carbon cycle.



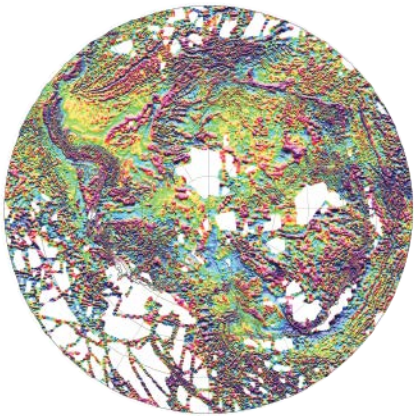

*Sediment cores from the ocean floor were analyzed with an X-ray fluorescence scanner (pictured) to trace changes in the abundance of calcium (superimposed red line) and titanium. Credit: Simon J. Crowhurst*

The results from the marine sediments offer new insights into the dynamics of the AMOC during past glacial periods. The study can help clarify how sensitive the AMOC was to past climate changes and how it might have affected atmospheric carbon dioxide concentrations in the past. (*Paleoceanography and Paleoclimatology,* https://doi.org/10.1029/2018PA003353, 2018) **—Aaron Sidder, Freelance Writer**

# A More Detailed Look at Earth's Most Poorly Understood Crust

Magnetic anomalies are especially important for studying the crust in Antarctica, where thick ice sheets preclude traditional geologic mapping. Now *Golynsky et al.* have greatly expanded scientists' ability to scrutinize the southernmost continent's geology by producing an updated version of the Antarctic Digital Magnetic Anomaly Project (ADMAP), the first comprehensive digital magnetic anomaly map of the region south of 60°S. The second-generation ADMAP, ADMAP-2, includes more than 3.5 million line kilometers of marine and aeromagnetic survey results that more than double the near-surface data incorporated in the original 2001 map. These new data significantly improve anomaly resolution and help infill the coverage of Wilkes Land, Dronning Maud Land, the Transantarctic Mountains, continent-ocean margins, and other regions of geologic interest.

With its unprecedented level of detail, ADMAP-2 offers the most comprehensive view to date of the magnetic field over the southern continent and its encircling oceans. By integrating decades' worth of data into a single resource, the authors have created a potent new tool to help geologists and geophysicists probe the planet's minimally understood crust. It will inevitably kindle new investigations of the southern continent's structure and tectonic evolution that will generate fresh insights into the events that have shaped Antarctica through multiple supercontinent cycles. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL078153, 2018) **—Terri Cook, Freelance Writer**



*The Antarctic Digital Magnetic Anomaly Project uses new data contributed by American, Australian, Argentinean, British, Danish, German, Italian, Japanese, Russian, and Spanish agencies. The colors represent the intensity of magnetic anomalies. Credit: SCAR ADMAP Expert Group*

# Satellite Observations Validate Stratosphere Temperature Models

*A view of the blue haze of Earth's atmosphere. Credit: iStock.com/sharply_done*

Depending on whether you look above the poles or above the equator, Earth's stratosphere can start anywhere between 6 and 20 kilometers above the surface. Regardless of its relative height, however, the atmosphere plays an important role in our planet's climate. It contains ozone ($O_3$), a molecule that readily absorbs harmful ultraviolet radiation from the Sun and protects life on the surface below. The more radiation that is absorbed, the higher the temperature rises.

Since the 1970s, however, some human-made compounds—especially chlorofluorocarbons—have been depleting ozone levels and thus cooling the stratosphere. Over this period, increases in long-lived greenhouse gases like carbon dioxide have also cooled the stratosphere. Accounting for these effects, scientists have modeled just how much cooler the stratosphere should be, but these models have not always closely agreed with actual observations from satellites.

A new study by *Maycock et al.* uses improved satellite temperature readings and shows that these observations are more in line with simulations from the Chemistry-Climate Model Initiative.

The primary evidence that modeled stratosphere temperature trends did not match observations came from a 2012 study. Observations of stratospheric temperatures from the late 1970s to the present rely primarily on measurements from a series of infrared sounders called the Stratospheric Sounding Unit (SSU), which are on board satellites orbiting Earth's poles.

On the basis of the data available at the time, the earlier study showed that modeled trends of stratospheric temperatures taken from Phase 5 of the Coupled Model Intercomparison Project and the Chemistry-Climate-Model Validation project differed significantly from the SSU record. It also showed that two versions of the SSU itself differed from each other in terms of temperature trends.

Since that time, however, other researchers have reprocessed and refined the SSU temperature records, and scientists have continued to improve the chemistry climate models, warranting the new comparison from the authors reported here.

The researchers report that the updated data sets are now in closer agreement, with the models now predicting temperature trends within the margin of error inherent in the satellite observations. They conclude that the improvement is mostly the result of the refined SSU observations rather than improvements in the models.

The temperature of the stratosphere is important as it relates to the ozone shield but also because processes in each layer of the atmosphere affect those around it. With the troposphere below warming at dangerous rates, understanding the behavior of the stratosphere will continue to be a vital field of research. (*Geophysical Research Letters*, https://doi.org/10.1029/2018GL078035, 2018) **—David Shultz, Freelance Writer**

### Hydrology

**Graduate Research Opportunities at Utah State University**

The Utah Water Research Laboratory (UWRL) at Utah State University (http://uwrl.usu.edu), a multidisciplinary laboratory in the Department of Civil and Environmental Engineering, attracts students from a variety of STEM backgrounds and is engaged in a wide range of challenging national and international research efforts. See https://cee.usu.edu/students/graduate/ apply for application information. Funded opportunities in the following research groups are described below:

WATER INFRASTRUCTURE AND THE ENVIRONMENT. PhD assistantship is available for highly motivated students. Potential research areas include but are not limited to fluvial hydraulics, computational fluid dynamics, hydraulic structures, scour and erosion, fluid mechanics and experimental techniques, and energy dissipation. Inquiries are encouraged and may be directed to brian.crookston@usu.edu.

HUMAN-NATURAL WATER MANAGEMENT. PhD and MS assistantships are available within the USU WET Lab (www.usuwetlab.org) at the intersection of hydrologic science, fluvial hydraulics, and water resources management, with a focus on data-driven solutions for the West's growing water management challenges. Potential research areas include integrating ecological and climate uncertainty in water management, investigating multi-scale topographic and streamflow controls on river functioning to inform restoration, and quantifying the utility of synthetic terrain generation for eco-hydraulic applications. Students with various backgrounds are encouraged to apply (e.g., hydrology, civil engineering, earth sciences, biology, statistics). Experience with programming, geospatial and statistical analysis strongly desired. Inquiries may be directed to belize.lane@usu.edu.

AGRICULTURAL WATER AND BIG DATA. PhD and MS assistantships available to develop solutions involving multi-resolution, high/low frequency data sources for agricultural characterization, monitoring, and forecasting. Potential research areas include but are not limited to remote sensing vertical integration, beyond line-of-sight UAV technology, data mining and Big Data applications in agriculture. Experience in HPC systems, data mining, remote sensing, water and energy balance, spatial statistics, and field data collection desired. Google Earth Engine experience is a plus. Inquiries may be directed to alfonso.torres@usu.edu.

MACHINE LEARNING AND HYDROLOGY. PhD research assistantship is available in machine learning applications in hydrologic (emphasis on groundwater) modeling. Potential research areas include but are not limited to data-driven modeling of hydrologic systems, uncertainty analysis, and integrated hydrologic modeling. Proven experience with programming and statistics strongly desired. Inquiries may be directed to tianfang.xu@usu.edu.

HUMAN IMPACT ON HYDROLOGY MODELING AND PREDICTION. PhD and MS assistantships are available in understanding watersheds as coupled nature-human systems and providing scientific support for water resources management. Specific focus areas are (1) human activities impact assessments (e.g., irrigation, resource consumption, renewable energy generation) using in-situ measurements and remote sensing products with machine-learning or statistical techniques and

(2) hydrologic model refinements by improving the human dimension. Students with various backgrounds are encouraged to apply (e.g., civil engineering, hydrology, earth sciences, remote sensing, mathematics and statistics). Experience with numerical simulation, statistics and spatial data analysis strongly desired. Inquiries may be directed to ruijie.zeng@usu.edu.

Application Deadline: March 15, 2019

(for full funding consideration for graduate studies starting fall 2019)

*Communication with respective contacts is encouraged before applying

USU is an AA/EO Institution

### Interdisciplinary

**UNIVERSITY OF ALABAMA**

Department of Geological Sciences
Chair and Professor

The Department of Geological Sciences at the University of Alabama seeks an individual with an outstanding record of proven leadership, teaching, research, and service, to be hired at the rank of Full Professor with tenure for the 12 month position of Department Chair. The successful candidate must be internationally recognized within the field, have an active research program that includes external funding, and be able to advance the research goals and stature of the faculty. This candidate should be able to forge a dynamic vision for the department by working with the faculty, and communicate that vision to the Dean of the College of Arts and Sciences and the Provost of the University.

We seek a chair who can build upon our strong foundation to increase the quality of our B.S., M.S., and Ph.D. students' experience and advance the Department's research productivity and profile. The Department's 22 faculty conduct research that spans the geosciences and collaborates with the Alabama Water Institute, the National Water Center, the Center for Sedimentary Basin Studies, and are establishing new energy industry consortia. The applicant should possess proven lead-

ership abilities, with a minimum of three years of significant administrative experience, and have an enthusiasm for the University's teaching and research missions. The candidate must hold a Ph.D. in Geology or a closely-related field and have expertise which complements that of existing faculty.

In addition, the successful candidate should demonstrate a proven record in the following areas:

- vigorous advocacy on behalf of faculty, staff, and students
- excellent leadership, particularly promoting collegiality in implementing change and coordinating diverse approaches to teaching and research
- innovative curriculum and program maintenance and development
- excellent budget oversight and facilities management
- experience with program assessment plan implementation and assessment data interpretation
- inspirational mentoring of colleagues and students

Details regarding existing department research programs, equipment, and facilities can be found at: www.geo.ua.edu. Questions should be directed to Dr. Kim Genareau (kdg@ua.edu), Chair of the Search Committee. Applicants should submit a cover letter, curriculum vitae, vision statement, and names and contact information for at least three references through the UA Jobs Website at: https://facultyjobs.ua.edu/postings/44323. Review of applications will begin 1 March 2019 and will continue until the position is filled. The University of Alabama is an equal opportunity/affirmative action employer and actively seeks diversity in its employees.

**ASSISTANT PROFESSOR**

Field-Oriented Sedimentology, Structural Geology, or Volcanology

The Nevada Bureau of Mines and Geology (NBMG) at the University of Nevada, Reno, seeks applicants for a tenure-track academic faculty position in field-oriented research in structural geology, volcanology, or sedimentology. NBMG is a public service unit of UNR and serves as both the state geologic survey of Nevada and as a research department in the UNR College of Science. Faculty at NBMG have tenure-track academic appointments, with both research and teaching obligations.

Position Responsibilities: The primary responsibilities of this position will be to develop broad programs in research and education in Sedimentology, Structural Geology, or Volcanology. Research will focus on the geologic framework and tectonic evolution of Nevada, utilizing innovative approaches to detailed geologic mapping, sedimentologic analysis, structural analysis, geochronology (e.g. U/Pb, detrital zircons, or $^{40}Ar/^{39}Ar$), and/or paleomagnetism. Position responsibilities and expectations include: 1) utilizing detailed geologic mapping to conduct basic and applied research; 2) working independently as well as collaboratively with NBMG faculty-staff, faculty in other geoscience units in the Nevada system of higher education, and others in industry and government in developing funded research projects; 3) contributing to the understanding of natural resources and geologic hazards in the region; 4) supervising graduate students and teaching courses in the successful candidate's area of expertise.

Qualifications: Applicants must have a doctorate in geology or a related geoscience field by the time of hire and a demonstrated record of research on topics related to sedimentology, structural geology, tectonics, and/or volcanology as indicated by dissertation research, industry experience, or peer-reviewed publications. The successful candidate must also have experience in field-oriented research and a desire to conduct detailed geologic mapping on future projects in Nevada. Excellent communication skills, as demonstrated in written application materials; commitment to public service; potential for, or established record of publications; and ability to attract funding are essential. Doctoral research must include one or more of the following disciplines: structural geology, sedimentology, or volcanology. We encourage candidates to explain achievable plans for funded research on Nevada-focused topics in their area of expertise in the letters of interest.

Salary and Date of Appointment: The position will be a tenure-track faculty appointment at the assistant professor level with an academic-year base salary that is competitive with other research universities. Starting date will be July 1, 2019 or shortly thereafter, depending on availability of the successful candidate.

For more detailed information about the position and to apply, please visit: https://is.gd/pgqdbK. Application deadline is March 1, 2019. For further information about NBMG, please consult our website http://www.nbmg.unr.edu.

The University of Nevada, Reno is committed to Equal Employment Opportunity/Affirmative Action in recruitment of its students and employees and does not discriminate on the basis of race, color, religion, sex, age, creed, national origin, veteran status, physical or mental disability, and sexual orientation. The University of Nevada employs only United States citizens and aliens lawfully authorized to work in the United States.

EEO/AA Women and underrepresented groups, individuals with disabilities, and veterans are encouraged to apply.

**Hydrogeochemist (Assistant Scientist or early career Associate Scientist)**

HYDROGEOCHEMIST – Geohydrology Section – Kansas Geological Survey – The University of Kansas, Lawrence. Full-time position to lead KGS hydrogeochemical investigations. Faculty-equivalent, sabbatical-eligible position at the rank of Assistant or entry-level Associate Scientist. Requires Ph.D. with an emphasis on aqueous geochemistry related to water resources and scientific leadership potential. Emphasis on state-of-the-science field studies and complementary theoretical research. Complete announcement/application info at www.kgs.ku.edu/General/jobs.html. Review of applications will begin March 4, 2019.

Apply online at http://employment.ku.edu/academic/13299BR. For further information contact Geoff Bohling (geoff@kgs.ku.edu) or Don Whittemore (donwhitt@kgs.ku.edu). For further information about other aspects of the position, contact Annette Delaney, HR, at adelaney@kgs.ku.edu or 785-864-2152.

KU is an EO/AAE, http://policy.ku.edu/IOA/nondiscrimination.

**Visiting Faculty Position–Volcanology and Geothermal Sciences, Kyoto University, Japan**

Kyoto University invites applications for a visiting Professor or Associate Professor in volcanology, geothermal sciences and related disciplines. The successful applicant is expected to work at Aso Volcanological Laboratory or Beppu Geothermal Research Laboratory, Kyushu, Japan. Attractive salary and traveling expenses are provided from the university.

The position is opened on October 1, 2019, and the tenure is 3 to 12 months by September 30, 2020. The applicant should be 65 years old or younger when his/her term in this position has terminated.

Send (1) CV including date of birth, nationality and publication list, (2) statement of research interests, (3) pdf files of 3 significant publica-

tions, (4) names and e-mail addresses of three references and (5) desired arrival and departure date, and place of assignment (Beppu or Aso) to Prof. Takahiro Ohkura through e-mail to VFP19*vgs.kyoto-u.ac.jp (please replace "*" with "@" in the e-mail address) by March 1, 2019.

For the details, please visit http://www.vgs.kyoto-u.ac.jp/igse/e-visiting_faculty_position.html.

Inquire in advance to a member of Aso or Beppu is encouraged.

**Lindahl Ph.D. Scholarships:** The University of Alabama, Department of Geological Sciences seeks Ph.D. students with specializations that complement faculty research interests. Exceptional students will receive Research or Teaching Assistantships and a Lindahl Scholarship totaling $22,000 for a nine month appointment, and the cost of non-resident tuition is covered. Funding is renewable for 4 years if expectations are met. Other fellowships are available from the Graduate School. Further details are at http://www.geo.ua.edu/. Applicants should contact Dr. Geoff Tick (gtick@ua.edu) to express interest. Review of applications for Fall 2019 admission will begin January 15, 2019.

**Assistant or Associate Professor – Economic Geologist (Hydrothermal Geochemistry)**

Nevada Bureau of Mines and Geology

The Nevada Bureau of Mines and Geology (NBMG) at the University of Nevada, Reno is seeking applications for a tenure-track faculty position focused on hydrothermal geochemistry and mineral deposits. NBMG is a research and public service unit of the University of Nevada, Reno (UNR) and is the state geological survey. Managed as part of the Mackay School of Earth Sciences and Engineering in the College of Science at UNR, NBMG functions as an academic unit, and its principal scientists are tenure-track faculty members. Nevada is one of the most exciting regions in the world to do research in the geosciences and the best in the U.S. for the study of hydrothermal mineral deposits. For further information about NBMG, please consult our website http://www.nbmg.unr.edu.

Interested applicants must have a doctorate in geology or a related geoscience field by the time of hire and a demonstrated record of research on topics related to hydrothermal mineral deposits as indicated by dissertation research or peer-reviewed publications. Excellent communication skills, as demonstrated in written application materials; commitment to public service; potential for, or established record of publications; and ability to attract funding are essential. Previous research must include economic geology or hydrothermal geochemistry with a focus on mineral deposits.

Preference will be given to candidates with: 1) academic experience in hydrothermal mineral deposits, particularly research that blends both quantitative analytical and field-based approaches; 2) demonstrated research productivity with publications in the peer-reviewed literature; and 3) achievable plans for funded research on Nevada-focused topics in economic geology, as described in the applicant's letter of interest. Additional preferred fields of expertise include: 1) geochemistry of metal solubility and transport; 2) geochemical modeling, 3) fluid inclusions, 4) stable isotopes, and/or 5) geochemical microanalyses

Position responsibilities and expectations include: 1) working independently as well as collaborating with NBMG faculty-staff, faculty in other geoscience units at UNR and UNLV, and others in industry and government in developing funded projects and conducting research; 2) focusing research on mineral deposits in Nevada, though some research can be conducted outside Nevada; and 3) supervising graduate students and teaching courses related to hydrothermal geochemistry. The position will be a tenure-track faculty appointment with an academic-year base salary (9 months) that is competitive with other research universities. Starting date will be July 1, 2019 or shortly thereafter, depending on availability of the successful candidate.

For more detailed information about the position, and to apply, please visit https://nshe.wd1.myworkdayjobs.com/en-US/UNR-external/job/University-of-Nevada-Reno-Main-Campus/Assistant-or-Associate-Professor-Economic-Geologist_R0113408-1. Applications will be accepted through February 21, 2019.

EEO/AA Women, under-represented groups, individuals with disabilities, and veterans are encouraged to apply.

**Physicists, Applied Mathematicians, and Electrical Engineers**

NorthWest Research Associates (NWRA; www.nwra.com) is a scientific research organization, owned and operated by its Principal Investigators, with expertise in the geophysical and space sciences. The nine current Ph.D. physicists and electrical engineers composing NWRA's Monterey, California location are respected experts in radiowave propagation and signal processing for radar and communication systems, ionospheric modeling, and signal scattering in randomly structured ionization. We are looking for physicists, applied mathematicians, and EEs, preferably at the Ph.D. level, to support several interesting new projects involving propagation modeling and signal processing for ionosphere and space-weather modeling. A strong ability in applied mathematics, especially inverse problems, is desirable.

New hires will work closely with our seasoned scientists on existing projects; early-career scientists would gain in further career growth from mentorship by world-class experts. NWRA provides a supportive environment for scientists who have a passion for their research, a desire to continue learning, and who enjoy communicating their research and research ideas through papers, presentations, and proposals. NWRA scientists can eventually become Principal Investigators of their own projects and co-owners of NWRA. US Citizenship is required.

NWRA offers a full benefit package including health, life, disability, and long-term care insurance and matching 401K contributions. Please send resumes to HR@nwra.com.

NWRA is an Equal Opportunity Employer for minority, women, veterans and disabled candidates.

**Become a Principal Investigator at the SETI Institute**

At the SETI Institute, we worry about the administration of your grant so that you can spend more time making the next breakthrough in your field. Read on to learn more about some of the advantages of partnering with the SETI Institute as a Principal Investigator.

How do I become a Principal Investigator?

Scientists working in the field of astrobiology can request to have their grants funded through the SETI Institute. If you don't already have a grant, the Institute can help you propose for one. A Ph.D is required to be a SETI Institute Principal Investigator.

What kind of proposal support is provided?

To maximize your chances of receiving a grant, we constantly look for proposal opportunities, review their requirements, and alert you early in the application process. In addition, senior staff are available to review your proposals and offer advice to increase your chances of success.

How am I compensated?

The SETI Institute salaries are competitive with comparable work environments in the Bay Area. Salary levels are based upon work experience, funds available, and other relevant factors. Additionally, the SETI Institute offers a generous benefits package that includes full coverage of medical, dental, and vision insurance for employee and all dependents, 8% 403(b) retirement contribution (after 1 year of employment), vacation and sick leave away from work, etc.

What is your indirect cost rate?

The SETI Institute was founded on the belief that indirect costs should be as low as possible in order to allow more resources to be applied to science. Since 2004, we have operated with an indirect cost rate of less than 36% while providing a superior level services at a fraction of the cost of comparable organizations. One way we achieve this is by affiliating with world-class organizations such as the University of Southern California and the NASA Ames Research Center.

Where do I work?

You can work at the Institute's headquarters in Mountain View, California. Purpose-designed to promote scientific collaboration, this impressive modern space features technology-equipped conference rooms and windowed offices. You can also choose to work at NASA Ames, located a mile from our offices if you have a collaborator there who can help you secure space, or work from your home office or other remote location.

Email applications to asaroian@seti.org

**Volcanology, Geochemistry, and Petrology**

**Tenure Track Assistant Professor, University of Georgia**

The Department of Geology at the University of Georgia seeks to fill a position for a tenure-track assistant professor in the field of igneous petrology/mineralogy. We encourage applications with strong backgrounds in chemistry and physics who may employ unconventional and interdisciplinary approaches to address big-picture questions including aspects of planetary evolution involving core, mantle, and/or crustal processes. A PhD in Geology, Earth or Planetary Science or other related discipline is required by August 1, 2019. The hire must be comfortable teaching undergraduate core curriculum classes in petrology, a graduate course in their specialty, and introductory geology courses. The hire will be expected to establish an externally funded research program, attract outstanding graduate students, and give oversite to an electron microprobe facility with long- standing technical support staff. Applicants should submit a cover letter, curriculum vitae, statements of research and teaching interests, and contact information for 3 references. Application should be made to http://www.ugajobsearch.com/postings/58518. To ensure full consideration all materials should be submitted by 5 PM EST February 15, 2019. The University of Georgia is an Equal Opportunity/Affirmative Action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, ethnicity, age, genetic information, disability, gender identity, sexual orientation or protected veteran status. Persons needing accommodations or assistance with the accessibility of materials related to this search are encouraged to contact Central HR (hrweb@uga.edu). Please do not contact the department or search committee with such requests.

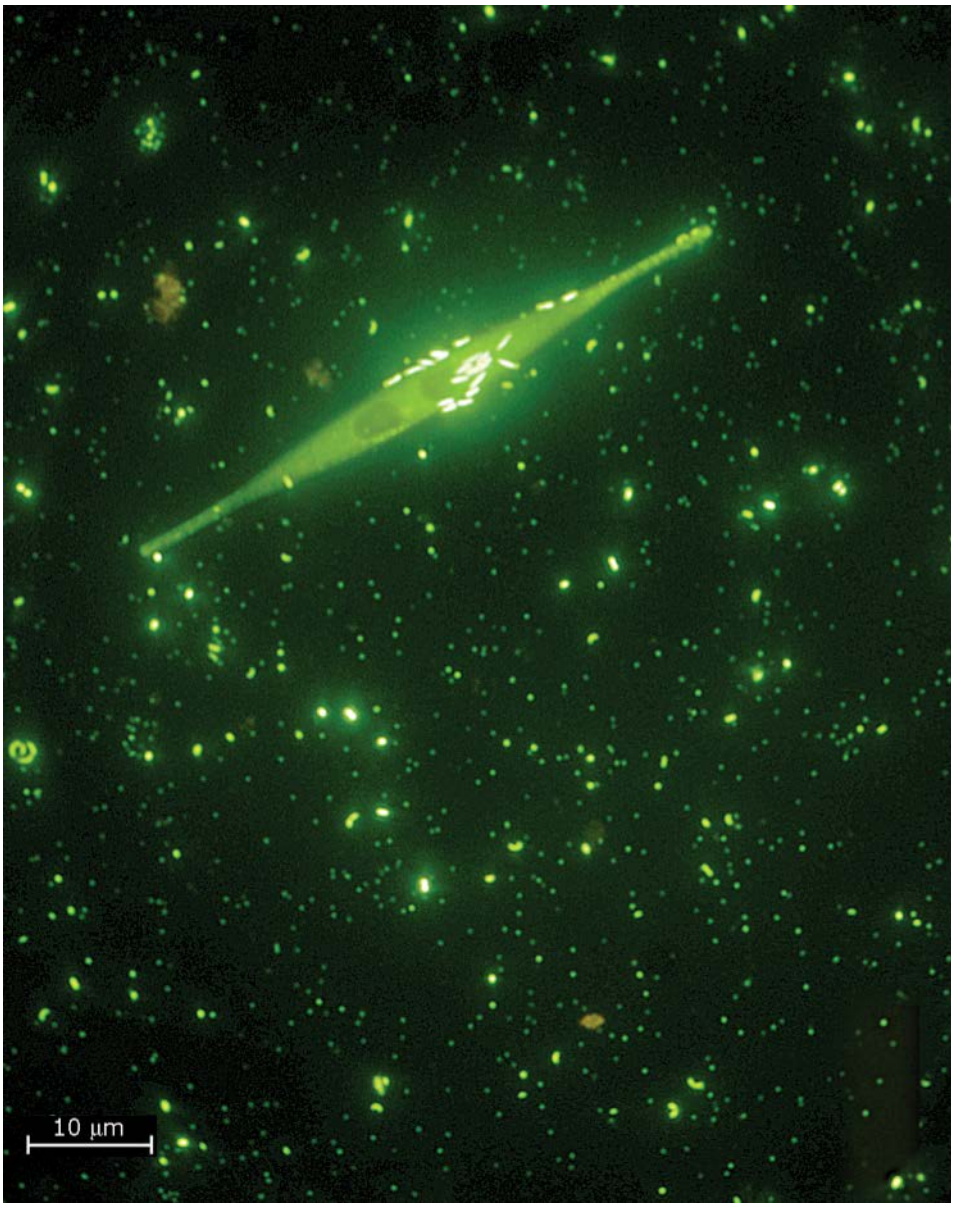
# Postcards from the Field

Dear Everyone:

We are inventorying microbes in Lake Michigan, the second largest of the Laurentian Great Lakes. At more than a million cells per milliliter of lake water, microbes stained with a nucleic acid–specific fluorochrome glow like stars in the sky under the epifluorescence microscope. The smallest green specks are viruses; the next largest are bacteria and cyanobacteria; and the largest, the spaceshiplike organism, is a diatom, ferrying many bacterial aquanauts. These tiny but abundant microbial plankton link our planet's watery "inner space" to the atmosphere and geosphere through their collectively massive activities such as photosynthesis and respiration.

**—Deb Dila,** School of Freshwater Sciences, University of Wisconsin–Milwaukee (uwm.edu/freshwater/); and **Bopi Biddanda,** Annis Water Resources Institute, Grand Valley State University, Muskegon, Mich. (www.gvsu.edu/wri/)

**View more postcards at** *bit.ly/Eos_postcard*



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