Eos
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When PG&E Turns Out the Lights on Science

A Dream Spacecraft for Neptune

Welcome to the Chibanian Age (770,000 Years Ago)

SCIENCE FROM THE SPILL

Ten years after the Deepwater Horizon blowout dumped millions of barrels of oil into the Gulf, a massive investment in science has been the silver lining.

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Deepwater Horizon's Legacy of Science

On 20 April 2010, a bubble of methane shot up an oil and gas well in the Gulf of Mexico and ignited when it reached the surface, killing 11 crew members and starting an uncontrollable fire on the Deepwater Horizon drilling rig. Given the catastrophic emergency, it wasn't until the rig sank 2 days later that anyone realized oil was being released into the Gulf. Not just spilling—gushing out from the well at the seabed at an enormous rate.

That's when Jerry Miller—*Eos*'s science adviser representing AGU's Ocean Sciences section—was called to action. Miller was serving as assistant director for ocean sciences at the White House Office of Science and Technology Policy (OSTP), a leader of the team developing the first National Ocean Policy.

Miller, who had previously lived on the Gulf Coast, and his coworkers were surprised by the initial scale of the explosion. He was heartened, however, by the broad government response, including several science agencies, and that was only the beginning. "Shortly after the event, and especially after a couple of weeks passed and the enormity of the oil spill started to become apparent, we began to receive offers of assistance from colleagues throughout the scientific community," Miller told me as he recalled the events. "Our scientific community stepped up and reshaped their own carefully designed research plans to focus on the Deepwater event."

Miller remembered one day a few weeks after the explosion, when OSTP needed experts to brief the White House and agency leaders. "On less than 24 hours' notice and at their own expense, several dozen scientists flew into Washington to provide their advice," said Miller. "Person after person for hours on end, old hands and new stepped to the podium and offered their expertise to serve the nation's needs."

The very worst situation brought out the very best in the science community. It's certainly the theme of the story we tell on page 18 in "Modeling Under Pressure," when hydrologist Paul Hsieh was called on to work through the night, by himself, to make an expert call on whether the cap BP had placed on its well would hold.

This month, on the tenth anniversary of the Deepwater Horizon disaster, we dedicate this issue of *Eos* to this community that not only pulled together in the moment but created massive collaborations dedicated to research in the Gulf that continue today.

Tens of billions of dollars came out of lawsuit settlements and other penalties against the companies involved, and a sizable amount of that was set aside to fund research. The Deepwater Horizon Project Tracker is following more than 1,200 projects using some of the $4.14 billion allocated for science and related environmental and educational programs.

One of the organizations created to run these projects is the Gulf of Mexico Research Initiative, or GoMRI. In "Deepwater Horizon and the Rise of the Omics" (p. 28), read more about one of these GoMRI projects. In that article, Joel E. Kostka and his coauthors write, "The DWH spill was also the first major environmental disaster for which genomics technologies had matured to such an extent that they could be deployed to quantify microbial responses over large spatial and temporal scales." Microbes were already part of the environment's natural response to oil spills. Today scientists have the gene sequencing techniques to properly study the role microbes play and the mechanisms with which they break down oil—with the hope that one day we might be able to deploy them deliberately to protect or restore the environment around a spill.

Visit Eos.org throughout April for more coverage of the science and community efforts that came out of what's now considered to be the largest oil spill in history. Our thanks go to Miller and the other scientists who have made this issue possible, and we hope you're inspired by the bravery and vision shown by everyone who rose to this challenge.

Heather Goss, Editor in Chief

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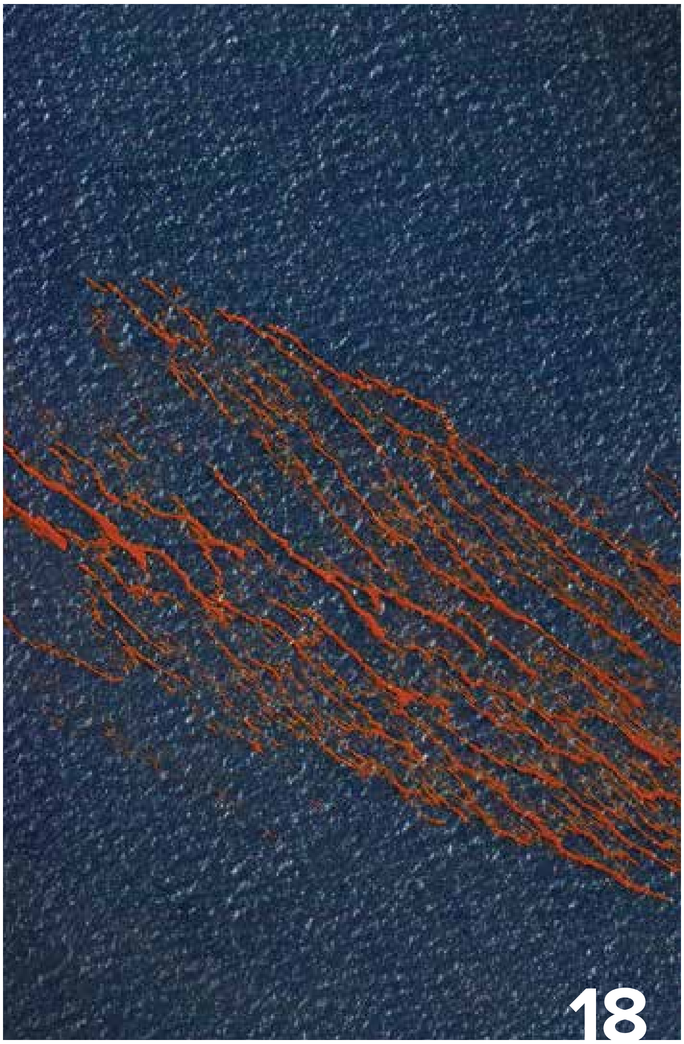

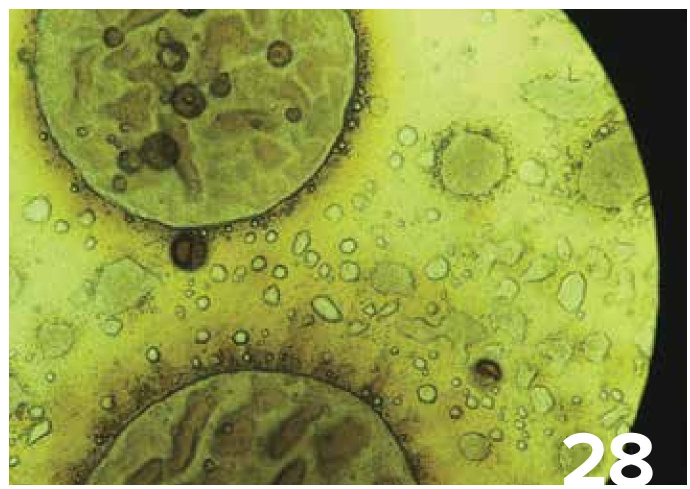

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A thick layer of oil from the Deepwater Horizon oil spill floats atop the Gulf of Mexico on 17 June 2012. Credit: David L. Valentine, University of California, Santa Barbara/NSF Multimedia Gallery

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River Ice Is Disappearing

As rivers snake and slice through landscapes, the ever moving water undergoes seasonal changes that have impacts on ecosystems, water systems, agriculture, and economies.

In middle to high latitudes, rivers can form ice shells, capping the underlying flow. This river ice is a multifaceted powerhouse: It influences nutrient cycling in rivers, can function as winter roads for travel, and can help block greenhouse gases from escaping from stream surfaces.

The importance of river ice has long been clear, but researchers have now peered into how global river ice cover might be changing in a warming climate. Using 400,000 satellite images from 1984 to 2018, the scientists found that on average, ice cover declined by almost a week over those decades.

They also projected ice cover losses for the turn of the next century and found that as temperatures increase, global river ice cover will continue to decline by about 16 days. This loss of river ice will affect the hydrology and ecology of rivers and hurt those who rely on ice for transportation.

The Zdobnice River in the Czech Republic will likely experience fewer days of ice in the upcoming century. Credit: Tadeáš Gregor, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

A Novel Way to Measure Change

In winter, ice does more than blanket the riverine system. "River ice plays an important role in the hydraulics, geomorphology, and ecology of rivers," said Ian Knack, a cold regions hydraulic engineer at Clarkson University in Potsdam, N.Y., who was not involved in the new research.

In their paper in *Nature* (bit.ly/river-ice), the researchers looked at the history of river ice cover around the world. The team used Landsat imagery from 1984 to 2018 to calculate the percentage of river ice cover. The decades-long record provided the team with "global coverage and multitemporal observations," said Xiao Yang, a paleoclimatologist at the University of North Carolina at Chapel Hill and lead author of the study.

The researchers used 400,000 images in their analyses, said Yang. "By analyzing 34 years of data, we estimated that about 56% of the rivers globally are affected by seasonal ice," he said. In addition, the team estimates "that there is a 2.5-percentage-point decline in river ice globally during this time."

"The paper presents an interesting means of evaluating global changes to river ice extent and timing," said Knack. "The use of Landsat for evaluating river ice conditions has become quite popular in the past few decades, but its use at the global scale to establish the extents of ice cover is novel."

Climate Modeling

The researchers also developed a model for the future of river ice based on temperature and the seasons. "We used climate simulation data to predict what will happen to river ice," said Yang. "What we found was that in a business-as-usual scenario, in terms of climate simulation, we're expecting to see 16.7 days' decline of river ice."

He added that this is an average value for all rivers globally. If you factor out the rivers that never experience ice, the number of lost river ice days rises considerably. "The actual ice duration decline for rivers that have ice will probably be over a month," said Yang.

Knack said he was "surprised how strong the relationship is between surface air temperature and river ice extent." He added that although temperature and ice formation are "strongly linked physically, river ice is also influenced by precipitation and solar radiation."

"Rain or snow events and clear spring days have led to significant ice breakup and jamming events in the past few decades, and I would have expected that those factors would have reduced the relationship with air temperature alone," Knack explained.

Although Knack found the approach to be an interesting start, he said the researchers focused on relatively large rivers. "While these rivers are very significant when it comes to river ice processes, small rivers are also strongly affected by river ice processes."

He also noted that Landsat sometimes has trouble telling the difference between smooth, clear ice and open water. "Although these areas were excluded from the study to reduce errors, it may have also excluded important rivers in the overall conclusions about the rate of change of river ice extents."

Future of River Ice

Yang said that although there is a plethora of research on sea ice and ice sheet monitoring with regard to climate change, he hopes that his team's research might spur more attention to freshwater ice changes.

"Lakes and rivers are actually the hot spots for a lot of geochemical processes happening on the landscape," said Yang. "And a lot of the things that we care about—for example greenhouse gas emission from these systems—are an important contribution to the global carbon budget."

Yang noted that wintertime is an integral part of the annual cycle of the river but is often understudied. "It's really important that we understand how the hydrology, the ecosystems, and the climate associated with these systems operate," he said.

By **Sarah Derouin** (@Sarah_Derouin), Science Writer

Body-Based Jargon Can Be Harassment When It Turns Sexual

Content warning: *This article contains examples of body-based and sexual terms applied to geoscience concepts. In some cases, this language has been used to harass and discriminate against people with marginalized identities.*

Geoscientists frequently use body-related terms to describe scientific concepts, but body metaphors that become sexual may contribute to the high risk of sexual harassment and assault in fieldwork.

"It's not a problem to say a rock looks like a head," said Tamara Pico, a postdoctoral scholar studying the last ice age at the California Institute of Technology in Pasadena. "I'm not saying that in itself is dangerous but, rather, that it might create a framework that makes sexual analogies more prevalent. And then the use of sexual language is dangerous."

Pico wanted to quantify how common it is to use body or sexual metaphors to talk about geoscience concepts, so she asked attendees of AGU's Fall Meeting 2019 to share their personal experiences. She found that people of all genders and ages could recognize and identify this type of language and give examples of when they had heard it in the field or classroom.

Pervasive and Uncomfortable

Bodied language has been entrenched in how scientists have described geologic concepts for hundreds of years. Landscapes are naked or bare. Scars mar the face of a plateau. Soil is fertile, barren, or sterile. Glaciers go through binge-purge cycles.

Bodied language can at times help communicate complicated science, Pico said, but it is important to understand that the language scientists use has shaped generations of scientific culture. Moreover, the use of body metaphors can often be sexualized.

Pico recalled an early field experience in which the instructor related geologic dikes to the homophonous homophobic slur. "At the time, [I] and a few other mostly women in the field talked about how it made us feel uncomfortable that the instructor would make jokes about the dikes that we saw, like, 'Oh, check out that dike on dike action,'" Pico said.

"When I was an older grad student, I heard younger grad students complaining about [that] type of language, and that's when I realized, 'Oh, I don't think this is a one-off thing,'" she said. "This is pervasive language that gets used, and it makes people uncomfortable."

During her poster presentation, Pico gathered dozens of examples of gendered, bodied, and sexualized language used in the classroom, in field research, and in other professional settings like conferences.

The responses contained some commonalities: "sexy" scientific results; "pornographic" images of a field site; a photo of breasts in a bra to describe rock cleavage; the ocean, Antarctica, or the wilderness described as a mistress to be tamed and conquered; the mineral cummingtonite said with a wink and a nudge.

Unsafe Environment

Title IX of the Education Amendments of 1972 protects students from sexual and gender-based harassment, including "verbal, nonverbal, or physical conduct of a sexual nature."

"Using that type of sexualized language, that in itself constitutes a hostile environment and in itself can constitute sex- or gender-based harassment," Pico argued.

Moreover, a recent study found that normalizing such language fosters physically unsafe environments. In a 2014 survey, 71% of women responded that they had experienced sexual harassment during a field research experience, and 26% reported a physical assault. The geosciences are no exception to that statistic.

Pico is collecting more examples of gendered, bodied, and sexualized language in the geosciences to better track its use in the classroom and in the field. She says that raising awareness through personal stories helps a great deal but that quantitative data will help define the scope of the problem and bolster efforts for change at an institutional level.

"It's very much in the culture to talk about geology in this way," she said. "But once that becomes sexually explicit, that's what crosses the line in terms of violating university policies."

Bodied language can at times help communicate complicated science, Pico said, but it is important to understand that the language scientists use has shaped generations of scientific culture.

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

Japan Puts Its Mark on Geologic Time with the Chibanian Age

The name Chibanian derives from strata like this, discovered in Ichihara in Chiba Prefecture, east of Tokyo. The Chibanian geological age spans from 770,000 to 126,000 years ago. Credit: Kyodo News/Getty Images

Earth's newest geologic time interval has been named after a jurisdiction outside Tokyo. The International Union of Geological Sciences (IUGS) recently ratified the name Chibanian, for a period of time stretching from 770,000 to 126,000 years ago, during the Pleistocene epoch.

Equating to the Middle Pleistocene subepoch, the Chibanian is named after Chiba, one of Japan's 47 prefectures, and marks the first time a Japanese name has been used in the geologic timescale as well as in a Global Boundary Stratotype Section and Point (GSSP). GSSPs are reference points defining the lower boundary of a time interval in the geological timescale. There are dozens of GSSPs around the world, with most in Europe and some in North America and China.

The name was chosen following the discovery of a stratum in Chiba's Ichihara City, about 55 kilometers southeast of central Tokyo. The stratum lies in a cliff along the Yoro River flowing through the Bōsō Peninsula, which separates Tokyo Bay from the Pacific Ocean. The stratum consists of thick layers of late Cenozoic marine silt or clay-bearing marine deposits, minerals, and volcanic ash deposits.

"This sedimentary sequence, called the Kazusa Group, has a total thickness of 3 kilometers with an anomalously high deposition rate reaching 2 meters per thousand years on average," said Makoto Okada, a professor of paleomagnetic studies at Ibaraki University in Mito, Japan. "It is probably the unique case in the world that a deep-sea deposit formed younger than 1 million years ago (especially around the Matuyama-Brunhes geomagnetic reversal boundary) can be observed continuously on land. Moreover, this sequence provides us reliable geomagnetic polarity signals and abundant marine microfossils."

Magnetic Field Reversal Record

The nomenclature is significant for Japan not only because it puts the country on the geological map but also because of an important event that occurred eons ago. The Chibanian is when the last reversal of Earth's magnetic poles took place, and the section in Chiba has one of the best records of that event. The Brunhes-Matuyama reversal is named for geophysicists Bernard Brunhes of France and Motonori Matuyama of Japan, who was the first to discover that the north and south magnetic poles had changed places in the past. The polarity era that came before the current one is named the Matuyama Chron in his honor.

"As a Japanese geologist, I am happy they made a good decision," said Hiroshi Kitazato, a professor at Tokyo University of Marine Science and Technology and an IUGS executive member who participated in the discussions. "The Chibanian section is certainly the most well preserved paleomagnetic reversal transition from Reversal (Matuyama) to Normal (Brunhes).... We are grateful to put a GSSP at the site that is the Brunhes-Matuyama geomagnetic reversal horizon."

The Brunhes-Matuyama reversal is estimated to have taken place about 775,000 years ago, but its duration is disputed. A 2019 study in *Science Advances* by researchers in Japan and the United States estimated that the flip took approximately 22,000 years to occur (bit.ly/last-reversal).

Stanley Finney, a professor of geological sciences at California State University, Long Beach and the IUGS secretary general, noted the importance of the Chiba site in light of findings that the current magnetic field is changing, possibly signaling another polarity reversal.

"In that section in Chiba, you have one of the best records of the reversal interval of anywhere in the world," said Finney. "It's a significant record of past Earth history that helps us see what may happen now."

Source of Local Pride

The effort to name the interval after Chiba passed multiple screening processes, overcame charges by a Japanese group that related documents had been falsified, and beat out two rival sites in Italy.

The IUGS ratification has become a source of pride in Chiba, with Ichihara mayor Joji Koide commenting in a special city leaflet, "Above all, I would like to share the joy of becoming Japan's first GSSP-certified place with our community. We expect worldwide attention in the future. As a city, we will move forward with efforts to prepare the environment for visitors."

A temporary visitor's center was erected at the site in December 2019 ahead of the construction of a permanent facility. A dedication ceremony will be held at the stratum site to recognize the work of the researchers involved in the naming effort, and a GSSP bronze disk, known as a golden spike, will be placed in the cliff face.

"At many of these sites, we have great monuments for illustrative purposes or panels or geoparks," said Finney. "These are international geostandards, and you can't take them into a museum; it's something there in the field."

By **Tim Hornyak** (@robotopia), Science Writer

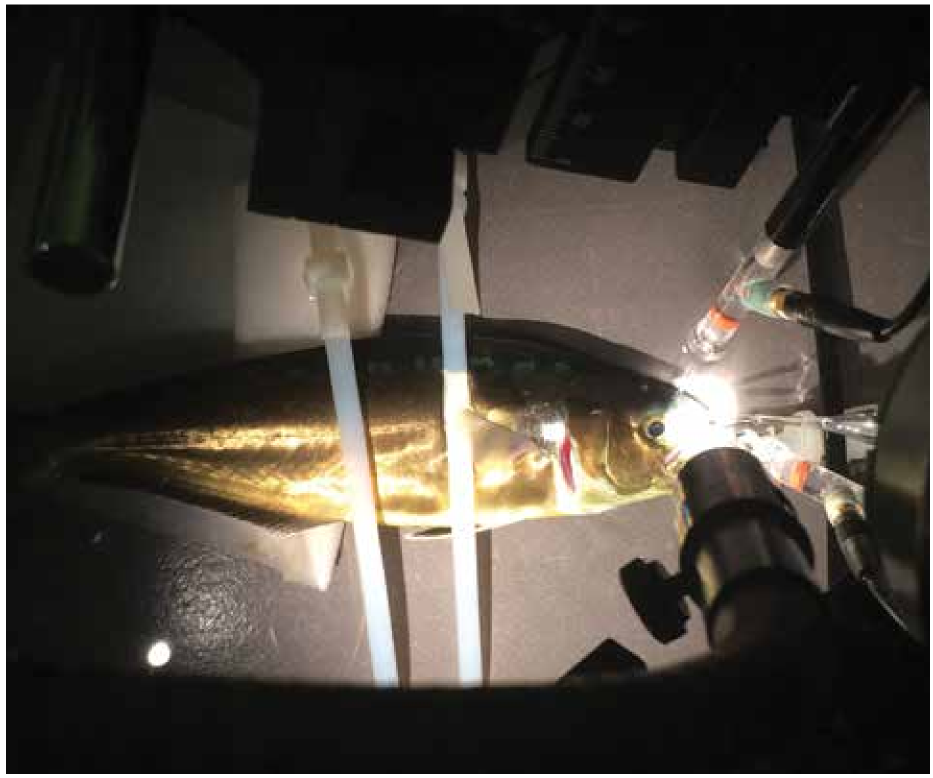
Oil-Exposed Mahi-Mahi Less Likely to Avoid Oil

In the aftermath of oil spills, photographs often depict oil-drenched pelicans and sea otters, but under the water and away from the public eye, fish species are also affected.

Federal, state, and tribal authorities estimate that between 2 trillion and 5 trillion fish were killed following the 2010 Deepwater Horizon oil spill, which spewed nearly 5 million barrels of crude oil into the northern Gulf of Mexico (bit.ly/gulf-spill-restoration).

Lela Schlenker, a fish physiological ecologist at the University of Miami in Florida added that this estimate "didn't account for the sublethal effects of exposures" on such fish as red snapper and mahi-mahi. These effects, which can include reduced cardiac output, visual acuity, and swimming speed, don't immediately kill fish but can cause harm or eventually lead to their deaths.

The Deepwater Horizon spill overlapped with the prime location and timing of mahi-mahi spawning, said Schlenker. To investigate whether affected mahi-mahi could still detect and avoid oil exposure (and its unhealthy effects), she and her colleagues conducted behavioral and electrophysiological tests on juvenile fish in captivity. Each fish was either exposed to an oil mixture (within the concentration range measured after the Deepwater Horizon disaster and prepared by diluting oil collected from the spill) or held in control conditions.



Lela Schlenker, a postdoctoral researcher at the University of Miami in Florida, tags a mahi-mahi prior to releasing it. Credit: The RECOVER consortium

It's "alarming that even though the fish can apparently detect oil in the water, they don't seem to avoid it after just a day of exposure."

Remarkably, oil exposure didn't damage the sense of smell in mahi-mahi, according to the results of electro-olfactogram (EOG) experiments, which measured and recorded changes in electrical potentials in tissues of the fish's nasal cavities.

"It was surprising to me that 24 hours of oil exposure did not seem to impact EOG responses to oil or other odorants," said Tricia Meredith, an assistant research professor studying olfaction in elasmobranchs at Florida Atlantic University, who wasn't involved with the study.

"This may be due to a lack of peripheral impacts or it may be due to some other factor, like the duration or concentration of the oil exposure, the particular odorants chosen for the experiment, the EOG protocol used, or the type of oil used," added Meredith.

Lack of Avoidance

Behavioral testing, however, showed that mahi-mahi in the exposed group were less likely than those in the control group to avoid additional exposure to oil.

During the behavioral experiments, the fish were tested with seawater containing polycyclic aromatic hydrocarbons (PAHs). PAHs are toxic components of oil that have previously been shown to affect behavior patterns in different fish species.

The oil-exposed fish were neither attracted to nor avoidant of the oil. Schlenker thinks this change could be due to central nervous system damage in exposed fish and also noted that more work is needed to understand how oil exposure in one generation of fish affects future generations—research that scientists at the University of Miami are currently conducting.

Meredith expressed some surprise at the study's dual results. It's "alarming that even though the fish can apparently detect oil in the water, they don't seem to avoid it after just a day of exposure," she wrote.

The new research was published in *Environmental Science and Technology* (bit.ly/oil-fish).

By **Rachel Crowell** (@writesRCrowell), Science Writer

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The Ice Giant Spacecraft of Our Dreams

If you could design your dream mission to Uranus or Neptune, what would it look like?

Would you explore the funky terrain on Uranus's moon Miranda? Or Neptune's oddly clumpy rings? What about each planet's strange interactions with the solar wind?

Why pick just one when you could do it all?

Planetary scientists recently designed a hypothetical mission to one of the ice giant planets in our solar system. They explored what that dream spacecraft to Uranus would look like if it incorporated the newest innovations and cutting-edge technologies.

"We wanted to think of technologies that we really thought, 'Well, they're pushing the envelope,'" said Mark Hofstadter, a senior scientist at the Jet Propulsion Laboratory (JPL) and California Institute of Technology in Pasadena. "It's not crazy to think they'd be available to fly 10 years from now." Hofstadter is an author of the internal JPL study, which he discussed at AGU's Fall Meeting 2019.

Some of the innovations are natural iterations of existing technology, Hofstadter said, like using smaller and lighter hardware and computer chips. Using the most up-to-date systems can shave off weight and save room on board the spacecraft. "A rocket can launch a certain amount of mass," he said, "so every kilogram less of spacecraft structure that you need, that's an extra kilogram you could put to science instruments."

Nuclear-Powered Ion Engine

The dream spacecraft combines two space-proven technologies into one brand-new engine, called radioisotope electric propulsion (REP).

A spacecraft works much like any other vehicle. A battery provides the energy to run the onboard systems and start the engine. The power moves fuel through the engine, where it undergoes a chemical change and provides thrust to move the vehicle forward.

In the dream spacecraft, the battery gets its energy from the radioactive decay of plutonium, which is the preferred energy source for traveling the outer solar system where sunlight is scarce. Voyager 1, Voyager 2, Cassini, and New Horizons all used a radioisotope power source but used hydrazine fuel in a chemical engine that quickly flung them to the far reaches of the solar system.

The dream spacecraft's ion engine uses xenon gas as fuel: The xenon is ionized, a nuclear-powered electric field accelerates the xenon ions, and the xenon exits the craft as exhaust. The Deep Space 1 and Dawn missions used this type of engine but were powered by large solar panels, which work best in the inner solar system, where those missions operated.

Xenon gas is very stable. A craft can carry a large amount in a compressed canister, which lengthens the fuel lifetime of the mission. REP "lets us explore all areas of an ice giant system: the rings, the satellites, and even the magnetosphere all around it," Hofstadter said. "We can go wherever we want. We can spend as much time as we want there....It gives us this beautiful flexibility."

A Self-Driving Spacecraft

With REP, the dream spacecraft could fly past rings, moons, and the planet itself about 10 times slower than a craft with a traditional chemical combustion engine. Moving at a slow speed, the craft could take stable, long-exposure, high-resolution images. But to really make the most of the ion engine, the craft needs onboard autonomous navigation.

"We don't know precisely where the moon or a satellite of Uranus is, or the spacecraft [relative to the moon]," Hofstadter said. Most of Uranus's satellites have been seen only from afar, and details about their size and exact orbits remain unclear. "And so because of that uncertainty, you always want to keep a healthy distance between your spacecraft and the thing you're looking at just so you don't crash into it."

"But if you trust the spacecraft to use its own camera to see where the satellite is and adjust its orbit so that it can get close but still miss the satellite," he said, "you can get much closer than you can when you're preparing flybys from Earth" at the mercy of a more than 5-hour communications delay.

That level of onboard autonomous navigation hasn't been attempted before on a spacecraft. NASA's Curiosity rover has some limited ability to plot a path between destinations, and the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) will be able to detect hazards and abort its sample retrieval attempt.

The dream spacecraft would be more like a self-driving car. It would know that it needs to do a flyby of Uranus's moon Ophelia for example. It would then plot its own low-altitude path over the surface that visits points of interest like chaos terrain. It would also navigate around unexpected hazards like jagged cliffs. If the craft misses something interesting, well, there's always enough fuel for another pass.

A Trio of Landers

With extra room on board from sleeker electronics, plus low-and-slow flybys from the REP and autonomous navigation, the dream spacecraft could carry landers to Uranus's moons and easily drop them onto the surface.

"We designed a mission to carry three small landers that we could drop on any of the satellites," Hofstadter said. The size, shape, and capabilities of the landers could be anything from simple cameras to a full suite of instruments to measure gravity, composition, or even seismicity.

The dream spacecraft could survey all 27 of Uranus's satellites, from its largest, Titania, to its smallest, Cupid, only 18 kilometers across. The mission team could then decide the best way to deploy the landers.

"We don't have to decide in advance which satellites we put them on," he said. "We can wait until we get there. We might decide to put all the landers on one satellite to make a little seismic network to look for moonquakes and study the interior. Or maybe when we get there we'll decide we'd rather put a lander on three different satellites."

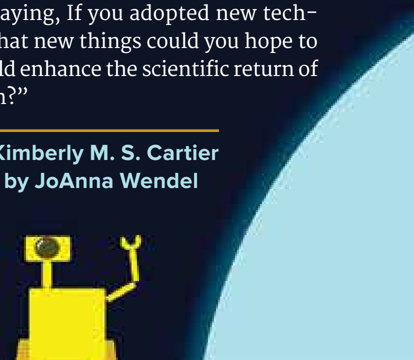
"Ice"ing on a Cake

The scientists who compiled the internal study acknowledged that it's probably unrealistic to incorporate all of these innovative technologies into one mission. Doing so would involve a lot of risk and a lot of cost, Hofstadter said. Moreover, existing space-tested technology that has flown on Cassini, New Horizons, and Juno can certainly deliver exciting ice giant science, he said. These innovations could augment such a spacecraft.

In February, NASA shortlisted the Trident mission as one of its four possible Discovery Program investigations. Trident is a proposal to explore the outer planets, including flybys of Jupiter and Neptune and with a focus on Neptune's largest moon, Triton.

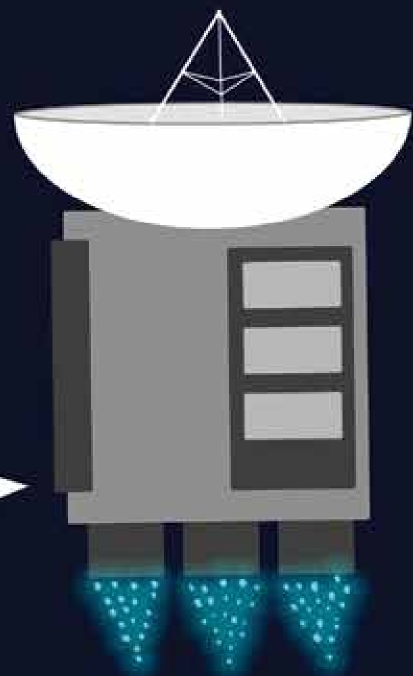
"It's almost like icing on the cake," he said. "We were saying, If you adopted new technologies, what new things could you hope to do that would enhance the scientific return of this mission?"

Article by Kimberly M. S. Cartier
Illustration by JoAnna Wendel

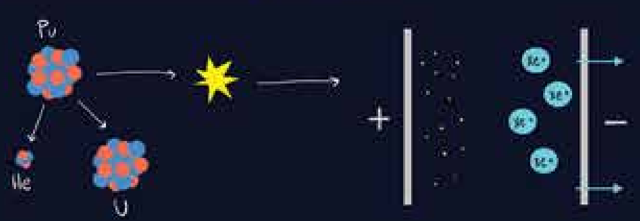


Discovering Uranus: The Dream Spacecraft

The dream spacecraft that scientists imagine might visit Uranus or Neptune would have it all: an energy- and fuel-efficient engine, onboard autonomous navigation, and three landers to explore to your heart's content. With these innovations, the spacecraft could visit every one of Uranus's moons and its ring system. It could map the entirety of the planet's magnetosphere and taste the atmosphere. It could capture sharp and clear images of a moon's terrain and place instruments on the ground. Any one of these innovative technologies would enhance a tried-and-true spacecraft design and boost its science capabilities. All three would be a dream mission come true.



The dream spacecraft would have a nuclear-powered ion engine. Decaying plutonium would provide the power. Ionized xenon gas accelerated through an electric field would provide a weak thrust. The engine could last for years or even decades, allowing for a leisurely but comprehensive tour around an entire planetary system.



The dream spacecraft could get closer to a satellite's surface than other orbiters thanks to its quick and independent decision-making. That, coupled with slow flyover speed, means that it could get sharp, high-resolution scans of the surface or even precise gravimetric measurements.

The dream spacecraft could carry up to three small landers or one larger rover on board. Deployed separately or together, the landers could perform long-term in situ studies of any of an ice giant's satellites the team wants to explore up close after surveying the system.

Helping Alaskan Communities Face Climate Risks

Shishmaref is a town on Sarichef Island off the coast of Alaska threatened by erosion and sea level rise. Credit: Bering Land Bridge National Preserve, CC BY 2.0 (bit.ly/ccby2-0)

Darlene Tocktoo Turner fondly recalls growing up in Shishmaref, Alaska, a community on Sarichef Island, just north of the Bering Strait. She remembers, for instance, venturing out with her family and the dog team to the spring camp where her father would hunt for bearded seals.

"It was fun," she said, reminiscing about a time before they used snowmobiles and when sea ice better buffered waves from hitting the coast. "That was kind of like vacation."

Everything is changing in Shishmaref, however, with Alaska warming twice as quickly as the global average and faster than any other U.S. state.

Shishmaref, on the front lines of climate change, faces increased flooding, erosion, and thawing permafrost, and a December 2019 assessment prepared for the Denali Commission ranked it as the second most threatened community in Alaska. (The Denali Commission is a federal agency that provides utilities, infrastructure, and economic support throughout Alaska.)

At a recent forum, Turner wondered what will become of her hometown, and scientists pondered how they can better use their knowledge to help Shishmaref and other at-risk communities.

"The changes, especially now, are very rapid. It's like, what's next? What do we do next? How do we survive? How do we prepare for these changes?" asked Turner, an educational aide and librarian at the Shishmaref School. Turner, who is involved in various native and community issues, spoke as part of a recent panel about how rapid environmental changes in the Arctic are prompting questions about the most effective ways of informing policy with scientific knowledge. The panel was part of the National Council for Science and the Environment's annual conference held in Washington, D.C.

Turner said she wants the world to know about Shishmaref's predicament. "With the changes that we have seen with our hunting patterns and our weather patterns, I'd like to bring the message that we are vulnerable to erosion. Our community can easily disappear, because our foundation is permafrost. If that disappears, then, because we are on a sand barrier island, we're gone. Our culture is gone. Our existence is gone in the community that we grew up in. That would be my message: that we're here right now and we'd like to remain here."

"We all know that the planet is warming and altering the environment in ways that have never been seen in the history of modern human beings. A big question for all of us is, How do we respond?"

Turner said her community is exploring whether to expand or relocate to the Alaskan mainland.

Matching Science with Needs

Scientists on the panel said although climate research and models are providing valuable information about what's going on in Shishmaref and elsewhere, more needs to be done to help local people and communities.

"We all know that the planet is warming and altering the environment in ways that have never been seen in the history of modern human beings. A big question for all of us is, How do we respond?" said Brendan Kelly, executive director of the Study of Environmental Arctic Change, a program focusing on developing scientific knowledge that is relevant to decision-making. "We need to adapt how we do our science to meet this need."

Kelly said that the needs are multifold, including adjusting science to the urgency of climate change, working with Indigenous knowledge holders to include their understanding, and communicating with policy makers in a way that can make a difference in terms of disaster mitigation and other issues.

"We need to structure and frame the way we ask and answer questions in a way that will truly be useful. The buzzword is 'use-inspired research,'" Kelly said, noting that agencies including the National Science Foundation are putting more focus on this.

"We also need people to address the meteor coming at us," he added, referring to rapid climate change in Alaska.

Twila Moon, a research scientist at the National Snow and Ice Data Center in Boulder, Colo., agreed that scientists need to do better at providing useful information for society. "It seems clear that the way that science and policy have interacted in the past has not led to really fruitful, long-term relationships in which scientifically sound and well-established information is always getting into the hands of policy makers and that policy makers have science-appropriate questions they are asking," said Moon.

She urged a change "so that the back-and-forth between science and policy is more productive, and especially more productive on shorter timescales" that could prove useful in places like Shishmaref.

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

An Ice Sheet's Footprint on Ancient Shorelines

Six years ago, Christine Chen stood on the ancient shoreline of Lake Bonneville, a body of water that once rivaled Lake Superior in size. The largest remnant of Lake Bonneville, which stretched throughout the eastern Great Basin, is Utah's Great Salt Lake.

Chen, now a geology postdoc at the California Institute of Technology in Pasadena, was tracing Lake Bonneville's shoreline deposits throughout the state, carefully measuring their elevation with GPS. Researchers have long known that the weight of the massive lake compressed Earth's crust, which rebounded as the lake drained over time. Chen and her colleagues also found the footprint of the Laurentide Ice Sheet, the behemoth glacier that once covered much of northern North America.

A New Angle on an Old Site

Lake Bonneville reached its maximum size (about 51,000 square kilometers) roughly 18,000 years ago, when the Great Basin enjoyed a much wetter climate than it does today. But even at its largest, islands broke through the surface of the lake, leaving behind peaks with the telltale signs of ancient shorelines. The ancient lake has long been a beacon for geologists.

"This is a very classic study site," said Jacqueline Austermann, an assistant professor at Columbia University in New York and lead author on the new study.

In the late 19th century, Grove Karl Gilbert, a titan of geology, traced these ancient shorelines on horseback, taking careful measurements of their elevations. In 1885, Gilbert noted that curiously, the shoreline elevation of the islands was higher than the perimeter of the lake. Perhaps, Gilbert suggested, Earth's crust was viscous, compacting and then rebounding as the water level dropped and the weight of the ancient lake disappeared.

The rebound phenomenon at Lake Bonneville provides researchers with insights into the structure of Earth's shallow interior.

Austermann's team revisited the arid shores of both Lake Bonneville and another massive paleolake, Lake Lahontan, in what is now western Nevada. "What's new in the work that we've done," she said, "is not just how the lake has deformed the shorelines but also how ice sheets have deformed the shorelines."

"It's a really neat study," said Pippa Whitehouse, an associate professor of geography at Durham University in the United Kingdom not involved in the new research. "It combines the field I look at, which is global response to ice sheet change, with this local response to the lake loading that you have in the western U.S., with a couple of different techniques to understand more about both the Earth's structure [and] the history of the lake loading and the ice history. I'm just jealous that I didn't do it myself."

The study was published in *Earth and Planetary Science Letters* (bit.ly/ancient-shorelines).

Investigating Earth's Crust

The team knew that if the weight of the lake could compress the Earth's crust, the weight of a massive ice sheet would also compress the Earth beneath it—and cause the crust to bulge around its edges.

Christine Y. Chen stands next to a deposit of tufa formed on top of bedrock at Utah's Antelope Island in 2012. Tufa, a type of porous carbonate rock, formed within the waters of Lake Bonneville and serves as additional evidence left behind by the now relict lake. Credit: Adam C. Maloof

The researchers used their updated shoreline elevations to model the deformation of the crust due to the lake alone. When they removed the lake-induced deformation data from the equation, they could still see a residual tilt in the topography that they suspected was due to the weight of the Laurentide Ice Sheet thousands of kilometers to the north.

In addition, the lighter load of the lake has long provided researchers with information on the viscosity of the structure of the crust directly beneath the lake, but isolating the tilt from the heavier ice sheet allowed researchers to draw conclusions about the viscosity of deeper structures in the wider region.

"Here, because they've got two loads of different sizes, then you can separate that to some degree," said Whitehouse. "So they've got constraints on the shallow structure and, independently, the deeper structure, which is really rare in our field."

From Shorelines to Ice Sheets

The researchers used ice sheet models to find out what size of ice sheet could produce the shorelines we see today. However, the team had to account for another factor long ignored in rebound studies of Lake Bonneville: Earth's gravitational field. Researchers studying lake load deformation didn't have to look at the water body's effect on the gravitational field because it was negligible, but the ice sheet, with its much greater mass, does impact the gravity field.

The team expected to find that a larger ice sheet would indicate a bigger bulge and thus a steeper tilt, but they found that the ice sheet's effect on the gravity field would have counteracted some of the bulging effect. "The findings that I hope will be useful are the constraints that this data and model can put on the shape of the Laurentide ice sheet and the viscosity of the upper 1,000 kilometers of the mantle," Austermann said.

Although researchers have been studying this site for more than 100 years, it may not be preserved for much longer. "A lot of the paleoshoreline features on Lake Bonneville now are being mined for gravel," Chen said, "and so a lot of these features are actually being actively removed and might not be able to be studied in the future."

By **Kate Wheeling** (@katewheeling), Science Writer

Power Outages, PG&E, and Science's Flickering Future

Lawmakers on Capitol Hill met in January to discuss the cascading effects of wildfires on the nation's power grids as a new wildfire season approaches.

Members of the U.S. House of Representatives spoke about the wide-reaching consequences of the public safety power shutoffs initiated by California utilities and pressed for answers about short- and long-term solutions to maintaining electric utility infrastructure.

"It is crazy to think that [we're] living in a modern society where one must constantly worry whether the lights are on," said Rep. Fred Upton (R-Mich.).

The solutions could have an impact on the lives of millions who live in California and other western states, as well as on scientists who live or work in blackout-prone areas. The University of California, Berkeley and Lawrence Berkeley National Laboratory (LBNL) both sit in the footprint of California's largest utility, Pacific Gas and Electric Company (PG&E), and their researchers lost both time and data due to PG&E's shutoffs in 2019.

PG&E said that the outages will likely occur for the next 10 years. As lawmakers debate the web of local, state, and federal regulations needed to upgrade the country's aging infrastructure, intermittent power may be a new reality.

"In science, you always take into account that something can go bad," said Sara Molinari, a postdoctoral researcher at Rice University who was visiting LBNL in October 2019 during the shutoffs. "Shutting down the power every time the wind blows? It's surely not a sustainable solution."

A "Planned Disaster"

Massive wildfires swept through California from 2017 to 2019, killing more than 100 people and burning over 4 million acres. Sparks from PG&E's power lines led to California's deadliest wildfire, the Camp Fire, in 2018. In fact, one half of California's most disastrous fires are linked to electric utility infrastructure, said Rep. Bobby Rush (D-Ill.) at the hearing, held by the House Committee on Energy and Commerce.

To avoid another disaster, PG&E enacted the largest public safety power shutoff in the state's history, leaving 2.5 million people in the dark for several days in October. Later that month, PG&E and the Southern California Edison utility issued another shutoff, which affected half a million people.

The shutoffs succeeded in protecting human life, but those left in the dark paid another kind of price: They drove on roads without working traffic lights, came home to refrigerators without power, and found cell phones without service. People with medical devices bought generators or went to emergency shelters, and schools and businesses closed their doors without knowing when they'd reopen.

PG&E president and CEO William Johnson said in his testimony at the hearing that "the shutoffs were the right thing to do for public safety, even as [such actions are] not the way PG&E wants to serve its customers."

Irwin Redlener and Jeff Schlegelmilch, director and deputy director, respectively, of the National Center for Disaster Preparedness at Columbia University, said that the shutoffs were a type of "planned disaster."

"PG&E is, in effect, conducting a controlled burn on the people of California to prevent a larger disaster," they wrote in The Hill. Even though the shutoffs were not a natural disaster, they had many of the symptoms of one. As Rep. Anna Eshoo (D-Calif.) said, the shutoffs "have just caused hell in people's lives."

Barriers to Science

For scientists working in areas affected by the shutoffs, the outages meant lost time and lost samples as well as a new source of uncertainty in their work.

University of California, Berkeley Ph.D. student Stefanie Engert couldn't use a batch of fruit flies she'd been raising before the shutoff. Engert raises *Drosophila melanogaster* to study how the brain processes sensory information like taste. She grows batches of fruit flies and then images their brains using neuronal activity imaging, but during shutoffs, she said, "we couldn't get to our animals." Each generation of flies takes about 20 days to reach maturity, she said.

"It wasn't horrible, but I think if it keeps on happening, and keeps on happening, then it becomes a problem," she said.

Postdoctoral researcher Molinari lost a week of work to the first shutoff. Molinari was visiting LBNL to learn how to grow a new type of bacterium but had to restart the experiments after the shutoffs. "PG&E makes it hard to work," Molinari said.

At LBNL, the power outage affected hundreds of scientists who use the lab's special equipment, like its nanoscience facility and supercomputer, according to lab spokesperson John German. The lab said that the power shutoffs "significantly" affected its science mission.

The shutoff came at a particularly tricky time for one lab: Researchers at the Space Sciences Laboratory had a scheduled satellite launch the same week that PG&E cut power in mid-October. (See "How to Launch a Satellite During a Blackout," p. 13.) The lab had to MacGyver a solution to keep its status of mission control with NASA.

Grid Independence

As lawmakers discussed the effects of the shutoffs, microgrids rose to the surface as one way to make California's communities more resilient.

David Eisenman, director of the Center for Public Health and Disasters at the University of California, Los Angeles, said that public safety power shutoffs have many "cascading hazards." These cascading effects "will only increase as our sociotechnical systems grow in interdependency and complexity," Eisenman said.

Some communities in California already have access to their own power, and PG&E is exploring the use of resiliency zones that can be isolated during shutoffs.

The Blue Lake Rancheria tribe in Humboldt County runs on a microgrid powered by solar panels and storage batteries. During the PG&E shutoff, the tribe served more than 10,000 people, inviting nearby residents to pump gas, set up a makeshift newsroom, and house critically ill patients, according to the *Washington Post.*

Borrego Springs in Southern California can go off San Diego Gas and Electric Company's grid during outages, thanks to its mix of energy from renewable and other sources. The rural community draws power from solar panels, energy storage, and diesel generators, as well as from the grid.

The independence that microgrids offer is enticing: The Santa Barbara school district is assessing the feasibility of solar power and batteries to get off the grid, reports the *Santa Barbara Independent.* The district is interested in part due to the public safety shutoffs becoming the "new norm."

University of California, Berkeley has the ability to provide power in-house, though its capacity can't meet the campus's full electrical demand. The university's cogeneration plant produces steam for its buildings and burns fuel—mostly natural gas—to provide a portion of the campus's power needs. During the shutoffs, the university used the plant to keep the lights on in student dorms and power some essential buildings. The Space Sciences Laboratory successfully launched the satellite, thanks in part to the university's power plant.

But the cogeneration plant will need to be replaced in the next 10 years. The university declined to comment on future plans for the cogeneration plant but said that a task force has been assembled to "create a plan for Berkeley that works for students, faculty, and staff."

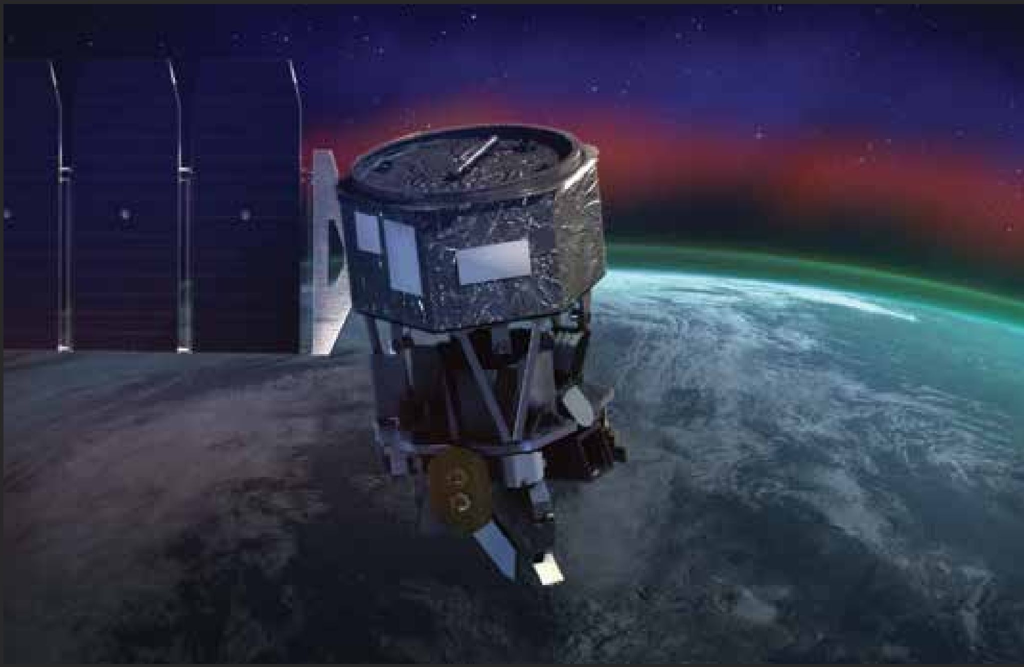
For Berkeley Ph.D. student Whitney Loo, going through the shutoffs "just put everything into perspective."

"Anything can come and disrupt your research plan at this point, is what we've learned," Loo said. "I don't think anyone who said, 'I'm going to go to Berkeley and get my Ph.D. in chemical engineering,' was expecting to have to deal with the power going out."

Loo urged the university to find solutions for the upcoming year. "Fire season is coming. We can't push that back," Loo said. "If they don't come up with an alternative solution for what they did last year, we'll be back at the same place before we know it."

By **Jenessa Duncombe** (@jrdscience), Staff Writer

How to Launch a Satellite During a Blackout



NASA's ICON satellite is helping scientists study the effects of Earth and space weather on the ionosphere. Credit: NASA Goddard's Conceptual Image Lab/B. Monroe

The same week that scientists at the Space Sciences Laboratory at the University of California (UC), Berkeley planned to launch a satellite with NASA, lab director Steve Beckwith got news that the power might go out.

California was in the midst of its fall fire season, and the utility that delivers power to UC Berkeley's campus, Pacific Gas and Electric Company (PG&E), feared that high winds, hot air, and dated equipment could spark a fire. Just in case, the utility sent out word: They'd preemptively cut power to 800,000 customers the following day, Wednesday, 9 October 2019. The outage would be the largest in the state's history.

Beckwith knew his team had a problem. The spacecraft carrying the Ionospheric Connection Explorer (ICON) satellite was scheduled to launch from Cape Canaveral, Fla., that week, and Beckwith's lab needed to be online to act as mission control when the spacecraft deployed the instrument in orbit. To do that, the lab would need not only power but also a viable source of backup power. "At first, I didn't think we could do it," Beckwith said.

The power shutoffs were a Hail Mary from a utility plagued by a laundry list of safety issues. PG&E provides power to 16 million household customers across central and Northern California, but its low-tech infrastructure, long transmission lines, limited personnel, and a myriad of other problems have left it vulnerable. The investor-owned utility sparked the Camp Fire in 2018, which left 85 dead and destroyed the town of Paradise. In January 2019, a judge suggested the utility preemptively cut power to customers during high winds as a stopgap measure while the company fixes its larger, more systemic safety concerns.

Ten months later, California residents in 34 counties felt the consequences when the utility shut off power. Those living or working in the footprint of PG&E's grid had to answer new questions about how to be resilient: How long could they go without power? What backup power did they have? Beckwith needed something more concrete: extension cords. High-capacity, heavy-duty, 50- to 100-foot extensions cords. And he needed them immediately.

Time to Improvise

The Space Sciences Laboratory sits on a hill in the Silver Lab Addition Building, on the northeastern corner of UC Berkeley's main campus. The lab had emergency power outlets, located in each floor's clean rooms. The trick would be connecting the emergency outlets with workstations in the building's library, where scientists would crunch numbers in real time as the satellite made its first pass over California. After dropping about a thousand dollars on extension cords from Home Depot, Beckwith said, they had the library powered.

The next step was determining where the power would come from. The team members had one backup generator, but they ordered a second and lined up a contact in San Jose with a truckload of diesel fuel ready to drive their way at a moment's notice. "We were confident we could pull it off on generators if we had to," Beckwith said. But they had another option, a backup power source that could become a lifeline for UC Berkeley in years to come: the school's cogeneration plant.

The plant originally had a boiler that sent steam to the campus's buildings, but the university expanded it to burn natural gas for electricity. The plant operates around the clock but can supply only part of the campus's electricity demand.

Fortunately for Beckwith's team, the Space Sciences Laboratory was on the shortlist of emergency labs that stayed on power. Once PG&E shut off power Wednesday night—after delaying much of the day—the campus's cogeneration plant picked up the slack.

Replacing natural gas is the "hardest nut to crack to achieve carbon neutrality."

As the makeshift mission control at the Space Sciences Laboratory counted down to deployment on Thursday night, fueled by Costco snacks and 400-gallon water tanks, the team could rest easy with two sources of power to rely on: the cogeneration plant and their extra generators. Under a watchful team of electricians, "we were able to acquire the satellite that night and verify [its] health and safety," said Beckwith.

Pulling off the launch was "like watching a choreographed performance turn into a jazz improvisation as problems came up and the individual team members solved them in real time feeding off one another's talent and energy," said Beckwith.

Future Questions

The launch's success relied in part on the campus's cogeneration plant, which has an uncertain future. (See "Power Outages, PG&E, and Science's Flickering Future," p. 12)

University chancellor Carol Christ said at a graduate student assembly meeting in 2019 that the aging facility needs to be replaced in the next 10 years. PG&E has said the power shutoffs are likely to occur over that time period.

In addition, the cogeneration plant burns natural gas, and the University of California system is just 5 years away from reaching its sustainability pledge of carbon neutrality.

The sustainability plan, announced in 2013, declares that UC buildings and vehicles must have net zero greenhouse gas emissions by 2025. Presently, three quarters of UC Berkeley's emissions come from powering the campus's buildings, according to the university's Office of Sustainability. For the university to reach carbon-neutral levels, it will need to reduce total emissions by 80%.

Replacements for natural gas are expensive and hard to come by. As E&E News reported, the university's sustainability director, Matthew St. Clair, called replacing natural gas the "hardest nut to crack to achieve carbon neutrality."

UC Berkeley spokesperson Janet Gilmore said that the university has convened a task force for addressing future power shutoffs. UC Berkeley declined to comment on long-term plans for the cogeneration plant or the impacts of burning natural gas on the 2025 carbon-neutral pledge.

Beckwith said that the experience made him and his team more resilient. "If we had another blackout," he said, "I don't think [working through it is] going to take an enormous effort on my part."

As to the launch? "We never had a power glitch," Beckwith said.

By **Jenessa Duncombe** (@jrdscience), Staff Writer

8 Lessons I Learned Leading a Scientific "Design Sprint"

Participants in the design sprint dine out together. Developing a supportive, open, and enjoyable team culture is an important element in a successful sprint. Credit: Ryan McGranaghan

Even a cursory glance at how Google operates will uncover the secret sauce behind many of its innovative ideas and products: the design sprint, a regimented 5-day process intended to accelerate progress toward key business questions, product development, or other goals. According to GV (formerly Google Ventures), which developed the concept, the design sprint is "a 'greatest hits' of business strategy, innovation, behavior science, design thinking, and more."

Design sprints have been used primarily by companies, but could this approach be useful for, say, the Earth and space science community?

That's a question a colleague and I entertained recently after finding out that our proposal to the International Space Science Institute (ISSI) to lead a team on an ambitious and fast paced project (not quite a "loonshot," but not far off) studying the space environment had been accepted. The scope of challenges confronting the project seemed similar to those that Google and other product developers face, so I decided to test whether the sprint could work for space science.

This article shares advice and lessons learned from my experience leading the first of two design sprint–inspired meetings—held in February 2019 at ISSI's headquarters in Bern, Switzerland—that could be relevant across scientific disciplines.

Warming Up for the Sprint

The proposal we wrote to ISSI was to study how energy from the Sun reaches and disrupts the near-Earth space environment. The myriad processes through which this occurs, which sometimes have deleterious effects on our well-being, are known colloquially as space weather. We specifically proposed to investigate how electric currents carried by particles in Earth's magnetic field transport energy and momentum between the magnetosphere and the upper atmosphere. This is one of the great unresolved questions in space science—so, you know, a small undertaking for two weeklong meetings.

The angle that won us the award from ISSI was that of embracing a "new frontier" at the intersection of traditional approaches to space weather research and innovation from data science. In other words, big data + data science + [insert your favorite Silicon Valley buzz phrase here] = radical new understanding. In this relatively undefined space, the possibilities that lay in front of us were huge and sprawling.

This was the first time I would be leading a group of people from across the world on a project that we had envisioned. That kind of responsibility comes with stress. As I'm the type to overprepare, my response was to spend long hours leading up to the first week thinking of all the possible paths our team might go down, preparing materials to support each one, and familiarizing myself with the specifics. None of this time was wasted per se, as I learned a great deal, but it was not efficient, nor did much of my preparation end up directly facilitating the team.

LESSON 1. You can't predict everything.

You don't know where a team will go during a design sprint. (That is the whole point, really—to break away from the expected.) For sprint leaders, efficient preparation is key, so spend your time planning for what you know *will* help your team and avoid a "just in case" mentality that has you planning for what you think *might* help.

Although it might not be apparent at the outset of a sprint week, know also that each day during the sprint will bring unexpected twists and turns, which will require sacrifices on the part of the leaders. Be prepared to pivot, adapt, and develop new plans on the fly—staying up late and getting up as early as needed—to help the group succeed.

As important as topic-specific preparation is, the importance of team dynamics and logistics cannot be overstated. I suggest offloading logistical planning to others to the maximum possible extent. Find a facility that provides meeting rooms, amenities, and support staff. Mark my words, there will be challenges to overcome, and you *will* have difficulties with and tension among team members, but constructive team dynamics flow better and are more easily managed when scheduling and logistics run smoothly.

Sprint Week

We arrived at ISSI's headquarters early on 18 February 2019 ready to sprint. According to GV's design sprint process, day 1 should be devoted to developing a common understanding among the group, with participants providing their relevant perspectives and engaging in freewheeling discussions.

LESSON 2. Start with an icebreaker.

Start the week off in an unexpected way to create new ground for your group, and do not steer the discussion. It's important not to jump right into technical material. We instead began with a unique icebreaker meant to foster comfort with one another, have some fun, and generally avoid the common scripts to which individuals and groups default. In short, we wanted to preempt normal conversation. Some of the great interviewers of our time (e.g., Terry Gross) do the same, and the technique seems to have a way of creating better conversations. In that spirit, I asked each person, What is one thing outside of your field of study or work that you are fanatic about? This question should be open-ended, novel, and lighthearted.

After all my preparation for the week, it was difficult to resist directing the conversation. Doing so would have been a mistake. I often bit my tongue when my mind told me to intervene, opting instead to let these discussions go where they would. I was floored by what I learned as the discussion unfurled in surprising directions. For instance, although we thought we understood team members' interests and positions on the basis of material in their publications, conference presentations, and more formal interactions, they raised many unexpected and insightful ideas seemingly disparate from their traditional lines of thought, even on the first day.

Day 2 is about wandering around in your new understanding of the problem space and ideating as a team, as subgroups, and as individuals. This exploratory brainstorming session should be as exhaustive as possible, with everyone contributing—this is when the best ideas emerge. It is important for everyone to be aware of the characteristics of questions that best help ideation. Sometimes the best way to get more out of a discussion is to turn a question on its head.

LESSON 3. Become an artist of the question.

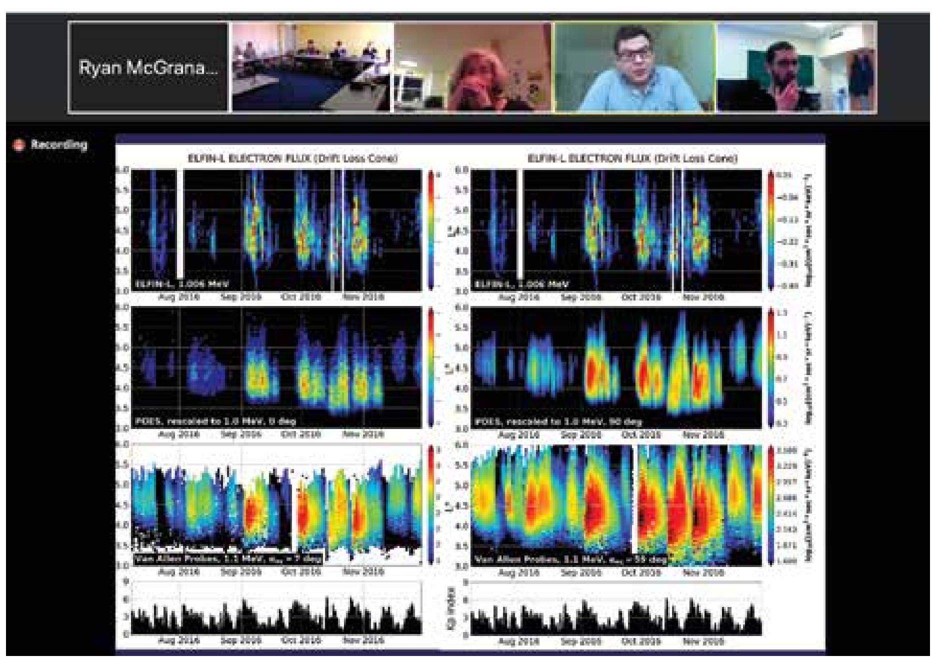
In the context of our topic, for instance, we began with a counterquestion. Instead of asking what we know now about space weather electric current systems, we asked, What do we *not* know about the current systems? It's a slight but nuanced difference. Suddenly we were thinking less like traditional space physicists and more like entrepreneurs and designers, amalgamating old and new information in novel ways and making new connections, arrangements, and relationships—all in the name of *creating*.

Learning the art of asking better questions and fostering a designcentric environment will create fertile ground to sow new ideas. These ideas need support to bear fruit, though, which means having solution-oriented people on your team. You can facilitate this mindset with best practices from other fields, such as the neurological and behavioral sciences and the study of team science. We used the morning stand-up, a concept adopted from start-up culture that was new to the scientists on our team but drew their praise by the end of the sprint.

LESSON 4. Be open-minded and stay together.

You can also make life easier on yourself by working with individuals who are open to new ideas rather than with those unlikely to budge. Select your team from among the early adopters and the early-accepting majority rather than the late and laggard adopter groups.

Day 2 made it clear that we had to rely on the dedication and commitment of the team. We were sprinting in Switzerland, with jet-lagged team members who had come from



Design sprint team members, both those assembled in Bern (top row, second from left) and those participating remotely, take part in the team's hackathon on day 3 of the sprint week, as seen in this screen capture. The plots show data collected and used to describe the temporal and spatial states of particle transport through the magnetosphere and ionosphere. Credit: Ryan McGranaghan nine different time zones. On top of this, some misfortunes meant that a few people who'd intended to join us in Bern had to participate remotely, often at odd or inconvenient times for them. One team member, for example, punctually joined our meetings from 3:00 a.m. to 2:00 p.m. her time, breaking only to teach an hour-long graduate course. She was instrumental.

Finally, if you are like me, you seek solitude after long days in deep discussion—and you will be exhausted after day 2. But avoid the temptation to let your team disband that evening and instead schedule a group dinner so that everyone can be together away from the sprint. Group dinners are an important aspect of team culture, which needs to be supportive, open, and enjoyable for your sprint to work.

We spent Tuesday night at a brewery alongside the River Aare, about a 2.5-kilometer walk from our accommodations. Over the next few days, I realized how important this evening was in helping us sustain our camaraderie.

Day 3 of a design sprint involves building solutions around ideas produced during the first 2 days. The goal is to arrive at a small subset of the most valuable solutions, with paths to those solutions laid out as storyboards.

In our case this step could occur only by working with data. So we introduced yet another relatively new concept for space scientists: the hackathon (see "Hackathon Speeds Progress Toward Climate Model Collaboration," March 2020). Most projects will require some activity like this that dictates side-by-side teamwork beyond group discussions. Tailoring this activity to your project and preparing for it by collecting necessary elements (e.g., data and technologies) are vital for getting your group to buy in and ultimately for its success.

LESSON 5.
Embrace the hackathon.

The hackathon does two things. First, it facilitates rapid assessment of an immense number of possible solutions, allowing everyone to quickly realize what is and is not possible. Second, it creates *action*.

On day 3, participants typically begin to feel worn and tired, which hurts productivity. Our group returned from a team lunch lethargic and at risk of falling short of our goal to select two candidate solutions with corresponding plans to achieve them. But we embraced the hackathon. Team members worked together in small groups, sharing data and code to build new data sets and software to help meet our solutions. The directed action and hands-on work helped us to push through our fatigue. That afternoon was one of the most productive of the week.

LESSON 6.
Stick to successful new practices.

By day 4, the fruits of adopting and enjoying what were new and (initially) uncomfortable approaches for team members were showing. There was a visceral change in the meeting room during that morning's stand-up as excitement and coherent plans replaced the reticence and uncertainty of previous stand-ups. It was not always a fluid process, but our success that day was validation that our persistence with these new practices was key.

Day 4 is for poking holes in your approaches and solutions, patching those holes, updating your solutions, and "red teaming" prototypes. Then you repeat, repeat, and repeat that process. As exhaustion sets in and the week wears on, it is important to build regular progress checkpoints into your efforts, such as roundtable lightning presentations before breaks to collect status updates. There will certainly be problematic issues by this point. Checkpoints can help identify these issues before they derail the entire sprint.

LESSON 7.
Chart your own path.

The normal, business-oriented design sprint regimen spells out a customer review of a prototyped solution on the final day of the sprint. Until this point, we had followed the standard design sprint plan, but by day 5, this no longer exactly fit with our goals as a science team.

Over the preceding several days, we had discussed "prototypes" of new particle transport models that might explain the complex magnetospheric processes we are interested in illuminating. But armed with agility and capability from the fresh approach of the week, we had become wildly ambitious. No longer was a solution to just one grand challenge in space weather enough. We also wanted to position this sprint as a foundation for future efforts to tackle other unresolved questions in our field of space science as well as more broadly across other disciplines.

So the ultimate deliverable we premiered to colleagues was an experience-based set of guidelines for how to achieve radical progress in addressing scientific questions. On the final day, we shared these guidelines, alongside the technical solutions we had developed, with colleagues outside our team who joined our meeting virtually. Our sprint had not led to a stopping point but instead had created a "community of practice:" an open, extensible, and cross-disciplinary group that achieves deep knowledge integration and benefits from methodology transfer. Our focus in concluding the sprint was therefore not only on providing the near-term deliverables related to the particle transport models we'd discussed but also on curating the week's resources, making them *usable* into the future, and identifying long-term directions.

LESSON 8.
Capture knowledge in the moment.

Capturing the results of the week and charting a path forward gave our team a basis to benefit our field over the coming months and years. Do not risk the progress you have made by believing you will remember everything that occurred during the sprint. Hold a concluding discussion and make detailed notes and slides that capture all the valuable input from the week. Make the learning and progress explicit.

Post-sprint Reflections

The design sprint requires an openness to nuance and to reconsidering our own individual design philosophies. During our sprint week, team members were exposed to many new ideas and approaches, and as a result, we experienced lasting unexpected benefits. We perceived, adopted, and adapted to these ideas, coalescing our shared experience into a new and dynamic team culture.

Our success with the design sprint suggests an alternative approach for other scientists—a radically interdisciplinary one—in which the intersection of disparate disciplines (i.e., science and design) can yield new and innovative outcomes. This is new territory for many scientists, but I hope it will spur the kind of progress for others that we witnessed firsthand in our group.

Acknowledgment

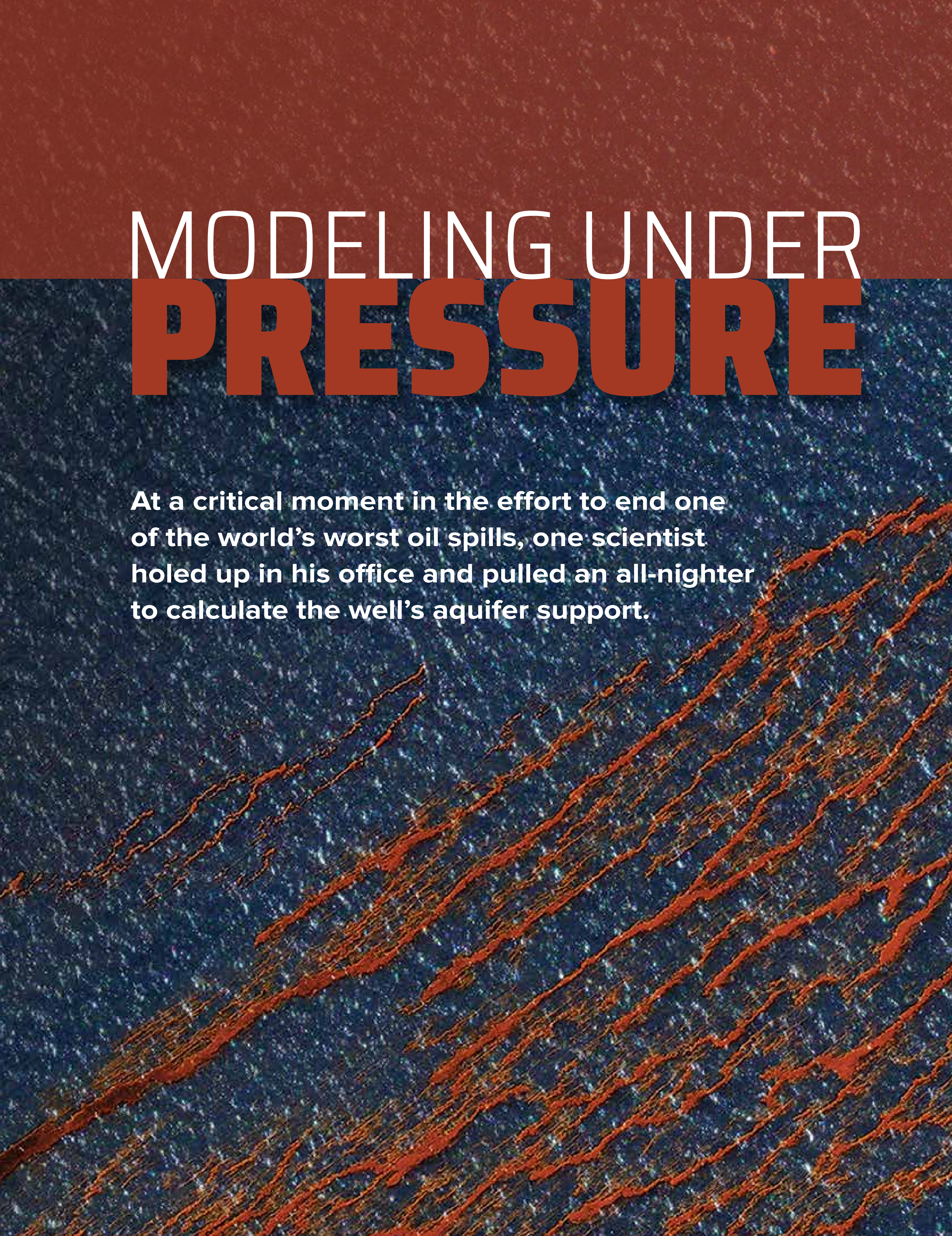
Our team thanks the International Space Science Institute, Bern, Switzerland, for providing financial support, meeting facilities, and generally fantastic support of the Earth and space sciences.

By **Ryan McGranaghan** (rmcgranaghan@astraspace.net), Atmosphere and Space Technology Research Associates, Louisville, Colo.

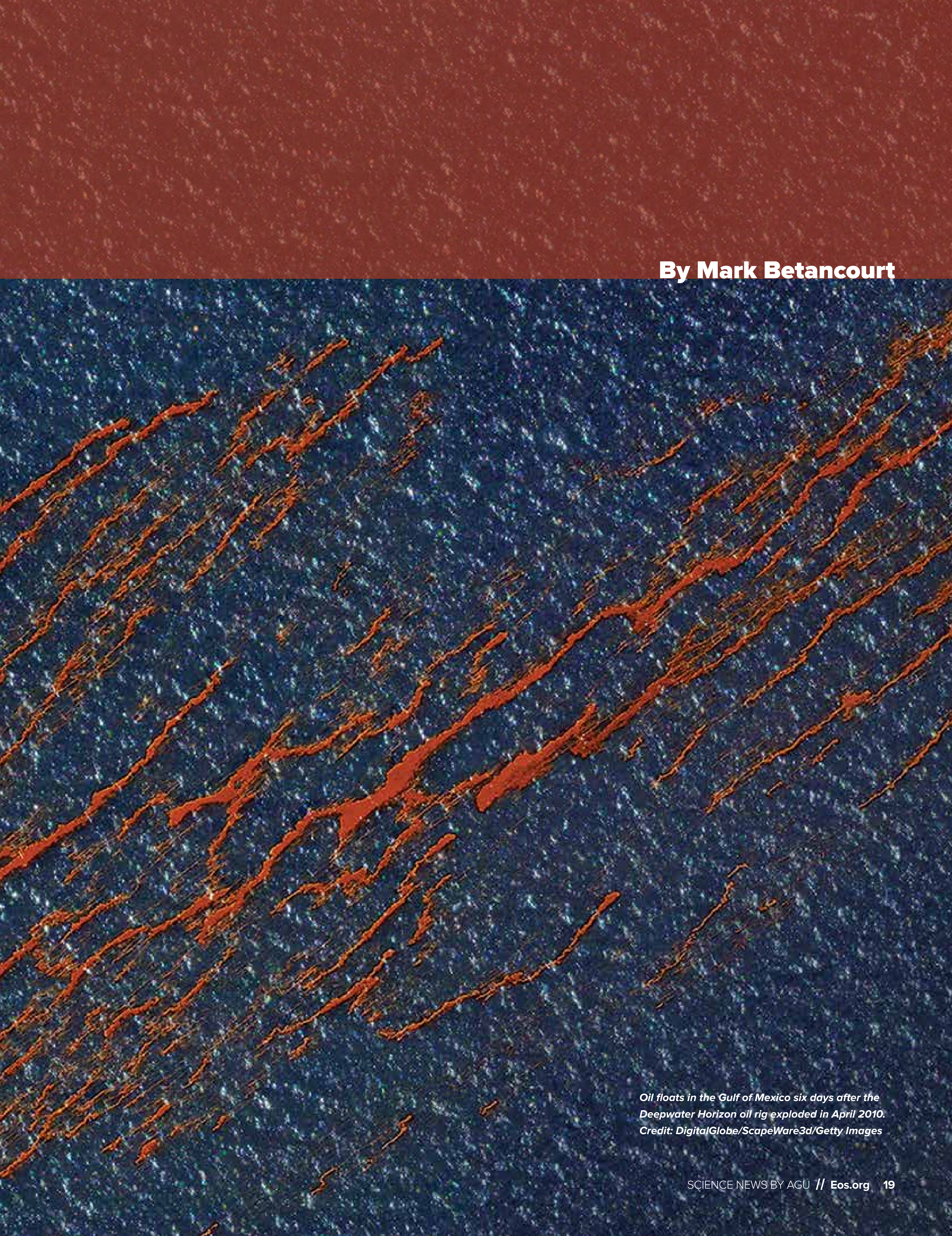
▶ **Read the article at bit.ly/Eos-design-sprint**

MODELING UNDER PRESSURE

At a critical moment in the effort to end one of the world's worst oil spills, one scientist holed up in his office and pulled an all-nighter to calculate the well's aquifer support.



By Mark Betancourt



Oil floats in the Gulf of Mexico six days after the Deepwater Horizon oil rig exploded in April 2010. Credit: DigitalGlobe/ScapeWare3d/Getty Images

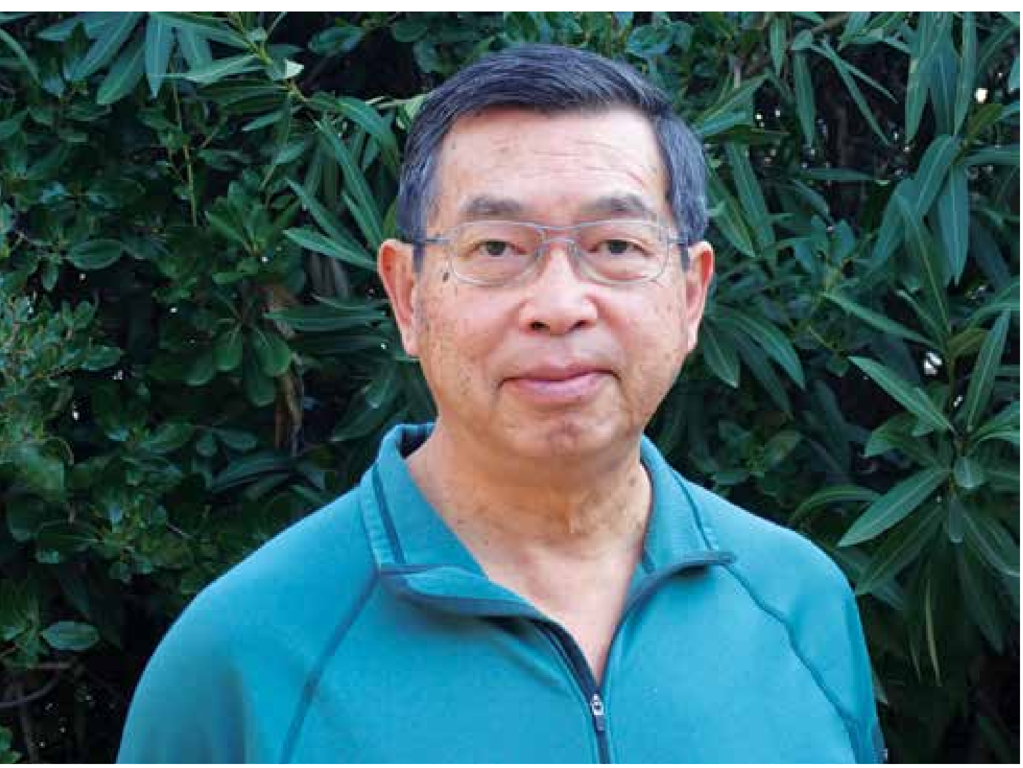
Paul came recommended as *the* person who had the best ability to do modeling of flow in reservoirs. As a team of one, he could do the work when push came to shove.

In June 2010, all that Paul Hsieh knew about the Deepwater Horizon oil spill in the Gulf of Mexico was what he had read in the news. Then Marcia McNutt, director of the U.S. Geological Survey (USGS) at the time, left him a voice mail.

"Monday morning, I got a phone message from the previous Friday," recalled Hsieh. "[McNutt] called and said, you know, 'Can you come to Houston to help us?'"

Hsieh, a hydrologist now retired from USGS, was researching groundwater contamination at the time. He knew that an oil rig in the Gulf had exploded and sunk and that every day for 2 months, tens of thousands of barrels of crude oil had been flowing freely into the sea. Oil had begun washing up along 1,700 kilometers of the Gulf Coast, threatening delicate marshes and estuaries in four states.

Hsieh, whose research focuses on mathematical modeling of how groundwater interacts with the surrounding geological features, had never worked with oil before, but he would come to play a key role in the effort to mitigate the Deepwater Horizon spill. The geoscience community responded quickly and effectively, with many scientists contributing extraordinary efforts. Among them was Hsieh, whose solitary work one night in July hugely influenced the capping of the leaking well.



Paul Hsieh

The U.S. government, led by the Nobel Prize–winning physicist who happened to be secretary of energy at the time, Steven Chu, had assembled a diverse group of scientists to help find a way to mitigate the unprecedented environmental crisis. The alternative was to rely solely on experts at BP, the company ultimately responsible for the disaster. Many of the scientists, including McNutt, had set up shop near BP's offices in Houston, where they could monitor what was going on in the Gulf.

"The way I think of us is the staff," said Hsieh, who made several trips to Houston in the weeks after McNutt's call. "We were often given assignments to calculate something or evaluate something or read through what BP had done and evaluate it."

The first thing they needed to figure out was how fast the oil was coming out of the well. As an expert in modeling underground reservoirs, including how various conditions in and around a reservoir affect the rate of flow through a well, Hsieh was well suited to the task.

Hsieh also had an outstanding reputation: USGS hydrogeologist Steve Ingebritsen described him as "a zealous and unselfish collaborator, motivated entirely by the goal of achieving high-quality science" when nominating him for an AGU Ambassador Award in 2014.

"Paul came recommended as *the* person who had the best ability to do modeling of flow in reservoirs," said McNutt, now president of the National Academy of Sciences. "As a team of one, he could do the work when push came to shove."

A Reservoir Under Pressure

By the time Hsieh was brought on, all attempts to stop the flow of oil had failed, and the army of oil industry engineers and government scientists had settled on using a relief well—drilled at an angle to cut the original well off at the base, then injected with a plug of cement—to stop the flow of oil once and for all. But it would be several months before the relief well would be completed.

In the meantime, Hsieh and several colleagues were tasked with verifying BP's assessment of the oil reservoir into which the Deepwater Horizon had been drilling, a part of the informally named Macondo prospect. (A prospect describes a site where hydrocarbons have the potential to accumulate in a reservoir.) The Macondo prospect sits nearly 4,000 meters below the seafloor, deep enough that the oil there is heated to about 116°C by radioactive decay in Earth's interior. It lies beneath a basin called the Mississippi Canyon, and—particularly relevant to Hsieh's assignment—it's under a good deal of pressure.

Most oil reservoirs sit within permeable layers of rock. Just as a wet sponge squeezed between your hand and a table leaks water onto the table, the reservoir is squeezed by the weight of the rock above it, and the pressure can reach equilibrium as liquid escapes into the surrounding formation.

But for millions of years, the Mississippi River and its ancestors have dumped sediment from the continent onto the floor of the Gulf—all kinds of sediment, from coarse sand to fine silt. Over time, the silt has been compressed into dense layers of rock, effectively sealing reservoirs like Macondo under an impermeable barrier. As the river keeps piling on sediment, pressure within the reservoir has nowhere to go.

So when the Macondo well blew, oil didn't just leak into the ocean; it was ejected at a rate of more than 50,000 barrels per day.

Soon after Hsieh's first trip to Houston, the question of whether the well could be contained from the top, like replacing the cap on an exploding soda bottle, arose.

BP had maintained for weeks that capping the well was a bad idea. Without a release of pressure at the wellhead, engineers thought, oil would leak through openings in the damaged well casing and into the surrounding rock formation. From there, it could end up pushing up through the rock and eventually find its way to the seafloor.

The constantly gushing well was an unprecedented environmental disaster, but it would pale in comparison to such a widespread underground blowout. There would be no way to contain the spread of oil, which could flow from multiple places. The natural gas mixed with the petroleum could liquefy the seafloor into a kind of hydrocarbon quicksand. Eventually, the pressure in the wellhead would have equalized with the water pressure at that depth and the flow would have stopped, but by then the reservoir could have emptied as much as 4 times more oil than it already had, Hsieh now estimates.

But then BP engineers changed their minds. Now, they said, capping the well could work. Or rather, they could try it, and use pressure measurements taken in the crucial first hours to determine whether the oil could stay shut in.

Hsieh and his colleagues were asked to double-check that analysis.

Modeling the Reservoir

Until the end of the 20th century, well integrity calculations were done analytically. The equations were necessarily simple, assuming the reservoir was box shaped and the permeability around it was uniform. Later, complex computer algorithms were developed to model the reservoir itself, making it easier to account for all kinds of factors, like the varying permeability of the formation or the relationship between an irregular shape in the reservoir and the location of a well.

Hsieh had never put together a model for an oil well, but he knew that the same hydrological principles that governed water reservoirs would apply to petroleum reservoirs.

His team spent several weeks determining what the current pressure of the reservoir was likely to be, given how long and at what rate it had been draining into the Gulf. The idea was that once the well was capped, that baseline pressure could be compared with the pressure readings at the top of the well.

The team members settled on two key numbers. If they saw anything above 7,500 pounds per square inch (psi) (about 51,710 kilopascals at the well head), the well was sound—there was no leak in the casing—and the full pressure of the reservoir was pushing up on the well cap. The cap could stay in place, and the oil spill would be over. Less than 6,000 psi would mean the pressure was being released somewhere else, and oil eventually would find its way to the surface through that breach. In that case, the cap would have to be opened again to relieve the pressure, spilling oil into the Gulf for another 2 months until the relief well could be completed.

The problem was the no-man's-land between 6,000 and 7,500 psi. There weren't enough data to say conclusively what a pressure reading in that zone would mean, and all the scientists could do was hope the capped pressure they measured wouldn't fall in that range.

So, of course, it did.

Determining Aquifer Support

On 15 July, hours after the cap was in place, well pressure had risen to 6,600 psi and was only creeping up. There was a decision to make. "For the first time in almost 3 months, there was no oil flowing into the Gulf of Mexico," said McNutt. "And everyone was devastated at the thought that we might have to open that up again."

The safest thing would have been to let the oil continue to flow and wait for the

**The problem was the no-man's-land between 6,000 and 7,500 psi. There weren't enough data to say conclusively what a pressure reading in that zone would mean, and all the scientists could do was hope the capped pressure they measured wouldn't fall in that range.
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A USGS colleague who was at BP's headquarters snapped a photo of the pressure curve and texted it to Hsieh.

relief well. The potential consequences of an underground blowout weren't exactly known at the time, but it was clear that that scenario was unacceptable. "If it actually hydrofracked to the surface through other channels, there was no way we could control that," said McNutt. "We would have actually actively made a bad situation worse."

But maybe the well was sound, and there was an explanation for the low pressure readings. If someone could make a convincing argument for the latter, the cap could stay in place, at least until more data could fill in the uncertainties. The group needed to come up with an answer within 24 hours, before a potential underground oil leak would have time to reach the seafloor.

To do that, scientists and engineers would needed to know whether it was plausible that the initial threshold of 7,500 psi was wrong. Could the pressure in the reservoir be lower? All they could do was plug the known conditions into a computer model and fiddle with the variables until the model produced out a pressure reading like the one they were seeing on the wellhead. They now had the extra parameter of how fast the pressure had changed after the well was shut, and it might be just enough to narrow the possibilities.

The only person on the government science team with modeling experience was Hsieh, who wasn't even in Texas at the time.

It was already evening at his office in Menlo Park, Calif., by the time Hsieh was tapped to build the pressure model, and he needed to present his results first thing in the morning, Central time. Knowing he wasn't going home anytime soon, he got to work. He would have preferred to have many months to arrive at a publishable model, with plenty of discussion with colleagues and, eventually, peer review of the finished results. But Hsieh had only hours, by himself.

"If I were to call up somebody and explain [it] to them, that would have taken so much time," he said. "It was just something that I had to do."

First he needed data. BP had not been sharing direct readouts of pressure gauges at the wellhead, fearing that advance knowledge of how the mitigation effort was going could leak out and lead to insider trading. But Hsieh had to know how the pressure had changed over time, so a USGS colleague who was at BP's headquarters snapped a photo of the pressure curve and texted it to Hsieh.

Hsieh loaded the photo into an Excel spreadsheet and superimposed it onto the graph from a rough model he'd built. Then he adjusted the variables in his model—for example, the compressibility of the rock surrounding the reservoir—until his graph fit the curve in the photo. He had a number of ways to make his curve match the pressure readings at the wellhead, assuming there was no underground leak. He just had to determine which scenario was actually possible.

"The thing that made the biggest difference was the aquifer support," said Hsieh. Aquifer support describes a phenomenon that sometimes occurs when oil reservoirs are surrounded by a larger region of water, causing higher well pressure than if no water were present.

BP had used seismic reflection, a method similar to sonar, to survey and map the geological vicinity of the reservoir and had determined that the volume of water in the aquifer surrounding the well was 4 times that of the oil. That number had been a determining factor in the science team's initial estimate of the 7,500 psi baseline.

But interpreting seismic reflections can be tricky. What if the BP engineers had missed the mark, and there was far less water in the aquifer than they thought? Hsieh dialed down the aquifer support to zero, and sure enough, that could easily explain the 6,600 psi showing at the wellhead.

As the night wore on, Hsieh ran the model three times, once in the English units the oil industry uses (barrels of oil), once in metric (cubic meters of oil), and once using different code. He checked and rechecked his math, recalling an ill-fated Mars mission in which engineers' failure to properly convert units led to the loss of a $125-million spacecraft (see bit.ly/metric-mistake).

"In our field of work, timelines are so spread out that if you make a mistake, you can catch it, there's peer review and all of that," Hsieh said. "And here…if you make a mistake, you're screwed."

Matching the Model

The Sun came up. Hsieh wrapped up his model, threw together a PowerPoint, and presented his results to the group in Houston via conference call. When he finished, there were no questions—just silence.

"I didn't know what happened," he said. "People were just, like, thinking about it."

Within a few hours, Chu's scientists agreed with BP to keep the cap in place. Underwater drones would monitor the seafloor for any signs of erupting hydrocarbons; research ships would do daily seismic reflection runs; and at the first sign of an underground blowout, the team would open the well again.

That didn't happen. As pressure readings continued to come in, they closely matched with Hsieh's model. The well stayed shut. Nine weeks later, the relief well permanently ended the crisis.

In the end, Hsieh saw his role as that of an accountant, not a decision-maker. He was concerned mostly with getting his model right, not with how it would be used and what the consequences could be. As long as he'd done the calculations correctly, all he had to do was present the likely scenario based on the data he had.

"I tried to kind of take myself out of the picture," he said. "I think being a scientist, you are kind of trained to do that."

He added that Earth scientists in particular are used to not being able to give a definitive answer to any question. There are just too many variables, too many unknowns. They so often deal with the invisible and the hidden and therefore only the plausible, the likely.

"The actual working environment and mental condition was something that I am very used to," said Hsieh, citing plenty of marathon modeling sessions during which he took breaks only to eat and sleep.

Although the future of the Gulf of Mexico's ecosystems and its vast economy could be affected by decisions based on the accuracy of his analysis, it wasn't that different from his normal job assessing aquifers and other groundwater resources.

"In a strange way, it could be almost routine."

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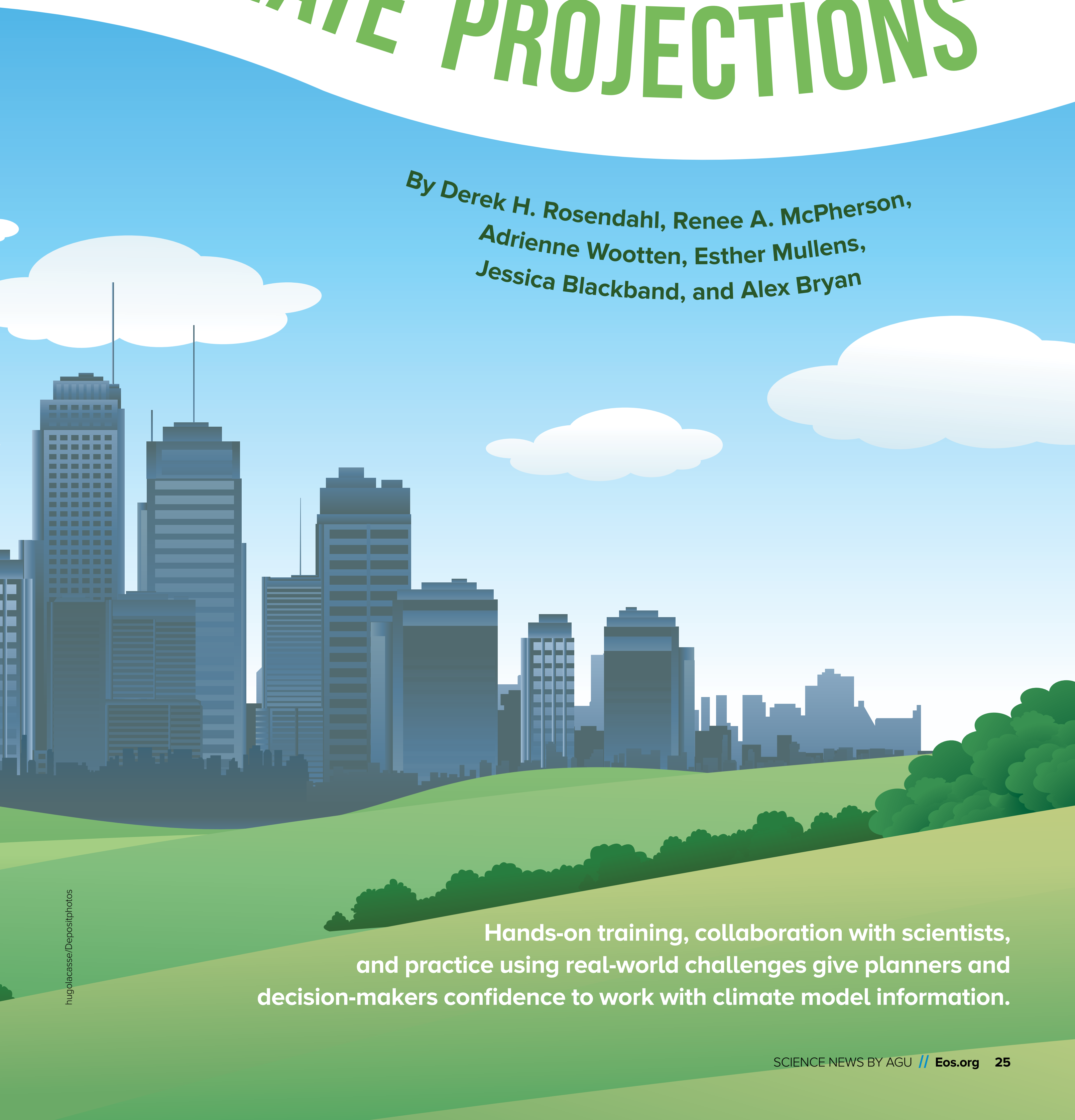
▶ **Read the article at bit.ly/Eos-Deepwater Horizon**

MAKING SENSE OF LOCAL

CLIMATE PROJECTIONS

By Derek H. Rosendahl, Renee A. McPherson, Adrienne Wootten, Esther Mullens, Jessica Blackband, and Alex Bryan



hugolacasse/Depositphotos

Hands-on training, collaboration with scientists, and practice using real-world challenges give planners and decision-makers confidence to work with climate model information.

Many planners and decision-makers—some of whom have already experienced clear impacts of climate change firsthand—hope to adapt to or mitigate future impacts by using climate model projections to improve outcomes for their organizations or jurisdictions. However, these practitioners may be frustrated to find there is not one "best" climate projection available for their particular application. How does a nonscientist practitioner choose among—or combine—various climate model projections and determine how much confidence to place in the results?

Another problem practitioners face is that these climate model projections typically must be downscaled from coarse-scale global models to higher spatial resolutions if they are to provide meaningful, spatially detailed local information on future temperatures, precipitation, or other variables. For example, water managers may use downscaled precipitation projections to plan for future changes in drought or heavy rainfall events that affect water quantity and quality in their municipality or state. How can practitioners identify which downscaled climate projections are appropriate for their application?

Scientifically justifiable interpretations and applications of climate projections can aid planning decisions and ultimately result in more resilient communities, businesses, and peoples. On the other hand, misapplication could be costly at best and maladaptive at worst [e.g., *Nissan et al.*, 2019].

In 2017, our team developed and offered a role-playing activity to better equip practitioners in their efforts to include downscaled climate model projections in their adaptation planning efforts. We have now implemented this activity multiple times with various participants and have found that participant groups are more comfortable using climate projections and working with climate scientists as a result.

A Daunting Task

Our collective experiences at the U.S. Department of the Interior's regional Climate Adaptation Science Centers (CASCs) have shown us the frustration that practitioners face when multiple sources of uncertainty [e.g., *Wootten et al.*, 2017] confront them with the need to use many projections. For example, current best practices at the South Central CASC encourage decision-makers to use multiple emissions scenarios, global climate models, initial conditions (i.e., for natural variability), and downscaling techniques in creating an "ensemble" of projections that represent a realistic range of uncertainties in our future climate.

This task is daunting for practitioners, who typically lack the necessary time and climate science staff to create such ensembles. Plus, each application depends on organization-specific factors (e.g., risk tolerance, time horizon, geographic region). Therefore, the combined expertise of climate scientists and practitioners is desirable to identify, interpret, and apply a useful and scientifically justifiable subset of future projections. How do we encourage these collaborative relationships?

Practitioners from various disciplines participate in a group exercise during a training session on using climate projections. Representatives from the U.S. Department of the Interior's regional Climate Adaptation Science Centers train planners and decision-makers to work with downscaled climate projections by solving a real-world management challenge. Credit: Jessica Blackband

In our hands-on training for practitioners, our CASC team aimed to build participants' confidence in working with downscaled climate projections by solving a real-world management challenge.

Training Structure

Our team first conducted the hands-on activity at the 2017 National Adaptation Forum in Saint Paul, Minn. After a brief, nontechnical presentation that introduced the scientific uncertainties in climate projections, we simulated a real-world water management challenge in breakout groups of six to ten people. Participants varied in disciplines, backgrounds, and professions; their specialties included energy policy, hydrology, air quality, conservation biology, environmental planning, and health care. Some participants had no prior experience using climate projections; others had applied projections in several projects.

At each table, CASC facilitators played the roles of climate scientist and science translator (i.e., someone who both understands the relevant science and is capable of clearly communicating it to nonspecialists). Participants each played the role of district water managers who had to recommend whether their state governor should sign a 50-year contract to sell water from a regional aquifer to a growing, water-hungry metropolis in a neighboring state.

Our activity sheets detailed the challenge, including physical (e.g., watershed attributes) and societal (e.g., water needs) information, along with a suite of climate plots. These plots included annual and springtime precipitation from historical climatology (1981–2010) and future regionally downscaled projections (early, middle, and late 21st century) from three global climate models, three downscaling techniques, and two future emissions scenarios (e.g., Figure 1). We omitted state boundaries on the plots to expand the applicability of the activity to multiple regions.

Participants were not expected to gain a complete understanding of climate projections. Rather, they saw a glimpse of how to use projections in their own planning efforts. We also demonstrated the benefits of building relationships among practitioners, science translators, and climate researchers, encouraging collaboration among these groups.

What We All Learned

During the activities, we found that a participant's prior experience using climate model projections was the most important factor in having successful group discussions. If small groups comprised both experienced and inexperienced users, our facilitators struggled to keep every participant engaged. Group members with similar levels of experience with projections spoke with one another; they disengaged from discussions when information was either too basic or too advanced for them.

Science translators at the trainings had to use strong facilitation skills to direct conversations and strike appropriate balances between discussions of climate factors and other related and tangential topics. Some

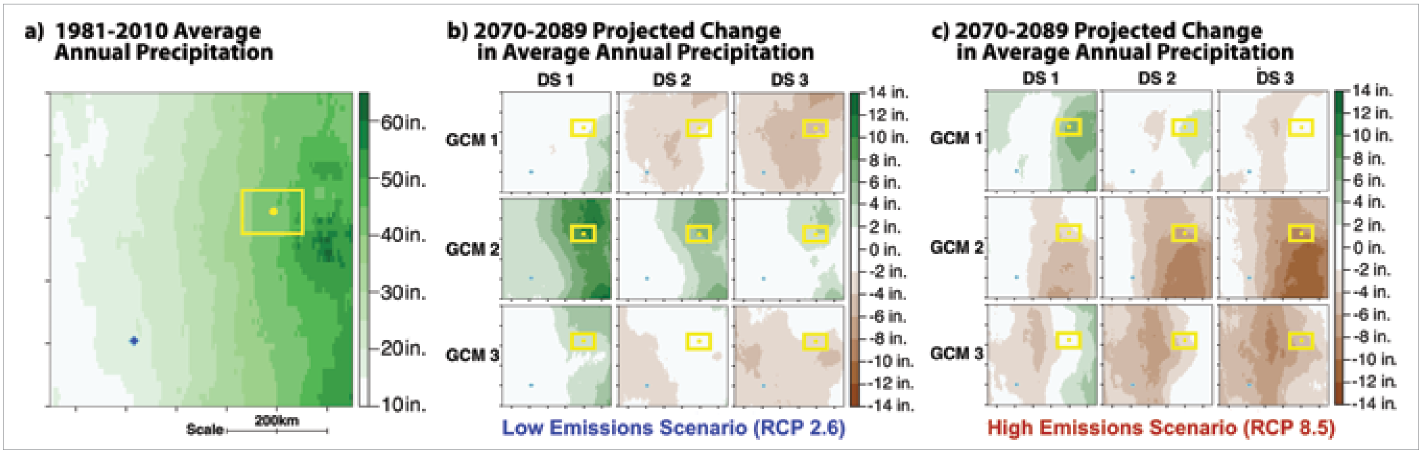


Fig. 1. Example plots from one training activity represent (a) 1981–2010 average annual precipitation across a selected area as well as (b) the average projected change in annual precipitation by 2070–2089 relative to the earlier period using a lower emissions scenario (Representative Concentration Pathway (RCP) 2.6) and (c) a higher emissions scenario (RCP 8.5). In Figures 1b and 1c, projections are based on three different global climate models (GCM) and three different downscaling techniques (DS) and are representative of the sources of uncertainty in such climate projections. Dots represent the location of the city providing water (yellow) and requesting water (blue). The yellow rectangles represent the regional aquifer. Credit: Adrienne Wootten

participants, for example, focused significant attention on nonclimatic details of the management challenge (e.g., how water would be moved or how elections or water prices might affect the agreement), distracting others from the primary goal of applying the climate projections. However, participants with more climate projection experience benefited from the added realism of discussing these nonclimatic factors.

After the activity, we asked participants what they had learned. The most common responses were that climate projections have multiple sources of uncertainty, so policies and plans should be designed flexibly to accommodate multiple possible outcomes, and that climate science translators (e.g., at the CASCs) can assist practitioners in using projections.

Many practitioners were unaware that these science translators are available as a resource; thus, the climate science community must continue building bridges to practitioners. Overall, participants stated that they better understood how to interpret the ensemble of climate projections, would use them for their own planning, and would seek climate science translators to help them. These outcomes are similar to those of *Rumore et al.* [2016], who have organized community engagement activities related to climate information, adding more evidence that role-playing activities can improve the scientific literacy and collaborative capacity of participants.

Moving Outward and Forward

Our activity has been adapted for multiple venues. In 2018, we conducted a training at the Inter-Tribal Emergency Management Coalition Summit to assist tribes in Oklahoma with all-hazards preparedness planning. In 2017, 2018, and 2019, we conducted the role-playing activity for undergraduate students in climate science internship programs and climate change courses at the University of Oklahoma. In addition, members of Natural Resources Canada and Environment and Climate Change Canada (ECCC) held a training at the Eighth Annual National Roundtable on Disaster Risk Reduction and Canada's Climate Change Adaptation Platform Plenary—developed after an attendee of our 2017 National Adaptation Forum session expressed interest in adapting the activity for their constituents. Since then, modified versions of the activity have been held in Madison, Wis., at the 2019 National Adaptation Forum and for Canadian audiences through the Canadian Centre for Climate Services at ECCC.

In response to participant feedback, we will expand our water management–centered activity to other management challenges, such as emergency management or public health. Eventually, we will design introductory and advanced versions of our trainings to reduce the difficulty in facilitating groups with different experience levels. We also intend to transfer our team's knowledge and materials to others who desire to partner with practitioners by developing a "train-the-trainer" short course.

With the continuing development, sharing, and implementation of such hands-on trainings, we hope to foster improved understanding of climate projections among as many local and regional planners as possible so they can confidently apply this knowledge to improve the flexibility and resilience of their communities in the face of a changing climate.

For more information, contact info@southcentralclimate.org.

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▶ Read the article at bit.ly/Eos-climate-projections

DEEPWATER HORIZON AND THE RISE OF THE MICS

Microbial genomics techniques came of age following the Deepwater Horizon spill, offering researchers unparalleled insights into how ecosystems respond to such environmental disasters.

By Joel E. Kostka, Samantha Joye, and Rita Colwell

Photograph of oil beneath the surface of the Gulf of Mexico following the Deepwater Horizon spill (background). In the inset, microscopic specimens of Candidatus Macondimonas diazotrophica *are visible both inside and around the edges of oil droplets (large round shapes) in this microscope image. Credits: Rich Matthews/AP images (photo); Shutterstock/CoreDESIGN (DNA illustration); and Shmruti Karthikeyan (inset)*

Almost everywhere scientists have looked on or near Earth's surface—from ice-buried Antarctic lakes to arid, ultraviolet-baked deserts and ecosystems ranging from pristine to heavily polluted—they have found abundant and often highly diverse populations of microorganisms. Microorganisms, or microbes, are everywhere; they are adaptable, and they play key roles in element cycling and ecosystem functioning in nearly every environment on Earth.

Microbes are the great decomposers in ecosystems, breaking down dead and dying organic matter and recycling major nutrients for use by plants. And by reacting rapidly and adapting to changing conditions, they act as first responders in helping restore balance and stability to ecosystems after such disturbances as pollution or catastrophic storms. Microbes are, for example, intimately involved in ecosystem responses to oil spills.

Like organic matter derived from modern-day primary production, oil formed over geologic time can act as a carbon source that fuels microbial growth and metabolism. Hydrocarbon-degrading microbes have been studied for decades and are thought to be ubiquitous and diverse and to have adapted to consuming oil over millions of years [*Head et al.,* 2006]. And biodegradation mediated by indigenous microbial communities is considered the primary fate of most petroleum (oil and gas) that enters the marine environment through natural mechanisms like seeps [*Leahy and Colwell,* 1990].

As researchers began unveiling the complexity of microbial communities and illuminated fundamentals of how they operate in recent decades, though, much remained unclear about their structure and functioning in nature. The reason for this was in part because of a shortage of techniques for studying them. Because of their small size, microbes evade easy observation, and most cannot be cultured in the laboratory. At the time of the Exxon Valdez oil spill in 1989, for example, environmental microbiology was a relatively nascent field. But in the past decade, a variety of so-called omics techniques, focused on parsing the genetic makeup of cells, have emerged and offered researchers powerful new ways to study microbial communities and the roles played by specific groups of microbes.

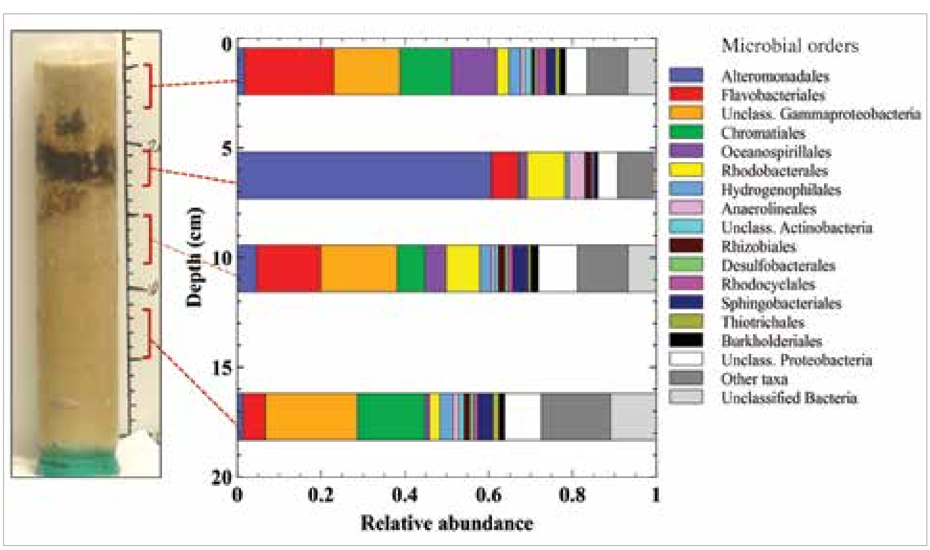
Omics Emerge

The 2010 Deepwater Horizon (DWH) oil spill in the Gulf of Mexico is the largest accidental oil discharge into a marine environment for which a proportional emergency response effort was mounted. In contrast to the Valdez spill, the last major spill affecting the United States before 2010, the DWH discharge occurred in deep water, with extraordinarily large volumes of chemical dispersant applied during emergency response efforts.

The DWH spill was also the first major environmental disaster for which genomics technologies had matured to such an extent that they could be deployed to quantify microbial responses over large spatial and temporal scales. As a result, the field of environmental genomics matured during the past decade in parallel with the DWH response. Technical advances in genomics enabled direct, comprehensive analyses of the microbes in their natural habitat, be it oil-contaminated or uncontaminated seawater or sediments. Researchers studying the effects of the DWH spill presided over an explosion of microbial genomics data that enabled major advances in oil spill science and allowed scientists to answer the question, What microbes are there?, in complex communities in unprecedented detail.

Metagenomics, the sequencing of all genes for all organisms in a sample, enabled determinations of the full range of microbial species present. It also provided assessments of these organisms' metabolic potential to carry out important ecosystem processes like photosynthesis and the degradation of certain carbon compounds. Application of metatranscriptomics, the sequencing of active or expressed genes, provided opportunities to decipher the functions or activities of those same microbes in nature, essentially answering the question, What are they doing?

Gene sequences are collected from the environment in fragments. Recent improvements in bioinformatics tools, which use high-performance computing to stitch these fragments back together into the genomes of individual microbial species, have allowed scientists to reconstruct microbial genomes over large scales, revealing the incredible diversity and complexity of microbial communities.



This sand core (left) collected on 30 June 2010 at Pensacola Beach, Fla., contains a pronounced oiled layer (dark brown). More than 50% of the microbes in that layer belonged to genus Marinobacter *(in the Alteromonadales order), a known hydrocarbon-degrading microbial group, far more than in sands below and above the oiled layer. Credit: Markus Huettel*

Jonathan Delgardio and Will Overholt of the Georgia Institute of Technology sample sand layers on 20 October 2010 at Pensacola Beach, Fla., which was heavily polluted by weathered oil after Deepwater Horizon discharge. Researchers used genomics to track how microbial communities changed in response to the oil by comparing oiled sand layers to pristine sands. Credit: Markus Huettel

Through a systems approach that incorporates genomics along with knowledge and tools from a range of other disciplines (e.g., biogeochemistry and oceanography), researchers can now monitor and assess ecosystem health—and identify disturbances that might otherwise go unnoticed—by analyzing microbial populations that both act as stewards for and represent bioindicators of ecosystems. With these efforts, global ecosystems can be better protected and, when necessary, restored in the face of diverse environmental stressors.

Transformative Discoveries

Prior to 2010, most studies of microbes associated with oil spills were conducted by growing them in the laboratory using pure cultures or enrichments. Consequently, we had a very limited understanding of the types and distribution of oil-degrading microorganisms—and of what they actually do—in the environment, because the vast majority of microorganisms in the natural environment have yet to be cultured. But in the wake of the DWH spill, multidisciplinary scientific partnerships enabled transformative discoveries detailing how microbes respond to petroleum discharges and facilitate ecosystem recovery.

Many of these partnerships were supported by the Gulf of Mexico Research Initiative (GoMRI), created with a $500 million, 10-year commitment from BP to fund an independent scientific research program dedicated to studying oil spill impacts and mitigation, particularly in the Gulf of Mexico. GoMRI has funded 17 international consortia and thousands of investigators (bit.ly/GoM-Research).

Armed with genomics tools, GoMRI researchers showed that oil-degrading microbes are, indeed, nearly ubiquitous, found almost everywhere around the world in low abundance even when crude oil is absent. These microbes, part of the pool of low-abundance species known as the rare biosphere, harbor a specialized metabolic capacity to use oil as a food source—a capability that can be rapidly activated upon exposure to oil [*Kleindienst et al.,* 2015].

From deep ocean waters to shallow coastal sediments, hydrocarbon-degrading bacteria responded profoundly to oil contamination after the DWH spill, increasing in abundance and expressing genes involved in hydrocarbon metabolism over days to months. It was shown in some cases that microbial communities were composed of up to 90% oil-degrading species after exposure to hydrocarbons [*Kleindienst et al.,* 2015; *Huettel et al.,* 2018].

Over time, successions of microbial populations bloomed as they consumed the different hydrocarbon compounds of oil and responded to environmental factors [*Kostka et al.,* 2011; *Yang et al.,* 2016; *Kleindienst et al.,* 2015]. Genomics research revealed that different microbial species are adapted to degrade specific types of hydrocarbon compounds (e.g., natural gases, straight-chain aliphatics, or aromatics) depending on environmental conditions like temperature and nutrient availability. These discoveries underscore the natural capacity of microbes in the Gulf of Mexico and elsewhere to bioremediate petroleum hydrocarbons.

How Oil Affects Ecosystems

Scientists have long hypothesized that the fate and impacts of oil in ecosystems are determined by interplays between the physical and chemical characteristics of the environment and by hydrocarbon chemistry and biogeochemical processes largely mediated by microbes. However, the complexity of these interactions has impaired our ability to decipher exactly how ecosystem functioning is affected by oil.

Oil can be a food source for some microbes, but it can be toxic to others, resulting in adverse effects on microbially mediated ecosystem services like the breakdown of organic matter and the regeneration of nutrients. Following the DWH discharge, GoMRI researchers observed through multiple lines of evidence that liquid and gaseous hydrocarbons from the spill rapidly entered the microbial food web and persisted for years [*Fernández-Carrera et al.,* 2016; *Rogers et al.,* 2019; *Chanton et al.,* 2020], with major implications for carbon and nutrient cycling through the environment. Genomics-enabled research revealed, for example, that ecosystem functions related

In the wake of the Deepwater Horizon spill, multidisciplinary scientific partnerships enabled transformative discoveries detailing how microbes respond to petroleum discharges and facilitate ecosystem recovery.

A sheen of oil coats the surface of the Gulf of Mexico in June 2010, as ships work to help control the Deepwater Horizon spill. Credit: kris krüg, CC BY-NC-SA 2.0 (bit.ly/ccbyncsa2-0)

to the microbial nitrogen cycle were drastically affected by oil.

Petroleum is made mostly of carbon and contains relatively small amounts of major nutrients like nitrogen and phosphorus. Thus, scientists expected that oiled environments would likely become limited in major nutrients, with negative effects potentially rippling through entire food webs. In numerous investigations of DWH-contaminated seawater and sediments, genes for nitrogen fixation—a process carried out by some microbes that involves converting inorganic nitrogen gas into fixed forms like ammonium, which can be used by all organisms—were shown to increase many times relative to pristine conditions, even when adjusted for the overall abundance of microbes present.

For example, a metagenomic time series revealed an increase in the abundance of genes that encode for nitrogen fixation (via the enzyme nitrogenase) that coincided with an increase in genes related to hydrocarbon degradation pathways [*Rodriguez-R. et al.,* 2015]. This increase then dissipated when the oil and associated hydrocarbon compounds disappeared. In addition, the abundances of genes related to degradation of specific hydrocarbon classes, such as alkanes and polycyclic aromatics, could be directly correlated with concentrations of the corresponding classes.

Genomic data were corroborated by research using isotopic tracers, which showed the incorporation of inorganic nitrogen into the microbial food web [*Fernández-Carrera et al.,* 2016]. Nitrogen-fixing microbes, also called diazotrophs, are well known to support crop growth in agricultural ecosystems and photosynthetic production in the open ocean [*Zehr et al.,* 2016], but nitrogen fixation by oil degraders in response to hydrocarbon exposure is a new discovery. The recognition that oil-degrading bacteria can supply themselves with nitrogen indicates that the microbial food web can compensate, at least to an extent, for influxes of nutrient-poor oil. Studies by GoMRI researchers further revealed that as overall microbial diversity declined in oil-contaminated environments, the oil selected for a few very abundant microbial species with the dual capability to fix nitrogen and degrade oil.

"Superbug" Discovered

Fertilizing water with nitrogen and phosphorus to stimulate microbial growth is a common bioremediation strategy for oil spill cleanup; it was used, for example, during the Valdez spill in 1989 [*Bragg et al.,* 1994]. But fertilizers are costly and difficult to apply over large scales and may result in unintended ecosystem consequences. Thus, practitioners charged with cleaning up after oil spills dream of a "superbug"—one that's native to the contaminated environment and capable of removing all components of oil while also generating its own nutrients.

Nature may have provided just such an organism. Guided by metagenomic field data, GoMRI researchers patched together the genomes of microbes thought to be diazotrophs that also degraded oil in marine sediments. After looking at the potential metabolisms of these microbes, they isolated a particular microorganism from the field samples. They used hexadecane, a

hydrocarbon, as the sole carbon and energy source and did not provide any nitrogen [*Karthikeyan et al.,* 2019]. Sequencing confirmed that the genome of the newly isolated microbe, KTK-01, contains genes that encode for nitrogen fixation and hydrocarbon degradation pathways as well as for biosurfactant production, all of which together facilitate growth in a nitrogen-limited, oiled environment.

Comparisons with genomes from publicly available data sets collected in other studies revealed that the newly isolated microbe—provisionally named *Candidatus Macondimonas diazotrophica* for the Macondo oil that was discharged during the DWH disaster—represents a novel genus of Gammaproteobacteria, a class that includes *Escherichia coli* and *Salmonella*, among many others. The screening also revealed a remarkable distribution of sequences identical or almost identical to those in KTK-01 in hydrocarbon-contaminated sediments from coastal ecosystems across the globe: Microbes with genomes matching this sequence often made up about 30% of their total communities but were almost absent in pristine sediments or seawater. *Macondimonas* thus appears to play a key ecological role in the natural responses to oil spills in coastal environments around the world and could prove to be a useful model organism for further studying such responses.

Oil Contamination Biomarkers

The ultimate goal of GoMRI-supported genomic research is to translate genomic findings into actionable information to help scientists monitor and restore ecosystem health in the face of natural or human-made disasters. Through examination of the organisms, genes, and metabolic pathways present in microbial communities, researchers can take the pulse of an ecosystem and identify functional deficits or gains in the communities that affect the overall health of the ecosystem. Such genomic indicators serve as biomarkers to guide mitigation strategies, much like blood tests can point physicians to disease diagnosis and treatment options.

During the DWH response, microbial genomics techniques have demonstrated the potential to develop effective genetic proxies or biomarkers for recording oil inputs, exposure regimes, and hydrocarbon degradation. Oil-induced ecosystem disruptions were identified by a reduction in community diversity; an overgrowth of certain species; or the emergence of novel genes, metabolic pathways, and ecosystem functions. For example, *Macondimonas* was shown to dominate microbial communities in oiled beach sands, and a large increase in the abundance of nitrogen fixation genes signified nutrient limitation and disruptions to the nitrogen cycle initiated by oiling [*Karthikeyan et al.,* 2019]. Further, a decline in the abundance of chemolithoautotrophic nitrifying microorganisms in oiled sediments followed by the rebound of these microbes in recovered sands provided evidence of ecosystem recovery [*Huettel et al.,* 2018].

Preparedness for Response and Restoration

Efforts supported by GoMRI to characterize responses of microbial communities in Gulf of Mexico ecosystems following the DWH oil spill generated knowledge with far-reaching impacts and spurred a wealth of discoveries. And newly developed tools and approaches have shown the proof of principle for deployment as part of the emergency response tool kit.

The need for ongoing research on these fronts is great because the risk of future oil spills like DWH remains as the petroleum industry continues tapping ultradeep marine wells for oil and gas production and because chemical dispersants—which may be toxic to organisms—remain the major response strategy. But lessons learned from DWH research so far can be applied to developing new mitigation strategies and improvements in predictive capabilities for responding to future environmental disturbances, such as those caused by extreme weather events or climate change.

For the first time, a data-driven approach for oil spill response and mitigation is possible. With advanced genomic tools and scientific expertise, microbiologists can quickly and inexpensively analyze field samples to provide essential information about microbial ecosystems before, during, and after spills.

We envision a future in which omics measurements enable assessment of environmental risks, identification of ecosystem deficits, selection of appropriate mitigation plans, and monitoring of ecosystem recovery and in which scientists play key roles in informing practitioners to improve response and restoration preparedness for future environmental disasters.

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Award and Prize Winners Honored at AGU's Fall Meeting 2019

Jobbágy and Wysession Receive 2019 Spilhaus Ambassador Award Grants

Esteban Jobbágy and Michael Wysession were awarded the 2019 Spilhaus Ambassador Award Grant at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The grants support work from previous Ambassador Award recipients that addresses one or more of the following areas: societal impact, service to the Earth and space community, scientific leadership, and promotion of talent/career pool.

Esteban Jobbágy

Response by Esteban Jobbágy

Over the past 2 decades we have learned that native vegetation replacement with annual crops in the extremely flat landscapes of the Pampas and Chaco in southern South America has pushed the system into a new hydrological state of shallower water tables and more frequent waterlogging and salt buildup in surface soils and waters. Following an "alternative state dynamics," these plains engaged in positive feedbacks that reinforce flooding or drying depending on the fraction of the territory that is cultivated and the decision rules and options of farmers. Not only farming but also infrastructure and rural settlements are affected. Seen as a regional emergency, most actions so far have been focused on pure hydraulic solutions that ignore the overwhelming importance of land use and land cover in the generation of water excesses and floods. Conceptual models linking agronomy, ecology, and hydrology are crucial to guide any land use decisions and adaptative management aimed at controlling the flooding and salinization. A shared narrative of the process, problem, and likely solutions is crucial to progress in the science-policy link but is still missing.

This grant will help to fill this gap by supporting ongoing work that I initiated 2 years ago, including (i) coverage of the science of hydrological changes in national and provincial newspapers, (ii) production and release of short documentary films, and (iii) coproduction workshops with key stakeholders. The grant will be specifically used to fund travel costs for two meetings with policy makers at the state and province level from farming regions of the plains of Argentina and Paraguay that are currently subject to fast and very widespread flooding and salinization processes. The goal of the meetings is to develop a unified vision of what has so far been coined "the hydrological crisis of the plains." Better narratives of the flooding and salinization processes that are taking place in several agricultural hot spots of the plains will be developed. Only when local communities acknowledge and understand problems can appropriable solutions emerge. An open presentation of the science and an honest treatment of its uncertainties are the necessary first step that this project takes.

—**Esteban Jobbágy,** Universidad Nacional de San Luis, San Luis, Argentina; also at Consejo Nacional de Investigaciones Científicas y Técnicas, San Luis, Argentina

Michael Wysession

Response by Michael Wysession

I will be working with Washington University's Institute for School Partnership (ISP) to support them in their revolutionary approach to bringing modern high-quality science to St. Louis regional elementary and middle schools. This nonprofit science program involves a complete curriculum of phenomenon-based scientific storylines designed from the ground up around the Next Generation Science Standards that is open source and available at cost to local Missouri schools. It is imperative that all American students, regardless of income, race, or other demographics, have access to high-quality science, technology, engineering, and mathematics (STEM) education, and this is where the ISP program is revolutionary.

The program is very inexpensive, to the point that over 250 elementary and middle schools in the St. Louis region (Missouri and Illinois) have now adopted it. Schools rent modular curricular "kits" for around $200/semester (largely to replace consumables). At four to five kits per grade, the entire cost of a school's yearly science program is less than $1,000/grade. The ISP staff even drop off and pick up the kits. The program now has over 9,000 kits used by over 2,500 local K–8 teachers to reach over 100,000 St. Louis area students per year. However, the program runs on a shoestring budget, and this grant will make a positive impact on the continued development of the program.

I will be contributing to the program in a variety of pro bono advisory roles, particularly in the way of scientific professional development for St. Louis region K–12 science teachers, helping them to increase their understandings of the fundamental big ideas of science, new cutting-edge scientific discoveries, best practices in science education (particularly in phenomenon-based learning and the importance of developing engaging storylines of instruction), and the goals of the Next Generation Science Standards.

—**Michael Wysession,** Washington University in St. Louis, St. Louis, Mo.

Basu, Ismail-Zadeh, Leinen, Millar, and Wu Receive 2019 Ambassador Awards

Sunanda Basu, Alik Ismail-Zadeh, Margaret Leinen, Connie Millar, and Lixin Wu were awarded the 2019 Ambassador Award at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is for "outstanding contributions to one or more of the following areas: societal impact, service to the Earth and space community, scientific leadership, and promotion of talent/career pool."

Sunanda Basu

Citation for Sunanda Basu

Dr. Sunanda Basu has strived tirelessly to promote the talent pool and diversity of early-career scientists across the globe, advocated nationally and internationally for space weather science, and reinvigorated international collaborations in emerging nations.

In service to the community, Sunanda cochaired the Scientific Organizing Committee for the International Heliophysical Year–Space Weather Science and Education Workshop (Ethiopia) under the auspices of the United Nations Basic Space Science Initiative. The workshop was followed by a meeting in Zambia, culminating in the prestigious international AGU Chapman Conference in Ethiopia, the first of its kind in space science in Africa. She served on the Scientific Committee on Solar-Terrestrial Physics's Long-Range Planning Committee and executive committees for the International Union of Radio Science (URSI), chaired the Climate and Weather of the Sun–Earth System (CAWSES) Steering Committee, and was an active leader of the National Science Foundation's Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program. At AGU, she was chair of the Development Board and served on the Board of Directors and award committees.

Sunanda's philanthropic contributions are of particular note. She and her late husband endowed the Basu International Early Career Award for scientists in developing countries, recognizing outstanding contributions to research in Sun–Earth systems science. This AGU Space Physics and Aeronomy section prize has recognized talented scientists from China, India, Peru, South Africa, and Nigeria. She later endowed the U.S. version of this award, followed by an URSI early-career endowment and two awards for early-career scientists living and working in Africa. The African Geophysical Society bestowed a fellowship in recognition of her substantial contribution to Earth and space sciences in Africa.

Her service and philanthropy took place in parallel with her excelling as an outstanding international scientist, representing the core of AGU's mission. The impact of her scientific leadership is recognized by her general lectures at international associations, such as "Impacts of Extreme Solar Events" at the URSI General Assembly, the International Association of Geomagnetism and Aeronomy Association Lecture on CAWSES science in Toulouse, and the CEDAR Distinguished Scientist Lecture. Her research into the ionosphere, its structure, and its irregularities has huge societal relevance associated with impacts on communications and satellite navigation. Sunanda contributed to the inception and very foundation of the U.S. National Space Weather Program Strategic Plan, now recognized at the highest levels in the Office of Science and Technology Policy.

Sunanda is an ambassador in every sense and a worthy recipient of AGU's Ambassador Award through her service and scientific leadership, her tireless and unwavering promotion of international scientific talent, and her advancing awareness of societal impacts of space weather.

—Tim Fuller-Rowell, University of Colorado Boulder

Response

It is a humbling experience to receive the AGU Ambassador Award, and for this I am very grateful to AGU. My nominator, Tim Fuller-Rowell, and my colleagues Louis Lanzerotti, Roderick Heelis, and Archana Bhattacharya all took time from their busy schedules to write letters of support. For this I owe them a big debt of gratitude.

I have now spent about 4 decades in the United States, coming from my native India. At first, my interest was to be immersed in science and use my insights to help others. Gradually, my passion evolved into helping the international community of scientists and, particularly, the next generation in whatever capacity I can. Growing up in a developing country and moving to the United States as a National Research Council postdoctoral scientist, I was able to realize how lucky I was to get this opportunity and how important it is to share my good fortune with others. My mother, if she were alive, would be, like AGU, 100 years old this year, and she instilled in me an obligation to try to meet the educational needs of young people with lesser opportunities.

My science and my life were a partnership with my late husband and colleague, Santimay Basu. In addition, both of us had been educated in India. Thus, with our global mindset and passion to help the next generation, we were able to endow through AGU annual early-career awards for scientists from developing countries within the space physics and aeronomy community, starting in 2008. Santi and I had spent our entire careers involved in space weather research and studying the societal relevance of the associated impacts on satellite-based communication and navigation systems. By definition, this research was global in scope and lent itself well to involving young scientists from developing nations. Tim Fuller-Rowell has provided a lively commentary of our forays into other parts of the world. Suffice it to say that being able to enhance the size and diversity of AGU's talent pool has been an award unto itself. Being recognized with the Ambassador Award is the icing on the cake!

—Sunanda Basu, National Science Foundation, Alexandria, Va. (Retired)

Alik Ismail-Zadeh

Citation for Alik Ismail-Zadeh

Dr. Ismail-Zadeh has the requisite research record, citations, and visiting professorships and fellowships that we expect of high-performing members of our fields. He is that and much more.

His scientific work is truly interdisciplinary, involving applied mathematics, geophysics, natural hazards, science diplomacy, and history across regions from the central Apennines to the Tibetan Himalayas. His engagement and leadership across the national and international geophysical scientific community are immense: He has helped promote geosciences from Earth observations and applications in the atmospheric, climate, and hydrological sciences to volcanology and space weather for the United Nations (UN) Educational, Scientific and Cultural Organization, the World Meteorological Organization, the Group on Earth Observations, and others. More broadly, he has supported disaster risk assessment and management efforts for the UN Office for Outer Space Affairs and the UN Office for Disaster Risk Reduction, including for controlling underground nuclear explosions through the Comprehensive Nuclear-Test-Ban Treaty Organization. In addition, he has initiated a number of outreach and education efforts, including the International Union of Geodesy and Geophysics (IUGG) Science Grants, Science Education, Science Publication, and Science Policy programs.

Dr. Ismail-Zadeh's impact is long-lasting. In one illustration, when he started the work on the formation of AGU's Natural Hazards focus group in 2009, only a few professed interest. Today, the Natural Hazards section unites thousands of researchers. To wit, both IUGG and AGU have selected issues of natural hazards and disasters as key foci of their centennial scientific themes and celebrations.

Two telling statements from other highly recognized researchers in our fields reflect on Dr. Ismail-Zadeh's singular characteristics: "What has been achieved in these areas has been due in no small measure, to Alik's inputs and unique qualities. His efforts are tireless and characterized by a willingness to use his own time in order to save yours.... Above all, I value his mature judgment and guidance." And "the sense of pride about his upbringing and family truly shows the human values he cherishes. Judging from his passion and commitment to our profession, this also reflects his feelings and unqualified commitment towards his scientific family, which has made him an ideal ambassador for Earth and space sciences."

There are many more such sentiments. Dr. Ismail-Zadeh's contributions have been "seismic" on many levels. His formal recognition as an ambassador is a credit to the vision of AGU and most significantly attests to the power of employing science to help secure the safety and sustainability of our societies and systems.

—Roger S. Pulwarty, National Oceanic and Atmospheric Administration, Boulder, Colo.

Response

I am honored to receive an AGU Ambassador Award and am grateful to Roger Pulwarty for nominating me and to Harsh Gupta, Yuan Tseh Lee, Özlem Adiyaman Lopes, and Soroosh Soroshian for supporting the nomination. I am honored twice to receive the award in 2019, the year of the AGU Centennial and my 25-year membership in the Union.

Graduating as a mathematician, I moved to geophysics and dedicated my life to studies of dynamics of the lithosphere and mantle and their manifestation in sedimentary basin evolution and, later, in earthquakes and volcanic activities. It was the time of eureka, when scientific discoveries brought satisfaction, enjoyment, and happiness. The beginning of the 21st century, however, changed my professional life from pure science to science for society. After the 2004 great Indian Ocean earthquake and tsunami, I asked myself, "What is the value of the science I am doing if this science cannot protect people against disasters? What is a missing link between science and society?" My scientific adviser and colleague V. Keilis-Borok liked to say that "a scientist is not merely a person who conducts scientific research; a scientist is a person who cannot live without doing so." So true…I would only add that a scientist is a person who should help society to improve well-being.

"An instant understanding, the efficiency of thought and action, and a good feeling that comes when the like-minded people work together…" (F. Press, as quoted by V. I. Keilis-Borok in *One Hundred Reasons to Be a Scientist*, p. 124, Abdus Salam International Centre for Theoretical Physics, Trieste, Italy, 2004). For the past 2 decades, I have tried to work together with natural and social scientists and engineers in solving challenging problems of society, including disaster risk reduction, and to speak to representatives of industry and international nongovernmental and intergovernmental organizations as well as to national and regional policy makers to convince them that science is available and ready to be used in their daily activities to benefit humanity. What brings me the biggest satisfaction after scientific discoveries are the results of my voluntary work in various capacities on behalf of AGU, the European Geosciences Union, IUGG, and the International Science Council. Creating new knowledge and delivering it to society, being an *ambactus* of the scientific community, and bridging nations via science are my credo. I am pleased that AGU recognizes the contribution to service to the Earth and space science community and science policy leadership with the award and happy to join AGU Ambassadors.

—Alik Ismail-Zadeh, Karlsruhe Institute of Technology, Karlsruhe, Germany; also at Russian Academy of Sciences, Moscow

Margaret Leinen

Citation for Margaret Leinen

Dr. Margaret Leinen's insightful and bold leadership, enduring scientific contributions, national and international impacts, and focus on quality and equity are virtually unique in our modern society of researchers, educators, and policy designers. She has played many roles in important institutions, bringing a powerful integrative mind-set to her myriad positions in professional organizations while remaining a champion of high-quality, societally relevant inquiry into how best to approach our future as a global society. She has conducted excellent research, has administered programs empowering cutting-edge scientific inquiries, and has been intimately involved in designing national and international portfolios that provide financial support for basic and applied research. Leinen is a trendsetter on multiple issues at the interface of science and society.

Leinen's influence has significantly enhanced organizations in academia, government, the private sector, and world policy-making bodies. Throughout all her work, she brings her considerable intellect and gracious generosity to ensure that all parties are enfranchised and engaged. Her work at the University of Rhode Island, the National Science Foundation, Climos, the Harbor Branch Oceanographic Institute, other institutions such as the State Department, and now as the director of the Scripps Institution of Oceanography and vice chancellor at the University of California, San Diego is replete with examples of her tenacious and unrelenting positive approach to provide cutting-edge solutions over the years. As but one specific example, her multiyear terms as part of AGU leadership as president (and associated offices) resulted in new policies that drew long-overdue attention to misbehaviors associated with harassment and bullying. Under Leinen's leadership, such actions were classified as "scientific misconduct," thereby linking—for the first time in the geosciences—professional and personal (mis)conduct.

A common thread of Leinen's accomplishments is her laudable ability to be involved in somewhat tense situations, capture the essence of the debate, and then offer tractable solutions. She is a prime example of what it means to be a true ambassador, whether addressing issues related to selection of sites for global change research in the early Joint Global Ocean Flux Study or the participation of underrepresented racial and ethnic groups in ocean sciences. She offers many examples as a role model for women scientists, and indeed for all scientists, in promoting efforts to increase participation of women and minorities in the geosciences.

Our world of geosciences is a better place because of Margaret Leinen.

—Richard W. Murray, Woods Hole Oceanographic Institution, Scituate, Mass.; and **John R. Delaney,** University of Washington, Seattle

Response

What a privilege to be among the 2019 Ambassador Awardees! I have been a member of AGU for over 40 years (time flies when you are having fun). During that time I have watched AGU grow from an organization that was primarily about publishing important journals for our fields—and organizing an annual meeting—to an organization that is committed to enhancing every aspect of members' educational, research, and professional experiences. And just in time. The cultural and organizational structure of our science in the past is no longer appropriate for a diverse, international, interdisciplinary community of scientists that must respond to urgent calls for solutions to vexingly complex problems *as well as* generate basic scientific discovery at the frontiers. The human impact on the planet—whether a result of how many of us there are or a result of what we transform and add to the air, sea, and land or a result of what we remove—is straining the basic habitability of Earth and results in demands for new knowledge and new approaches.

These demands are calling all of us to rethink the way we educate Earth and space scientists and communicate with the public. We are also being asked to break barriers of participation so that innovative ideas from everyone and everywhere can be incorporated into our thinking. We are being asked to engage those outside of our fields to bring creative ideas and connections from other disciplines. Our universities are rushing to try to keep up with this transformation. Our companies place a premium on being nimble and creative. Our governments are trying to develop less bureaucratic approaches.

With AGU's students, educators, researchers, business, and government, as well as our large international membership, AGU represents many human resources to generate geoscience knowledge. But AGU is also being challenged to serve this diverse membership during a time of incredible global and cultural change. Being an ambassador for our fields has never been more important. We who know and understand Earth and space science need to ensure that we reach out to all possible participants and partners to bring them into this commitment to a sustainable future. We also need to ensure that all can participate in an equitable way. I know that there are many AGU ambassadors out there and hope that this award can begin to show them the importance of their work.

—Margaret Leinen, Scripps Institution of Oceanography, La Jolla, Calif.

Connie Millar

Citation for Connie Millar

Dr. Connie Millar, who is fluent in genetics, paleoecology, forest ecology, climatology, glacial geology, landscape ecology, and wildlife biology, consistently integrates these disciplines to reveal insights about the dynamic biogeography of mountain ecosystems. As a scientific ambassador, she has built a community in mountain science and has catalyzed climate change adaptation on federal lands.

Connie's 2007 paper "Climate Change and Forests of the Future: Managing in the Face of Uncertainty" was recognized by the Ecological Society of America (ESA) in 2015 as "one of the most notable papers ever published" in an ESA journal (i.e., since 1920). In *Science* in 2015, in "Temperate Forest Health in an Era of Emerging Megadisturbance," Connie and coauthor Nate Stephenson outline how her research has turned traditional forest management on its head. Combining deep understanding of paleontology and genetics with observations of recent forest diebacks, they explain that there is no "ideal natural forest" to restore, and instead, managers must employ a tool kit combining "resistance," "resilience," and "realignment," including identifying regions of climate refugia and facilitating species change and adaptation. Connie pioneered the needed multidisciplinary research in these ecosystems for global change, including founding and fostering collaborations through interdisciplinary groups such as the Consortium for Integrated Climate Research in Western Mountains and the Global Observation Research Initiative in Alpine Environments, to provide the foundation for needed guidance for forest managers.

Connie's work on climate adaptation, particularly with reference to fire and planning, has resulted in shifts in the U.S. Forest Service identity. Agency leaders regularly quote Connie's work and rely on her to weave together various disciplinary ideas in a way that land managers can use. For this work, she received the Forest Service Chief's Excellence in Science and Technology Award in 2013 for "developing and delivering scientific principles, partnerships, and actions for adaptation to climate change in national forests" and the 2016 Distinguished Science Award for "leadership and exceptional scientific productivity."

Connie is an outstanding mentor. She works tirelessly to promote early-career, female, and minority voices in the *Mountain Views* newsletter she edits, as well in the many AGU sessions and MTNCLIM meetings she organizes.

Connie once remarked, "Interdisciplinary mountain research is for people who like steep learning curves." Just as John Muir worked across disciplinary boundaries to establish protected mountain areas for future generations, so has Connie worked tirelessly to establish both the key science and the future talent pool to guide how we should manage and protect those areas through times of unprecedented change.

—Jessica Lundquist, University of Washington, Seattle

Response

I send deepest thanks to my citationist, Jessica Lundquist, and the colleagues who supported my nomination. Their selflessness and willingness to prepare the nomination package humble me and bear witness to a genuine concern for our community of scientists. The honor of this award compels me to seek greater responsibilities in applying interdisciplinary science in novel ways to the challenges of land stewardship. Especially in mountain regions, complexities of terrain, climate, biodiversity, land use, and diverse stakeholder interests combine to create problems of a wicked nature. These require nimbleness, access to diverse and high-quality knowledge, and assertive action with uncertain outcomes. Where there is urgency for solutions, temptations may arise for scientists to overstep study results, adopt inappropriately alarmist attitudes, and communicate information beyond available data. Now more than ever we need to embrace strict objectivity in interpreting our research results and translating them faithfully into defensible approaches for land management. Where communities of practice emerge, such as our western North American mountain climate consortium, scientists and resource managers working together enforce reciprocal transfer of best available and transparent science in the context of environmental and management challenges. Involving students and young scientists in on-the-ground projects with resource staff provides valuable mutual benefits and serves to maintain realistic understanding and lessen risks in decision-making. For addressing problems of changing climate and related pressures on mountain landscapes, I am greatly encouraged and inspired by the courage, knowledge, and dedication of the rising generations of scientists who are committed to harnessing new knowledge for the protection and resilience of mountain ecosystems.

—Connie Millar, University of Washington, Seattle

Citation for Lixin Wu

Lixin Wu

Lixin Wu is widely recognized as a prominent leader in the field of multiscale ocean dynamics and climate change research. He pioneered the use of partial coupling systems (or model surgery) to unravel causative mechanisms operating in the complex oceanic and atmospheric feedback and subtropical–tropical linkage. He has made major original contributions to understanding the response of interannual, decadal, and interdecadal variability to greenhouse warming. He developed the first successful observation-based estimation of ocean mixing using high-resolution Argo floats in the Southern Ocean. He has discovered global warming "hot spots" along western boundary currents over the 20th century. His contribution has transformed the way we study these important issues.

While his scientific achievements are truly outstanding, his contribution to ocean sciences in enabling international collaboration is what makes him richly deserving of this Ambassador Award. The modern research landscape, science complexity, and limitation in resources present a plethora of challenges for scientists in any single country to tackle them alone, whether it is in the United States, China, or Australia. He initiated the Global Ocean Summit in 2014 to provide a regular platform for institutional leaders to enhance institutional coordination of global ocean observations. He launched a multidisciplinary research program known as Transparent Global Oceans in 2013 to build comprehensive observation systems for understanding ocean climate processes. "A Transparent Ocean" is now a goal of the United Nations Decade of Ocean Sciences. He established a workshop series, the International Symposium on Western Boundary Currents, that has been promoting interdisciplinary study of boundary current systems, particularly in a changing climate. He played a key role in the Northwestern Pacific Ocean Circulation and Climate Experiment, designed to observe, simulate, and understand the dynamics of the northwestern Pacific Ocean circulation and its climatic impact. More recently, Dr. Wu initiated the Centre for Southern Hemisphere Oceans Research, combining the research capability of the Commonwealth Scientific and Industrial Research Organisation, Qingdao National Laboratory for Marine Science and Technology (QNLM), and Australian universities to study Southern Ocean climate variability and change, and the International Laboratory for High-Resolution Earth System Prediction, integrating the world-class capability of QNLM, Texas A&M University, and the National Center for Atmospheric Research, to better predict and project extreme weather in the present-day and future climate.

In summary, Dr. Wu's sustained scientific accomplishments and influential leadership truly embody the code of a successful AGU ambassador. His contribution has had, and will continue to have, a substantial impact. He is an ideal and worthy recipient of AGU's Ambassador Award.

—Weijian Zhou, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China

Response

I am honored to receive the Ambassador Award on the 100th anniversary of the founding of AGU, and I am grateful to the Union for this recognition.

I started my career in physical oceanography after education in computational fluid dynamics. I have been fascinated by cross-scale interactions in the ocean and climate system, its complexity, and the pressing need to observe, understand, and predict its change in a concerted way. That fascination continues to be my motivation.

My first cruise was to the western Pacific in the summer of 2008 after a decade-long period of working on modeling and theoretical studies of ocean circulation and climate. The severe seasickness, over much of the cruise, provided a moment to think about integration of observations, theories, and predictions so that our ocean is more transparent. Soon after the cruise, we established observational networks in the western Pacific and started to build a "Transparent Ocean Community." Now, after a decade of progress, the community has become internationally famous, and the mission of Transparentizing Global Oceans echoes resonantly with the sustainable goal of the United Nations Decade of Ocean Science.

A Chinese proverb goes, "The ocean is vast because it admits all rivers." To facilitate the implementation of Transparent Ocean, we have held a series of biennial Global Ocean Summits since 2014, in which leaders of major marine institutions and organizations meet and discuss global partnership for ocean observations. In part as an outcome of these summits, we have established two international centers, the Centre for Southern Hemisphere Oceans Research and the International Laboratory for High-Resolution Earth System Prediction, which create opportunities and a platform for Southern Ocean research and high-resolution Earth system modeling and prediction, respectively. These collaboration hubs help galvanize concerted efforts and encourage broader participation in the endeavor to build a community of shared future for mankind. As an AGU Ambassador Award honoree, I look forward to working with colleagues and partners to accomplish this great cause.

My sincere gratitude goes to Weijian Zhou, my nominator, and supporting colleagues, as well as my family, friends, and students. With your support, I feel a lot more can still be achieved.

—**Lixin Wu,** Ocean University of China, Qingdao; also at Qingdao National Laboratory for Marine Science and Technology, Qingdao, China

James E. Broda Receives 2019 Edward A. Flinn III Award

James E. Broda was awarded the 2019 Edward A. Flinn III Award at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for an individual or small group who personifies AGU's motto of 'unselfish cooperation in research' through their facilitating, coordinating, and implementing activities."

James E. Broda

Citation

Dr. James Eugene Broda perfectly fits the criteria for the Edward A. Flinn III Award. He is truly one of those "unsung heroes who provide the ideas, motivation, and labors of love that build and maintain the infrastructure without which our science could not flourish." For (an incredible) 49 years, Jim has served hundreds of oceanographers, particularly marine geologists and geophysicists, who have relied on his unique blend of knowledge, creativity, careful planning, sharp intellect, and critical thinking to plan and bring to successful fruition both ordinary and extraordinarily outrageous scientific projects. His work over these 5 decades has enabled our science and greatly improved us as scientists.

In his lifetime of achievement, it is not easy to pick out the highlights. Among the "ordinary" accomplishments is his participation in an (incredible) 125 (and counting) oceanographic research cruises, 52 with Woods Hole Oceanographic Institution (WHOI) chief scientists, for a total of nearly 10 years at sea! Of course, it is inaccurate to use the term "participation" to describe Jim's role in these expeditions. He was and is, in most cases, vital to the success of the expeditions, from the earliest stage of planning, through the realization of the cruise, and afterward, through his indispensable role in curating in perpetuity the samples and data.

Many of Jim's accomplishments have been more "extraordinary" than "ordinary." One that stands out is his design of the WHOI "long corer," originally installed on the R/V *Knorr* in 1997 (now also installed or planned for installation on Korean and German research vessels). That system allowed scientists to retrieve many large-diameter piston cores of 30- to 40-meter length with nearly perfect recovery and quality. It is surely the most innovative and technically advanced sediment corer ever built. In this case, Jim responded to a community need and used his great abilities and perseverance to accomplish something that no one else could have. Many important scientific publications have followed, none of which would have been possible without Jim's work.

While these technical endeavors are exemplary, they barely touch on the body of work achieved throughout Jim's incredible career of accomplishment and self-sacrifice for the entire seagoing oceanographic community (time at sea exacts a cost both physically and emotionally). We are thrilled that this extraordinary man is finally being awarded the great honor that he so richly deserves.

—**Paul A. Baker,** Duke University, Durham, N.C.; and **Lloyd D. Keigwin,** Woods Hole Oceanographic Institution, Woods Hole, Mass.

Response

It is indeed an honor to be recognized by this award from AGU. I humbly express my deepest gratitude to all those who supported my nomination. Thanks also to the innumerable colleagues and shipmates with whom dedication to dreams and love of exploration were shared.

In the spirit of cooperation, part of the creed of this award, these others should share much of the praise for the contributions accredited to me. They enabled concepts to grow with funding and technical challenges. My career spanned over some of the greatest breakthroughs in ocean engineering, and I was blessed to be surrounded by those engaged in changing the way we look at and understand the ocean.

Over the decades and an excursion of the planet, I sought to evolve safer and more capable seafloor sampling systems. They grew in size and complexity to meet the challenges of the marine geological community. Seismic refraction operations that involved high explosives became a focus, and hundreds of tons of charges were deployed in discreet experiments. As ocean bottom receivers came to pass, so did our completely unique ability to deploy and detonate explosives on the seafloor at full ocean depth.

I was fortunate to have the support and inspiration to apply emerging technologies to solve marine geological equipment development issues. I had the rare opportunity throughout my career to learn by doing and take conceptual CAD drawings onto the shop floor, see them turn into finite objects, then head out to deep water to test and refine the creation.

Finally, sincere thanks to Dr. Paul Baker, Dr. Bill Curry, Dr. Rick Murray, and Dr. Mike Purdy for their generous citation, continued support, and shared adventures over the years. It is very gratifying to have shared so much with so many, from bosuns to postdocs and a visionary or two.

—**James E. Broda,** Woods Hole Oceanographic Institution, Woods Hole, Mass.

▶Read more citations and responses from recipients of AGU honors at eos.org/agu-news.

Brian May Receives 2019 Athelstan Spilhaus Award

Brian May was awarded the 2019 Athelstan Spilhaus Award at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for the enhancement of the public engagement with Earth and space sciences through devoting portions of their career conveying to the general public the excitement, significance, and beauty of Earth and space science."

Brian May

Citation

Dr. May's contributions to public awareness and appreciation of the space sciences are literally unique on the planet. World famous as the lead guitarist for the rock band Queen, he also holds a Ph.D. in astrophysics, which he was awarded in 2007 by Imperial College London for his studies of the zodiacal light. Just by being a rock star who went back to complete his doctoral studies, he conveyed to the public in a way that no one else could that *science is cool.* Dr. May has used his celebrity as a science collaborator on NASA's New Horizons mission to Pluto and the Kuiper Belt, the European Space Agency's Rosetta comet mission, and the Japan Aerospace Exploration Agency's Hayabusa2 asteroid mission.

Dr. May was an avid promoter of New Horizons during and after its 2015 Pluto encounter. He not only participated in numerous interviews and public appearances but harnessed the power of his Twitter account, which has almost 1 million followers. His work generating and publicizing stereo images from all these missions lets the public see the worlds we have explored with new eyes.

For New Horizons' 2019 encounter with the Kuiper Belt object Ultima Thule, Dr. May raised his impact to a new and extraordinary level: He wrote and recorded a new song, "New Horizons," to celebrate the mission. Coming as it did just a couple of months after the release of the enormously successful film about Queen, *Bohemian Rhapsody,* May's involvement in the Ultima Thule encounter was an incredible boost to the mission's visibility. Even readers of *Guitar World*'s website learned that Ultima Thule was giving us, in Dr. May's words, "precious clues about how our solar system was born."

The official video for "New Horizons" has been viewed 1.7 million times on YouTube, and countless more have heard the song on TV and webcasts. All have heard the world's only astrophysicist/rock star singer.

Limitless wonders in a never-ending sky
We may never, never reach them
That's why we have to try!

By using his rock star charisma to show the world not just what we explore, but *why,* Brian May is truly worthy of the 2019 Athelstan Spilhaus Award.

—**Andrew Chaikin,** Arlington, Vt.; and **John Spencer,** Southwest Research Institute, Boulder, Colo.

Response

My love of astronomy began when, as a boy in the early 1950s, I begged to be allowed to stay up late to watch Sir Patrick Moore present BBC TV's *Sky at Night* series. Around 1970, I began my Ph.D. studies at Imperial College London but left without completing my Ph.D., for a break to pursue my hobby of rock music—a break which turned into more than 30 years performing and touring the world with my band, Queen. It was Patrick Moore who encouraged me to resume work on my Ph.D. thesis, "A Survey of Radial Velocities in the Zodiacal Dust Cloud," which I completed in in 2007.

This opened the doors for me to return to the world of astronomy and astrophysics. Soon afterward, I entered into my first collaboration in authorship, along with Sir Patrick and Dr. Chris Lintott: We wrote and published the popular science book *Bang! The Complete History of the Universe.*

In all my travels around the world, I have never been far away from astronomy, and recently, I have been able to contribute to several space missions through another lifelong passion, stereophotography.

In 2015 I was invited by principal investigator (PI) Alan Stern to join his NASA New Horizons team as a science team collaborator, and I worked on creating the very first stereo images of Pluto. Four years and a billion miles later, Alan invited me back to write a song to accompany New Horizons' close encounter with the Kuiper Belt object Ultima Thule. My "New Horizons" single was released on New Year's Day 2019 and premiered on NASA TV, to coincide with the flyby.

In 2015 I also worked with PI Matt Taylor on the European Space Agency's Rosetta mission, creating stereo images of comet 67P/Churyumov-Gerasimenko. This year, in collaboration with the Japan Aerospace Exploration Agency's Hayabusa2 team I created stereo images of asteroid Ryugu, the first C-type (carbonaceous) asteroid to be imaged at close quarters. Many of the stereos created from data sent back to Earth by these remote scientific space vehicles have been made with the help of my own collaborator, Claudia Manzoni, and I would like to acknowledge her and thank her for her expert and invaluable work.

I note that this award is for public appreciation and awareness of the space sciences; if, by sharing my experiences in words, 3-D images, and music with those who follow my activities, I have done something to help bring to the public the excitement of space exploration and the associated science, I am content. But receiving this award is a wonderful and unexpected bonus!

My grateful thanks to AGU.

—**Brian May,** Commander of the Most Excellent Order of the British Empire (CBE)

Susan Hough Receives 2019 International Award

Susan Hough was awarded the 2019 International Award at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for making an outstanding contribution to furthering the Earth and space sciences and using science for the benefit of society in developing nations."

Susan Hough

Citation

Few scientists have had a greater impact on promulgating earthquake awareness and education in developing nations than Susan Hough. She has tirelessly enriched cooperative projects between the United States and local scientists in Kashmir, Pakistan, Haiti, Nepal, and, most recently, Myanmar—nations reeling from the trauma of recent devastating earthquakes or from political upheavals and uncertainties. Through workshops and training sessions in these countries, her collaborative projects have empowered local scientists to engage in earthquake activities ranging from running their own seismic networks to assessing seismic hazard and reporting scientific results. As part of these programs she has also enriched the experience of foreign scientists by inviting them to participate in visits to scientific establishments and professional meetings here in the United States.

Sue has also authored five books about earthquake science for the general public, several of which have been translated into foreign languages. In her books, not only does Sue distill complex scientific information in a clear and intelligible form for the general public, but she layers it with history, context, and color—and her excitement for the scientific enterprise is contagious throughout.

Perhaps more than anything, her eagerness to promote capacity building has been undertaken with a selfless determination and a complete absence of ego. In many countries, she has found herself disarming local officials with gentle persuasion and demonstrating by example that women in science are first and foremost scientists, able to contribute with equal integrity to pushing forward the frontiers of knowledge.

As an AGU Fellow with over 150 publications to date, Susan Hough is the rare combination of a top-caliber scientist who has also contributed immensely to hazard preparedness and resilience in developing countries. We are pleased to present her with AGU's International Award.

—**Roger Bilham,** University of Colorado Boulder

Response

I am honored and humbled to receive this award. Thank you so much, Roger, Morgan, and the others who wrote letters of support and, of course, AGU.

I would also need to acknowledge colleagues who have been vital contributors to Team USGS over the years: Irving Flores, Jason De Cristofaro, Emily Wolin, Dan McNamara, and Nicholas van der Elst, as well as Roger Bilham, who has made some contributions himself in an international arena. And none of my international work would have been possible without the support of the U.S. Agency for International Development, Office of U.S. Foreign Disaster Assistance, which understands the critical importance of long-term risk mitigation, and the dedicated professionals at the U.S. Department of State.

But let's talk about capacity development. Capacity development is only ever possible when there are existing capacities to be developed. One thing I have learned over the years is there are existing capacities in every country that faces earthquake hazard. It has been the privilege of a lifetime to work with and get to know students and professionals in the countries where I have worked: Myanmar, Nepal, Haiti, India, and Pakistan. I have been awed on a regular basis by the dedication, energy, and talents of partners who face enormous challenges on a daily basis. I've told the story of the day I landed in the mother of all traffic jams in Haiti—an adventure I will never forget—and the realization that hit me later, that my epic experience was just one more chaotic day in a lifetime of chaotic days for Haitians, who face daily life with a resilience and resourcefulness beyond what outsiders ever see. There is a hunger for training and resources in so many parts of the world where dedicated professionals and students understand the hazard and yearn to make their countries safer. As scientists we know that Earth science is a global science. But where capacity development is concerned, thinking globally requires acting locally, doing everything we can to strengthen existing local capacities. I accept this award on behalf of the professionals at institutions that continue to do the heavy lifting with risk reduction in their respective countries: the Myanmar Department of Meteorology and Hydrology, the Nepali Department of Mines and Geology and National Society for Earthquake Technology, the Haitian Bureau des Mines et de l'Energie and Université d'État d'Haïti, and others.

Thank you again.

—**Susan Hough,** University of Arizona, Tucson

David Moore Receives 2019 Excellence in Earth and Space Science Education Award

David Moore was awarded the 2019 Excellence in Earth and Space Science Education Award at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for a sustained commitment to excellence in geophysical education by a team, individual, or group."

David Moore

Citation

The fields of ecosystem ecology and land–atmosphere interactions owe a great debt to Dr. David J. P. Moore and his work in shepherding the next generation of Earth system scientists. Dave is at the vanguard of a community effort to train early-career scientists and technical professionals how to combine data and models to assess impacts of global change on ecosystems and associated biogeochemical cycles. Dave helped develop a first-of-its-kind summer course in flux observations and advanced modeling (Fluxcourse). Under his leadership, the 2-week course is now entering its twelfth year. The Excellence in Earth and Space Science Education Award recognizes Dave's passion and educational accomplishments in Fluxcourse and sustained contributions to education and professional development of early-career scientists.

More than 200 scientists from around the world have been trained by the course, in emerging global change fields that are increasingly important but not available at many universities. The course brings a diverse student body to a beautiful research station in the Colorado Rockies, where they gain hands-on experience in eddy covariance, integration of high-density databases, model-data fusion, and ecological synthesis and inference. Modules are taught by the world's experts, and the collaborative assignments foster career-building connections. Dave has succeeded in his commitment to increasing the participation of students and instructors traditionally underrepresented in the field, from multiple countries and institution types.

Dave's pedagogic framework is highly effective. He employs social media tools, professionally produced interactive film modules for international education, and personal alumnus contacts. Five years ago, Dave launched an initiative to expand the reach of the course, building it into a novel, globally based platform that fosters long-term student and postdoc collaborations. This strategy has created a multidisciplinary network of dispersed but highly motivated early-career researchers capable of tackling the difficult tasks of Earth system forecasting and climate impact assessment.

Dave's dedication to Fluxcourse is catalyzing a major transformation in the way we participate in international education and collaboration in our field. Scientists now collect and store more ecological observations than ever before, spurring a need for new analytical approaches built upon open data and collaboration that use empirical, statistical, and process-based modeling approaches. Fluxcourse fills a critical training and pedagogical need in model-data fusion that supports analysis at policy- and management-relevant scales and fosters the development of cross-discipline alliances that span career stages and expertise. Dave Moore's impact will be felt in our community for generations to come.

—**Ankur R. Desai,** University of Wisconsin–Madison; **Margaret S. Torn,** Lawrence Berkeley National Laboratory, U.S. Department of Energy, Berkeley, Calif.; and **Kimberley A. Novick,** Indiana University Bloomington

Response

I would like to thank AGU and my colleagues who nominated me. This is an honor for me and for those who have made the Fluxcourse a success over the past 12 years.

As an ecologist, I have witnessed profound change in how we create new knowledge. Contemporary ecological challenges extend beyond any one individual's expertise. Advances in data collection offer unprecedented opportunities to meet these challenges, and this has been mirrored by advances in mathematical modeling and analytic techniques. Combining models and data helps us ask clearer questions, collect more useful data, and design more skillful models. Whether your science is rooted in observation or focused on analytical models, a great deal of knowledge, skill, and dedication is required to succeed. However, effective communication between observationalists and modelers is challenging, and specialization can lead to the isolation of the two communities to the detriment of both. Each has evolved barriers in the form of their own languages, norms, and approaches—the Fluxcourse seeks to break these down.

Attendees work through the scientific and logistical issues of making measurements and the conceptualization and execution of mathematical models. We learn the benefits and shortcomings of different approaches and try to build a community of practice that emphasizes dedication to expertise and the willingness to collaborate.

There are many people to thank: Russ Monson and Dave Schimel for pulling me into this enterprise; Kim Novick and Betsy Cowdery, who maintain my faith in it; and Ray Leuning, who continues to inspire. The course is a coalition of the willing, and it succeeds because it has strong community support. Early-career scientists come from all over the world to learn, and instructors come from academia, research networks, and industry to help attendees learn and develop as scientists in a beautiful setting provided by the University of Colorado's Mountain Research Station. Instructors are all volunteers, some from the beginning, some whenever they could, others are eager to pitch in now—we could not run the course without their generosity. It is a delight to wander the halls of AGU and see the course alumni as they advance in their career. Fluxcourse was just one nudge along their scientific paths, but their assertion that it was formative and their willingness to return as course instructors tell me and our team that we should keep going.

—**David Moore,** University of Arizona, Tucson

Andy Green Receives 2019 Africa Award for Research Excellence in Ocean Sciences

Andy Green was awarded the 2019 Africa Award for Research Excellence in Ocean Sciences at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given in recognition of "significant work that shows the focus and promise of making outstanding contributions to research in Earth or ocean sciences."

Andy Green

Citation

Dr. Andrew Green is an exceptional young marine geoscientist, actively engaged in placing the African continent's marine geology in the international spotlight. His research career began when South African marine geology was at an all-time low because of a lack of academic expertise. He has, since his Ph.D. 10 years ago, become the hinge point behind the resurrection of South Africa's status as an international member of the marine geology community. His research unit, the only such in Africa, is a vibrant and productive center that draws international collaboration and students from countries across the continent and abroad.

Dr. Green's work has focused on examining coastal and shelf geomorphology and sedimentology in response to forcing induced by sea level change. His holistic treatment of shelf-coastal morphologic systems in the context of major changes in sea level has been novel and has confirmed the existence of meltwater pulses in SE African waters. Given the dense clustering of urban areas along the SE African coast, the detailed understanding of how past shorelines in the region responded to and were modified by high rates of sea level rise will be valuable data sets to adapt to and mitigate future sea level changes that are predicted to be as high as 2 meters by the end of the 21st century.

Dr. Green is a prolific scholar, producing significant research results in a part of the world that is comparatively poorly studied. To date, he has published 70 papers in peer-reviewed journals, 30 of these as first author and 23 as project leader of student-authored work. This emphasis on student-driven publication is a major boost to capacity development and skill training for young African scientists.

Dr. Green has significantly expanded African access to complex and expensive geophysical equipment and software. Considering that few universities in the world own their own bathymetric and seismic acquisition systems, he has positioned his team as the central touchpoint for research on the seafloor and coastlines of the continent. Dr. Green has a strong dedication to the University of KwaZulu-Natal in Durban; he was appointed lecturer while still a Ph.D. student, promoted to tenured lecturer in 2010 and associate professor in 2016, and serves as the academic leader of the Geology Department. His passion to gain experience in various geophysical tools and reinvest it into the South African tertiary education sector led to him being named an African Fulbright scholar in 2018.

—**John A. Goff,** Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin

Response

I am deeply honored to have been awarded the 2019 AGU Africa Award for Research Excellence in Ocean Sciences. I would like to thank AGU for the award and for placing Africa in the spotlight. I am encouraged now, more than ever, to spread the good news of our wonderful continent. Much is yet to be done from this part of the world!

I am indebted to my nominator, John Goff. In 2005, John selflessly reached out to a young Ph.D. student, located on the far side of the planet, with much-needed inputs to his first scientific paper. That student was me, and that was where my career began.

Peter Ramsay employed me throughout my M.Sc. and Ph.D. Under Pete's kind guidance, I was exposed to every facet of shelf geology possible. If there was a piece of equipment that could scan the seafloor, I saw it in action. Much of what I have learned was gleaned from Pete during the months spent sailing the Indian Ocean in the various rust buckets we called survey vessels.

Steve McCourt nurtured my early academic career. As the head of department, he was a source of unwavering support and advice. Steve taught me to think strategically and to seek the advantages amid the somewhat chaotic South African tertiary education system. My great collaborator and dear friend Andrew Cooper took me under his wing in the latter 8 years. The places visited, cold beers shared, papers written, and advice given will remain unmatched. Likewise, Burg Flemming has been an enthusiastic supporter and keen scientific sounding board. He too has provided me with many opportunities I think would not exist otherwise. Of course, I need to thank those who wrote letters of support for my nomination, Joe Kelley and Edward Anthony. I am deeply grateful.

Last, I thank my family. My parents supported my love affair with the ocean since I was a child. The many early-morning car rides to the beach, sunburns, and other injuries were all worth it. Your support has been the greatest gift. To my wife, Lauren, my greatest advocate, this is all meaningless without you. Last, I would like to dedicate this award to our yet unborn child. I hope this will prompt some of the changes needed for you to see the beaches and coasts of the world as we did as children.

—**Andy Green,** Geological Sciences, University of KwaZulu-Natal, Durban, South Africa

Andrew Akala Receives 2019 Africa Award for Research Excellence in Space Science

Andrew Akala was awarded the 2019 Africa Award for Research Excellence in Space Science at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given in recognition of "significant work that shows the focus and promise of making outstanding contributions to research in space science."

Andrew Akala

Citation

Dr. Akala received his Ph.D. in ionospheric physics and radio propagation at the University of Lagos in 2009. While pursuing his research on ionospheric irregularities and radio scintillation, he became keenly interested in their implications for aviation safety in Nigeria and abroad. An active proponent of aviation safety to this day, he was instrumental in founding the Nigerian Institute of Navigation about 6 years ago, and he currently serves as its president.

He has authored and coauthored more than 60 articles related to low-latitude scintillation morphology, occurrence statistics, and the impacts on Global Positioning System (GPS) receivers intended for aviation applications. More than 50 of these have appeared in peer-reviewed scientific journals.

His leadership has strengthened the space science unit of the Physics Department at University of Lagos and has led to the establishment of new courses in the area of space sciences at the university. This year, he was promoted to the rank of associate professor of space physics. He is a member of the University Senate and the deputy director of academics planning and development of the Distance Learning Institute of the university.

Additionally, his efforts have led to the establishment of new institutions dedicated to improving the safety of navigation through an improved understanding of space weather effects. Through his many outreach activities, he has encouraged the growing community dedicated to space science research to thrive at institutions throughout Africa and worldwide. At the 2018 International Symposium on Equatorial Aeronomy (ISEA) in Ahmedabad, India, he proposed the idea of Africa/Nigeria hosting the next ISEA meeting to expose young African students to ongoing research efforts of the international community. Dr. Akala currently serves as the general secretary of the African Geophysical Society, which is dedicated to the promotion of space science in Africa.

—**Charles S. Carrano,** Institute for Scientific Research, Boston College, Boston, Mass.

Response

I am deeply honored to receive the 2019 Africa Award for Research Excellence in Space Science. I thank Almighty God for this opportunity. Being recognized by a first-class professional body like AGU is very special to me. It is even more humbling for me to receive this award in the presence of so many leaders of our noble profession. My journey to space science was very unintentional! I had my first degree in physics electronics. My M.Sc. and Ph.D. adviser, the late Jibayo Akinrimisi, directed my steps to space science.

I thank my late father, Ogundeyin Akala, to whose memory I am dedicating this award. The support from my mother, Yetunde Akala, was also awesome. Against all odds, my parents deprived themselves of basic comforts of life to give me education.

I am grateful to the late Santimay Basu and to Sunanda Basu, the initiators of this award. I thank the award selection committee for selecting me, and the AGU Honors Committee for this prestigious recognition.

I was nominated for this award by Charles Carrano. The nomination was graciously supported by Sandro Redicella, Jacob Adeniyi, and Oliver Obrou. Carrano was my adviser during my Fulbright program at Boston College. Redicella is my adviser in the Regular Associate Scheme of the International Centre for Theoretical Physics (ICTP) in Italy. Aside from the great names above, I was privileged to be mentored by great space scientists, namely, Pat Doherty, Emmanuel Somoye, Larry Amaeshi, Christine Amory-Mazaudier, Nat Gopalswamy, Bruce Tsurutani, Keith Groves, Cesar Valladares, Victor Chukwuma, Babatunde Rabiu, Elijah Oyeyemi, and Dieter Bilitza. Space will not permit me to mention all the names. I am grateful to you all for being sources of inspiration to me.

For me, this award is a clarion call to higher service. I plan to expand my participation in public outreach services. I thank the past recipients of this award for their commitment to space research. I will join forces with them in advancing space science education in Africa and beyond.

I appreciate many organizations that have supported my research in one way or another, chief among which are the University of Lagos, Fulbright Board, ICTP, United Nations Office for Outer Space Affairs, Committee on Space Research, AGU, and others. I am indebted to all my past and present students and my research team for their contributions to my success story. Last, I thank my wife, Salomey, and my children for their continued understanding and support toward my career development.

—**Andrew Akala,** University of Lagos, Lagos, Nigeria

Franziska C. Landes Receives 2019 Science for Solutions Award

Franziska C. Landes was awarded the 2019 Science for Solutions Award at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for significant contributions in the application and use of the Earth and space sciences to solve societal problems."

Franziska C. Landes

Citation

The creativity, passion, and impact of young researchers is inspiring, and when applied to pressing, real-world problems like lead poisoning, these research characteristics take on an even more important and pressing tone. Dr. Franziska Landes has consistently demonstrated the drive to make real differences in communities, the creativity to develop new lead testing strategies and place them in the hands of the very communities that are burdened by lead contamination, and the scholarship to produce scientific products to share these innovations with the world.

Franziska uses citizen science and community-engaged research to identify and eradicate pollution in environments ranging from New York City backyards to mining villages in the Peruvian Andes. Achieving this scale of impact requires creative thinking about how to engage people in the discovery and research process and providing them with tools that they could use themselves in a practical way. It is also incredibly hard as a researcher to take the time to develop trust in the community and to develops tools that are user friendly, culturally appropriate, and understandable for the communities that need them. Franziska not only developed and validated low-cost, citizen-friendly testing kits for bioavailable lead in soils but also created a mobile-friendly database structure and autocapture system for demographics, observations, and lead data and in Spanish on top of all that!

Franziska is sharing the products of these efforts in several ways. She has followed the traditional publication route to share her technique development and implementation results. But perhaps as important, she worked with communities to develop locally appropriate research translation tools for communities and engaged actively with organizations in Peru to ensure sustainability of this program. She has also brought her passion to the AGU GeoHealth section, chairing the Early Career Committee and guest editing a special issue of the journal *GeoHealth* on community-engaged research and citizen science.

Overall, if I were asked to identify the type of scholar who should come out of the 21st century academy, it would be Franziska: scientifically diligent, passionate about using science to improve society, and engaging in the trenches on the important environmental health issues of the day. It is truly my honor to have been able to nominate Franziska for this award.

—**Gabriel Filippelli,** Indiana University–Purdue University Indianapolis

Response

I am greatly honored to be receiving this year's Science for Solutions Award. I would like to thank Gabriel Filippelli for organizing this nomination and for his leadership in community-engaged research and geohealth. I also want to thank my doctoral adviser, Lex van Geen, for his support and continuous encouragement to think about real-world applications. Thank you also to Peter Schlosser for establishing this award and his continued dedication to identifying solutions based in the Earth sciences.

On a global scale, we face a growing urgency to find solutions to enable living sustainable and equitable lives. By engaging communities in the scientific process and by enabling people to pose questions, conduct environmental measurements, and identify answers on their own, we as a society can be better positioned to find the solutions we need now and in the future. My work is motivated by a desire to improve human and environmental health, and on a daily basis I am inspired by community members, parents, teachers, and students striving for these same goals.

I would also like to thank the AGU community for their support of early-career scientists and especially the AGU GeoHealth leadership team for creating a welcoming community that incorporates early-career members at all levels.

I am continuously inspired by the work of these interdisciplinary researchers and practitioners, and I am excited to be a part of this community focused on the interactions between the health of people, ecosystems, and the environment.

—**Franziska C. Landes,** Lamont-Doherty Earth Observatory, Columbia University, Palisades, N.Y.

Alexandra Witze Receives 2019 Robert C. Cowen Award for Sustained Achievement in Science Journalism

Alexandra Witze was awarded the 2019 Robert C. Cowen Award for Sustained Achievement in Science Journalism at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for recognition of a journalist or team of journalists who have made significant, lasting, and consistent contributions to accurate reporting on the Earth and space sciences for the general public."

Alexandra Witze

Citation

Alex Witze has been writing about Earth science for nearly 25 years at major newspapers and magazines and as a book author. With her deft, lively style and great depth of expertise, she is one of the finest science writers working today.

Witze's writing skillfully marries the technical aspects of geoscience with the human experience of living on a volatile planet. This is clear in her heartbreaking *Nature* story on how scientists missed the warning signs of seismic dangers in western China prior to the 2008 Sichuan earthquake and in her article on the increasing incidence of extreme rain events in a warming world and their societal impacts.

A pillar of the broader science writing community, Witze serves on the board of directors and as treasurer of the National Association of Science Writers. She also sits on the board of The Open Notebook, an indispensable online resource for science journalists.

Witze began her career at *Earth* magazine and quickly moved to the *Dallas Morning News,* which sent her around the world to cover geoscience research. She traveled to NASA's Jet Propulsion Laboratory to cover the Mars Pathfinder landing and to the North Pole to report on climate science. In 2000, Witze won AGU's Walter Sullivan Award for her *Dallas Morning News* story on an ocean drilling expedition that explored the Kerguelen Plateau.

In 2005, Witze became a correspondent at *Nature,* where she has held down the Earth science beat ever since. Her work has also appeared in *Knowable Magazine, Air & Space,* and *Science News.* In 2014, she published *Island on Fire,* about the 1783 eruption of the Icelandic volcano Laki, which altered the course of human history.

The book, cowritten with her husband, Jeff Kanipe, was short-listed for the PEN/E. O. Wilson Literary Science Writing Award. Witze's work has won accolades from many leading science organizations, including the American Association for the Advancement of Science, the American Institute of Physics, and the American Astronomical Society.

In 2016, she won AGU's Perlman Award for her story on induced seismicity in Oklahoma. She is the only writer to have received both the Perlman and Sullivan Awards and now the Cowen Award—which honors her long and ongoing legacy.

—**Julia Rosen,** *The Los Angeles Times,* Portland, Ore.

Response

I'm so pleased to accept AGU's Cowen Award. Many, many thanks to Julia Rosen—a science writer of the highest caliber—for the nomination. And it was a thrill to get an email from Bob Cowen himself when the announcement went public.

The fact that AGU acknowledges lifetime achievement in this area means a lot. For so many writers, our jobs consist of an endless search to unearth untold stories and bring those to a wide audience. Much of this work is exhilarating, such as when we have the opportunity to cover path-breaking discoveries and report stories that end up in the history books. Much of the rest is not, such as when we need to illuminate the systemic factors that have prevented many scientists from performing to their fullest potential.

Science journalism is a niche profession and one that has struggled in recent years. I've been in this field long enough to see many traditional journalistic outlets close up shop. Some new ones have launched, but there's no question that journalism in the United States is facing an existential threat. In an era where reporters are belittled and jeered for doing their jobs, it's heartening to see AGU continue to highlight the importance of accurate and insightful journalism.

Over the years I've worked with too many excellent colleagues to name them all here. I'm grateful for my professional community and the opportunity to keep working in this field even as it evolves. Thank you also to all the scientists who have taken my calls, answered my emails, and allowed me to tag along in the field with them.

Most of all I'm grateful for my husband, Jeff Kanipe, whose love and support have made all our joint and individual science-writing work possible.

—**Alexandra Witze,** Freelance Writer

Sarah Kaplan Receives 2019 Walter Sullivan Award for Excellence in Science Journalism–Features

Sarah Kaplan was awarded the 2019 Walter Sullivan Award for Excellence in Science Journalism–Features at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for excellence in feature reporting about the Earth and space sciences, with a deadline of more than one week."

Sarah Kaplan

Citation

Planetary scientists gathered for a 3-day workshop last year to debate one of the most momentous decisions of modern space exploration: Where should NASA send its next Mars rover, a mission that will send back rocks to be examined for signs of life?

The decision was so difficult because we don't know where life evolved on Earth. The three candidate landing sites represented three theories of life's origins here: a river delta, a hot springs, and a mesa that exposes multiple layers that could have contained trapped water.

Sarah Kaplan showed readers the stakes of the decision and wove together what we know about Mars—a lot more than most readers realize—and the origins of life on Earth. Throughout the story, readers meet scientists deeply invested in this decision and thrilled at the opportunity to maybe, just maybe, find the first evidence of life on another planet.

The online presentation, a collaboration with Joe Fox and Brittany Renee Mayes on graphics, with a design by Leo Ji and photo editing by Karly Domb Sadof, paired satellite images of Mars with satellite images of comparable spots on Earth. A series of maps and insets showed where the candidate landing sites are on Mars and the geologic features a rover would encounter there. Columbia Hills, a former hot spring, was explored by the rover Spirit and is comparable to a hot spring in Yellowstone National Park. Jezero Crater is a former river delta feeding into a lake that might have entombed organic material. And Northeast Syrtis has minerals that suggest it was once part of an underground aquifer, as well as "megabreccias," or debris from ancient meteorite impacts.

The gorgeous images of Mars look familiar to an earthling, and the science shows the planets weren't all that different, once—before Mars lost its atmosphere and water and became a "failed planet," at least where life is concerned. The Mars 2020 rover is our best opportunity to find out if life ever existed there.

—Laura Helmuth, *The Washington Post,* Washington, D.C.

Response

Say you're going to launch a spacecraft to look for signs of ancient life on Mars. Where do you send it?

Mars is a big place, and even the most adventurous rover covered just 28 miles in its lifetime. Any mission to the Red Planet will get to explore only a very tiny spot. So scientists spend countless hours studying and debating in an effort to find just the right one.

As soon as I learned this, during a conversation with a deputy project scientist for NASA's Mars 2020 mission, I knew I had to witness the process myself. The 2020 rover (which is slated to launch this summer) was built to pursue one of the most meaningful questions humans can ask. Its landing site will determine how close we might get to an answer.

So in 2018 I asked my editor, Laura Helmuth, if I could fly to Los Angeles to attend NASA's final site selection workshop.

I wouldn't have blamed her if she was skeptical about the idea. Three days of jargon-filled debate in a windowless conference room doesn't exactly sound like a recipe for a compelling narrative. But Laura understood the potential for this story to give readers a glimpse at how the scientific process works—while the possibility of aliens hung in the balance—and for that I am tremendously grateful.

I am also indebted to the scientists who generously explained—and reexplained—their research during the workshop and afterward. Their enthusiasm and eloquence made Mars feel less distant and the search for life there more real.

Of course, "Next Stop, Mars" would not have been half as compelling if not for the brilliant work of my colleagues: Joe Fox and Brittany Renee Mayes, who created the maps with images taken by the Mars Reconnaissance Orbiter; Karly Domb Sadof, who edited the photos; and Leo Ji, who designed the whole story.

I'm thankful to AGU and its members, who give me so much to write about, and to the distinguished writers and researchers on the Walter Sullivan Award Committee who selected my story.

Most of all, I am grateful for readers. Amid an onslaught of grim news from this world, they make time in their lives and space in their minds to wonder about others.

—Sarah Kaplan, *The Washington Post,* Washington, D.C.

Ann Gibbons Receives 2019 David Perlman Award for Excellence in Science Journalism–News

Ann Gibbons was awarded the 2019 David Perlman Award for Excellence in Science Journalism–News at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The award is given "for excellence in news reporting about the Earth and space sciences, with a deadline of one week or less."

Ann Gibbons

Citation

This award is for a news story, written on deadline and pegged to a talk. But it's also an example of how habits honed in 2 decades of outstanding journalism can help a reporter seize an opportunity in a moment. Those habits helped Ann Gibbons crystallize a casual conversation into a sparkling gem of a story.

Ann, a contributing correspondent for *Science,* is a master at tracking research findings, such as an unexpectedly light isotope or the shape of a bump on an ancient bone. Crucially, she then also recognizes the moment when those details coalesce into a story the world needs to know.

Ann's a writer first, with English and journalism degrees from the University of California, Berkeley. She also studied science at Berkeley and with fellowships at the Massachusetts Institute of Technology and at Harvard. At *Science* she covers human evolution, and her award-winning stories include those on human sacrifice and ancient migrations. Her tales of how people actually lived in prehistory turn out to have huge relevance for today because we are not the first humans to struggle with climate change, mass migrations, and encounters with foreigners. One story, about the upright apes that gave rise to us all, was the jumping-off point for her book *The First Human: The Race to Discover Our Earliest Ancestors.*

Her story "Why 536 Was the Worst Year to Be Alive" arose as she sat over dinner and beer with sources at a conference. Talk turned to how terrible life was at certain times in the past, and both scholars named 536 CE as the very worst year. That was a year without a summer, when crops failed from Ireland to China. One researcher was part of a team tracing the year's cold climate to a volcano in Iceland.

Immediately recognizing the power of this result, Ann attended a symposium at Harvard where the scientists announced their findings. She was the only reporter there. Her story reveals how a new method allowed geoscientists to analyze elements in an ice core with astonishing precision, tracking storms and volcanoes to within a month or less. As Ann wrote, the ice core illuminates "a dark hour in what used to be called the Dark Ages." Her reporting does that too: She shines a light on the murky chapters of our history to help us understand the challenges of today.

—Elizabeth Culotta, *Science* Magazine, Washington, D.C.

Response

I am greatly honored to receive the David Perlman Award, which was named for the renowned science writer and editor at the *San Francisco Chronicle* who inspired so many of us to be science writers. I was an undergraduate at the University of California, Berkeley when I heard David give an inspiring talk about what it was like to be a science writer. I was always torn between studying science and writing, and Perlman was one of the first people who showed me a path to do both—and to make a living at it.

I also want to thank my longtime editors at *Science,* Elizabeth Culotta and Tim Appenzeller, who have given me the encouragement and resources to follow leads and to travel around the world to report on some of the most exciting topics in evolution. This story came out of a dinner conversation at a meeting in Germany where I had the time to muse over a beer with scientists about the worst time to have been alive. I thank all the researchers involved with the Initiative for the Science of the Human Past at Harvard and the Climate Change Institute at the University of Maine for inviting me to their closed workshop and accommodating my many inquiries for this story.

I think one of the most intriguing parts of being a science writer is to try to bring alive key events in the past—to show how humans evolved in response to natural disasters and changes in the climate or their habitats. The most important story of our time may well be to show how climate change has shaped us, for better or for worse—and how interconnected we are with the planet's cycles. Our ancestors had to adapt to changes in the atmosphere, weather, climate, and their habitats over millions of years. But now, in addition to having to adapt to the planet's natural cycles and sudden disasters, humans have to grapple with the rapid-fire effects of our own pollution and climate forcing. In my opinion, it is increasingly urgent for writers to show what scientists are learning from the past about how paleoclimate and pollution can affect life on the ground for real people and other creatures who inhabit the Earth. Plus, these are great human stories to tell, full of drama, heroism, and tragedy.

I also want to thank my husband, Bill Scherlis, and my children, Lily, Sophia, and Tom, for their support, ongoing interest in my work, and tolerating my long absences to distant places when I was traveling with researchers, often off the grid. Finally, I want to thank AGU for this award. It is the best type of encouragement.

—Ann Gibbons, *Science* Magazine, Washington, D.C.

Beth N. Orcutt Receives 2019 Asahiko Taira International Scientific Ocean Drilling Research Prize

Beth N. Orcutt was awarded the 2019 Asahiko Taira International Scientific Ocean Drilling Research Prize at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The prize is given "for outstanding transdisciplinary research accomplishment in ocean drilling."

Beth N. Orcutt

Citation

Beth N. Orcutt has made transdisciplinary contributions to microbiology and biogeochemistry in the deep oceanic subsurface through the International Ocean Discovery Program (IODP). She has made these advances largely through her research in ocean drilling, and she has also performed leadership roles in IODP, including serving on the Science Evaluation Panel and being chief scientist of expeditions.

In 2011, Orcutt used IODP-dilled boreholes to demonstrate colonization of native rock–hosted communities on mineral surfaces. This work opened up the basalt basement to direct microbial observation. From IODP Expedition 336 to North Pond, Orcutt showed oxygen consumption rates in subseafloor basalt-hosted ecosystems, using reaction-transport models of high-resolution oxygen concentration profiles to show that 1 nanomole of oxygen is consumed per cubic centimeter of rock per day in ~8-million-year-old basaltic crust. This was a major advance on previous work demonstrating widespread aerobic activity in subseafloor basalt.

From IODP Expedition 327 to the Juan de Fuca Ridge flank, Orcutt's group demonstrated the microbial connections between deeply buried subseafloor basalts and the surrounding sediments. They showed that sedimentary communities are stimulated by fluids coming out of the basalts, but the microbial community composition is not changed by the presence of different kinds of basalts. From the observatories installed on this same expedition, Orcutt's group used genomic techniques to determine the environmental role of one of the most enigmatic members of subseafloor basalt communities: the Hydrothermarchaeota. No microbial isolate has ever been obtained from this group, but it appears to be widespread among deep subseafloor ecosystems. Orcutt's lab demonstrated for the first time that this group of organisms likely uses carbon monoxide as a respiration substrate, allowing it to be somewhat decoupled from pure heterotrophy, achieving a C1 compound–supported lifestyle.

Orcutt is also an innovator in the methods used in scientific drilling. She has evaluated the suitability of construction materials for IODP boreholes and developed flow-through Osmo colonization experiments that enhance the quality of scientific experiments that can be performed with IODP-drilled boreholes. These findings set important boundaries on the extent of influence of subseafloor basalt communities and have enabled discoveries by other researchers as well. By continually being open and courageous with new methods, fieldwork, and data interpretation, Orcutt has made truly great breakthroughs that have made her a highly respected member of the scientific drilling community.

—Karen Lloyd, University of Tennessee, Knoxville

Response

I am deeply honored to receive the Asahiko Taira Prize for my involvement with the international scientific ocean drilling programs. Dr. Taira inspires me with his commitment to scientific progress and international collaboration, and I hope to live up to his leadership example within the AGU and IODP communities. I am also indebted to Karen Lloyd for her generous citation and unflagging support.

My interest in ocean drilling science was sparked during my undergraduate studies by reading papers on curious methane patterns in marine sediments. With the incredible support of Mandy Joye at the University of Georgia and Antje Boetius and Kai-Uwe Hinrichs in Bremen, Germany, I had the opportunity to delve into studying sediment hydrocarbon cycling during my Ph.D. research. These experiences opened my eyes to the possibilities for international collaborative research within the ocean drilling program and also inspired a peculiar passion for working with increasingly more difficult and low-biomass samples.

My immersion into the drilling program began in earnest under the leadership of Katrina Edwards at the University of Southern California, who supported me as a postdoc to design experiments to study microbe–mineral interactions in oceanic crust. This experience was foundational for my involvement in IODP Expeditions 327 and 336 specifically and for my career in general. Katrina's unapologetic enthusiasm for achieving aspirational scientific goals was infectious and unmatched. I am thankful for the lessons I learned from her and miss her dearly.

Through the doors that Katrina opened, I had opportunities to get involved with borehole observatory research, with the unendingly generous support of colleagues Keir Becker, Andrew Fisher, and

Geoff Wheat. I am indebted to Bo Barker Jørgensen for allowing me to pursue these efforts during my second postdoc, to Graham Shimmield for his encouragement to continue my interests as I started my own laboratory, to Gretchen Früh-Green for inspiring me to take on more leadership roles, and to Jan Amend, Julie Huber, and the entire Center for Dark Energy Biosphere Investigations community for making deep biosphere research so fun. Ocean drilling and observatory science are truly collaborative efforts, and I am grateful to all of the scientific teams and partners I have had the honor of working with and learning from.

—**Beth N. Orcutt,** Bigelow Laboratory for Ocean Sciences, East Boothbay, Maine

J. Marshall Shepherd Receives 2019 Climate Communication Prize

J. Marshall Shepherd was awarded the 2019 Climate Communication Prize at the AGU Fall Meeting Honors Ceremony, held on 11 December 2019 in San Francisco, Calif. The prize recognizes an individual "for the communication of climate science."

J. Marshall Shepherd

Citation

Marshall Shepherd is one of the most seasoned, most versatile, most dedicated, and most impactful climate communicators of our time. He effortlessly weaves his mastery of climate science with heartfelt care for all people, a finely honed moral compass, and a true passion for climate communication. As a decorated scholar in the atmospheric sciences, his dedication to effective communication is particularly noteworthy and makes him a treasured role model for many scientists who seek to incorporate a focus on public engagement into their careers.

It is hard to know where to begin in extolling the breadth and depth of Marshall's climate communication skill set. Broadcast TV—check. Popular science writing—check. Social media guru—check. Kid's weather book—check. TED (Technology, Entertainment, and Design) sensation—check. Yet for all these external markers of unbridled success, he is one of the most unassuming, tempered, and resoundingly clear voices speaking about the science of climate change and the important choices we face as a society. Whereas most climate scientists struggle through on-camera appearances, Marshall's talents are on full display during his frequent TV appearances. Through countless appearances on CNN, ABC, NBC, and Fox, he displays a knack for the sound bite while staying true to the science. To watch a single interview by Marshall is to watch a master class in climate communication. Another area of climate communication worthy of particular mention is Marshall's Twitter account (>44,000 followers at present), which is a stroll through the day-to-day reactions and thoughts of a meteorologist and climate scientist, only lightly edited. His approach makes him a trusted source to many—personable, accessible, and always respectful.

Many know Marshall as the smooth-talking meteorologist on the Weather Channel or the must-follow climate science account on Twitter or the insightful, funny, and humble TED speaker. And he is all those things. But what most don't see is that Marshall is deeply woven into the fabric of communities across Atlanta through a dizzying array of smaller appearances that escape the public eye. He is ever present in K–12 classrooms, science fairs, rotary clubs, and the like—wherever the public is in need of an honest, fact-based, but respectful conversation about climate science. In doing so, he doesn't shy away from raising awareness about the hurdles that members of underrepresented groups still face in science and society.

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

Response

It is with great honor and a sense of humility that I accept this tremendous honor. As I gaze at the names preceding mine on this prize, it reminds me that mentorship and inspiration are as important as the work that we do as scientists. I have been intrigued by the atmosphere since sixth grade. When I boldly declared that I wanted to be a meteorologist in elementary school, it was always with the intent of learning and understanding how our weather and climate system worked.

Through my experiences at Florida State University, NASA, and the University of Georgia, I have been able to teach, research, and share knowledge about processes that affect our water supply, food systems, national security, public health, and general well-being. Climate change represents a singular grand challenge of our time. If experts are not engaging with the public, policy makers, and stakeholders, then people with misinformation are happy to fill the void left behind by scientists. For this reason, I engage. I will continue to engage on behalf of my kids, personal family, and the collective family of humanity.

I want to thank my wife and kids for their partnership in my journey to do what I am blessed and called to do. I want to thank my mother, teachers, professors, colleagues, and even those that challenge the consensus basis of science. Each group aforementioned shapes and challenges me to be a better scientist and communicator. Thank you to AGU, my nominator, and the letter writers for seeing something in me worthy of this prize.

—**J. Marshall Shepherd,** University of Georgia, Athens

Where Does the Carbon Go When Permafrost Coasts Erode?

Researchers walk near an eroding shoreline on the southeastern side of Qikiqtaruk (Herschel Island) off the coast of Yukon, Canada. Credit: George Tanski

The Arctic is warming faster than almost anywhere else on Earth. As a result, the region is changing rapidly: Glaciers are melting, sea ice is disappearing, and permafrost is thawing, which could accelerate climate change. The northern permafrost region covers roughly a quarter of the land in the Northern Hemisphere and stores vast amounts of carbon—more than double the amount in the atmosphere today—much of it still locked away, frozen. Researchers have known for some time that permafrost could become a major source of greenhouse gases as the soil thaws and once-dormant microbes wake up and break down organic matter.

This thaw is accelerated in places along Arctic coasts, where permafrost is eroding into the sea. As sea ice–free conditions in the Arctic expand, cliffs and shorelines are exposed to storms and wave action for longer periods, accelerating erosion.

The Arctic's permafrost coastlines, which make up more than a third of Earth's coasts, are eroding at an average rate of roughly half a meter per year, though in some spots the rate tops 20 meters per year. Little is known, however, about the fate of the organic carbon in eroded permafrost as it enters the ocean. Climate models assume that it is consumed in primary production or buried offshore. But a new study by *Tanski et al.* suggests that a substantial portion is vented back into the atmosphere as carbon dioxide or other greenhouse gases.

Researchers quantified carbon release from eroding Arctic permafrost by simulating permafrost-seawater mixing in a laboratory, using permafrost and seawater collected from Qikiqtaruk (Herschel Island) just off the Canadian Yukon coast.

Permafrost samples were mixed with seawater for 4 months—the length of the average, open-water season in the Arctic—at 4°C to mimic real-world conditions and at 16°C to study the impact of warming temperatures. The team measured carbon dioxide and methane emissions under aerobic conditions, as well as the total and dissolved organic carbon, stable carbon isotopes, and the ratio of organic carbon to nitrogen, before and after the 4-month period to estimate carbon turnover.

The researchers found, depending on the depth from which permafrost samples were taken and the temperature at which they were incubated, that between about 1% and 13% of the initial total organic carbon in the samples was released as carbon dioxide. Most of this release occurred in the first 2 months after mixing, with production rates peaking after 11 days.

The authors noted that their laboratory setup did not account for some environmental conditions—varying pH and nearshore currents, for example—that could influence permafrost carbon release from eroding Arctic coasts. Still, the study shows that eroding Arctic coastal permafrost can emit substantial amounts of greenhouse gases—as much as 0.9 teragram of carbon dioxide per year from the entire Arctic coastline based on a rough extrapolation of the team's localized findings—which are currently unaccounted for in climate models, according to the authors.

Carbon cycle models assume that Arctic coasts and continental shelves are carbon sinks. As temperatures continue rising and the open-water season in the Arctic lengthens, accounting for coastal permafrost erosion will be critical in balancing the Arctic's carbon budget. (*Geophysical Research Letters*, https://doi.org/10.1029/2019GL084303, 2019)

—Kate Wheeling, *Science Writer*

Fault Dips Figured in Kīlauea's Caldera Collapse

An explosion from Kīlauea volcano's summit sends an ash plume into the sky on 27 May 2018. This and other explosions occurred as the volcanic caldera collapsed, adding pressure to the magma chamber below. Credit: U.S. Geological Survey Hawaiian Volcano Observatory photo by K. Anderson

In the spring and summer of 2018, Kīlauea volcano on the island of Hawaii erupted from its lower East Rift Zone. As the eruption progressed, the underground magma chamber beneath the summit caldera evacuated and could no longer support the ground above, leading to collapse at the surface. In total, Kīlauea caldera sank 500 meters over the course of the roughly 3-month eruption. The collapse occurred in 62 roughly periodic events of up to 8 meters each. Some of the early events were accompanied by explosions that sent plumes nearly 10 kilometers into the atmosphere.

Understanding the physics at play in these dramatic events is a challenge for scientists, but the Kīlauea eruption provided researchers with the best look yet at how caldera collapses occur, thanks to an array of GPS sensors, tiltmeters, and satellite- and drone-based sensors. *Segall et al.* used ground deformation measurements from these various sensors to create a simplified model of caldera collapse that they believe can explain several surprising features observed in the Kīlauea eruption.

One thing that initially puzzled researchers about the eruption was GPS and tilt data from the volcano's surface that showed that the ash-charged eruptions were associated with sudden upward and outward ground movements. Such motion, known as inflationary deformation, usually occurs with an increase of magma pressure below the surface. Sudden inflations have been observed in other caldera collapses but are not well understood. Inflation associated with explosions at Kīlauea was surprising, as eruptions normally cause magma pressure to decrease. Between collapse events, however, the volcano's summit showed subsiding and deflating behavior more in agreement with expectations.

To better understand what might have been happening inside the volcano during eruptions, the researchers created a mathematical model of the system in which faults intersect the magma chamber. When the model was run under the assumption that the faults in the volcano system were vertical or inward dipping (normal), it replicated several key features of the collapses, including both the inflationary and deflationary deformation modes. However, in the case of outward dipping (reverse) faults, the model did not match observations, leading the researchers to conclude that the Kīlauea collapse resulted from inward dipping or vertical faults.

Collapse events in caldera volcanoes are ultimately what keep eruptions going: As the caldera floor sinks, it applies pressure to the magma chamber, pushing more magma toward the surface. Piecing together what happens belowground in these systems should help scientists predict eruptive behavior during future eruptions. (*Geophysical Research Letters,* https://doi.org/10.1029/2019GL084689, 2019) **—David Shultz,** *Science Writer*

Anaerobic Activity Is a Big Contributor in Marine Dead Zones

Certain parts of Earth's oceans are so oxygen depleted that they can hardly sustain life. Climate models predict that these dead zones will expand as global warming progresses, affecting ecosystems, fisheries, and the climate itself. Now *Lengger et al.* provide new evidence that such predictions do not adequately account for the activity of anaerobic microbes that consume inorganic carbon within dead zones.

Dead zones form where photosynthetic algae rapidly flourish in surface waters. As vast numbers of algae die and sink through the water column, aerobic microbes break them down, consuming nearly all available oxygen in the process. With little oxygen left in deeper waters, microbes are unable to completely decompose much of the sinking organic matter before it settles on the seafloor.

The amount of organic matter in dead zone sediments can inform predictions of climate models, which usually assume that all this matter initially came from algae. However, in recent years, evidence has emerged that some of the organic matter in these sediments is instead produced by anaerobic microbes that eat dissolved carbon dioxide in oxygen-depleted waters.

To better understand this process, the authors studied microbes in the Arabian Sea, home to the largest dead zone in the world. They used the R/V *Pelagia* to collect sediment cores in the dead zone and conducted an isotopic analysis to investigate the origins of the organic matter in the cores.

The analysis revealed that anaerobic microbes could be responsible for one fifth of the organic matter found in seafloor sediments of the Arabian Sea dead zone. Climate models that do not account for the influence of such microbes may underestimate the extent to which dead zones will expand as global temperatures rise.

In this investigation, the researchers developed a new strategy for evaluating anaerobic consumption of inorganic carbon in deep waters. The method, which relies on detecting a distinct chemical signature of the microbes known as the bacteriohopanetetrol stereoisomer, could aid future investigations of dead zones around the world. (*Global Biogeochemical Cycles,* https://doi.org/10.1029/2019GB006282, 2019) **—Sarah Stanley,** *Science Writer*

Atmospheric Drag Alters Satellite Orbits

Earth's thermosphere extends between about 90 and 600 kilometers above the planet's surface and is where much human space activity occurs—the International Space Station usually orbits at an altitude of 400 kilometers, for example. Variations in atmospheric mass density subject satellites orbiting in the thermosphere to a drag force that decays satellite orbits and can even reduce their life spans. Imperfect modeling of this force leads to uncertainties in orbital predictions that create challenges for operators as they attempt to maintain orbits and avoid collisions among satellites.

Despite these concerns, the influences of variations in atmospheric density on orbiters remain poorly understood. *He et al.* use the Drag Temperature Model and the Thermosphere-Ionosphere-Electrodynamics General Circulation Model to investigate effects in time and space of atmospheric density variations on a circular orbit at 400-kilometer altitude. The researchers also looked at two smaller-scale variations: the equatorial mass anomaly (EMA), which describes a local dip in density at the planet's geomagnetic equator, and the midnight mass density maximum (MDM), which describes the tendency for atmospheric density to increase at the geographic equator after midnight.

Most notable, the authors show that the effects of atmospheric density are closely tied to the 11-year solar cycle. During periods of high solar activity, modeled orbits were altered by an order of magnitude more than during periods of low solar activity. For instance, when solar activity was high, the EMA could alter the daily orbit of a satellite by as much as 50 meters; when activity was low, the change was only 5 meters. The same pattern held true for variations at 8-hour, 12-hour, 1-day, 6-month, and 1-year timescales.

Across the timescales studied, semiannual variations had the largest effect on modeled orbits, altering them by as much as 800 meters during high solar activity, compared with 300 meters for annual variations.

The International Space Station orbits through the thermosphere in May 2010. Credit: NASA

Semidiurnal variations were similarly larger than diurnal ones, with orbits changing during high solar activity by as much as 100 and 50 meters, respectively. The team found that the MDM had a stronger influence than the EMA, shifting orbits by a maximum of 150 meters during high solar activity.

As more orbiters, including multisatellite constellations, are sent into low Earth orbit in the coming years, results like these may become invaluable for planning avoidance maneuvers, estimating mission longevities, and predicting satellite reentries. (*Space Weather,* https://doi.org/10.1029/2019SW002336, 2020) **—David Shultz,** *Science Writer*

Ordinary Security Cameras Could Keep an Eye on Rainfall

The same security cameras used on seemingly every busy city block could also capture instantaneous measurements of rainfall intensity: the depth of rain that falls over a given time period. Developed by *Jiang et al.*, this low-cost approach could help inform flood warnings, climate change research, water resource management, and other hydrologic pursuits.

Rain gauges traditionally provide intensity measurements but are often too sparsely spaced for high-resolution data, especially in topographically varied areas like cities. Remote sensing methods such as weather radar are too "big picture" and too indirect to aid real-time flood warnings. Instruments called disdrometers capture instantaneous rainfall intensity but are too pricey for widespread use.

The new, alternative strategy uses "opportunistic sensing," in which novel insights are gleaned from unrelated sources. Recognizing the ubiquity of closed-circuit television (CCTV) cameras, the researchers developed an algorithm that separates a CCTV video still into one layer capturing the streaky shapes of falling raindrops and another layer of the raindrop-free background. Image analysis then reveals instantaneous rainfall intensity.

The researchers tested their new raindrop identification algorithm in a series of virtual analyses. They found that it outperforms previously developed algorithms in separating raindrops from backgrounds with visual disturbances, such as moving cars and swaying trees.

They also tested their overall approach to rainfall intensity measurement in real-world settings during five different rainfall events and found that the approach has satisfactory accuracy over widely varying rainfall intensities. It also has a lower error rate than other camera-based strategies, despite its reliance on lower-quality cameras and testing with real-world scenes that are more complex.

The new approach highlights the possibility of using existing CCTV networks to opportunistically measure rainfall intensity at high resolution and low cost. Such observations could help researchers validate climate models and improve understanding of floods caused by intense storms, especially in urban settings.

The authors suggest several paths for future research, including fine-tuning the raindrop identification algorithm to capture a wider range of raindrop phenomena, such as splashing. Application of artificial intelligence techniques could also enhance the new approach. The research team is now working with the local meteorological department to implement this technology in Shenzhen, China's "tech megacity." (*Water Resources Research*, https://doi.org/10.1029/2018WR024480, 2019) **—Sarah Stanley,** *Science Writer*

Previous Research Has Underestimated Black Carbon Emissions

Aerosols are tiny particles suspended in the atmosphere that play a crucial role in regulating Earth's radiation balance. Although the majority of aerosols create a net cooling effect by scattering incoming sunlight, some are capable of heating the atmosphere by absorbing this light instead. Previous studies have primarily attributed this effect to black carbon, a substance produced when carbon-based materials such as biofuels and fossil fuels don't fully combust. Because black carbon contributes to atmospheric warming, understanding its historical emissions is critical for separating anthropogenic influences from natural climate variability in numerical simulations.

Although researchers have developed several historical inventories of black carbon emissions, discrepancies still exist between these estimates and long-term ambient air observations. To help resolve these disparities, *Sun et al.* identify several poorly estimated sources of black carbon emissions and use these findings to update the U.S. inventory from 1960 to 2000.

The results indicate that previous studies have underestimated black carbon emissions in the United States. In particular, the researchers determined that the emissions from several key sources, including pre-1980 residential boilers and heating stoves, specific off-road engines, and heavy-duty diesel and light-duty gasoline-powered vehicles assembled prior to 1970, should be increased significantly.

New constraints on the production of black carbon particulates, which absorb heat as they circulate around the globe, indicate U.S. emissions may have been significantly higher during the late 20th century than previous studies have estimated. Credit: NASA's Scientific Visualization Studio

The authors' revisions, which also take other potential sources of discrepancy into account, offer a very different picture of black carbon emissions compared to earlier inventories. Between 1960 and 1980, the updated U.S. emissions are 80% higher than previous estimates, totaling approximately 690 gigagrams per year in 1960 and 620 gigagrams per year a decade later. The revised inventory also exhibits a decreasing trend through 1980 that is not apparent in earlier reports.

By providing the first observational constraints on black carbon emissions in the United States, this study offers a credible analysis of the reasons these emissions have been previously underestimated. The far-reaching results suggest that modeling simulations based on earlier emission estimates, and potentially the inventories of other combustion by-products, will need to be reevaluated. (*Journal of Geophysical Research: Atmospheres*, https://doi.org/10.1029/2018JD030201, 2019) **—Terri Cook,** *Science Writer*

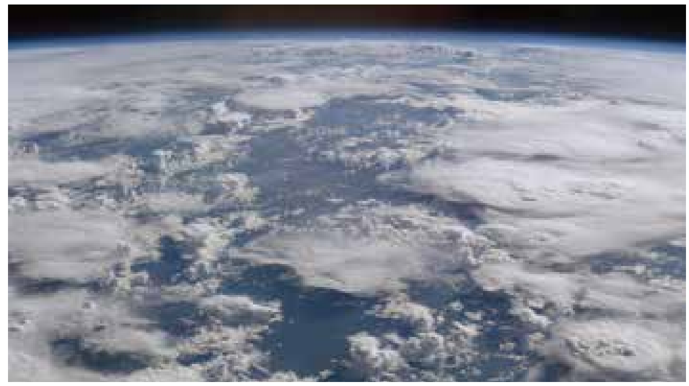
The Tropical Atmosphere's Balancing Act

Earth's balmy, relatively stable temperature relies on a complex balancing act. Much of the Sun's heat is lost to space through radiation emitted by Earth, a process called radiative cooling. Simultaneously, however, the atmosphere is warmed when water vapor condenses into droplets, releasing energy, and currents of air transfer heat from Earth's surface into the atmosphere.

For decades, scientists attempting to simulate Earth's climate have known that the global atmosphere as a whole maintains an idealized state called radiative-convective equilibrium (RCE), in which energy lost through radiation is balanced by heat released through the condensation of water vapor and the direct transfer of heat from the surface. When researchers observe Earth's atmosphere at smaller scales, however, it is often out of equilibrium, raising concerns about whether RCE exists at local levels.

A new study by *Jakob et al.* identifies the scale at which RCE breaks down in the tropical atmosphere—an area of around 1 million square kilometers. The team used several data sets to test whether RCE is present at different scales, including satellite observations of radiative cooling and convection, precipitation records, and images of clouds collected between 2001 and 2009.

As a whole, the tropical atmosphere remained close to RCE over the 9-year period, the analysis reveals. Clouds played a key role in maintaining RCE, which occurs frequently in areas 5,000 × 5,000 square kilometers or larger. It occurs most often when low clouds are widespread and there are a few convection hot spots, places where hot, moist air rapidly ascends and produces large amounts of rainfall. The two areas are connected through atmospheric circulation, which in turn provides the conditions for the different cloud types to exist.



Clouds like these over South America play a key role in maintaining radiative–convective equilibrium. Credit: NASA

RCE occurred less than 20% of the time in regions of the atmosphere smaller than 1,000 × 1,000 square kilometers, the team found. Many computer models used to study clouds focus on RCE for areas smaller than this scale when the real atmosphere is not likely to be in equilibrium. The finding could improve scientists' understanding of the interaction of clouds and circulation, a complex and poorly understood factor in climate change. (*Journal of Geophysical Research: Atmospheres*, https://doi.org/10.1029/2018JD030092, 2019) **—Emily Underwood,** *Science Writer*

Oceans Vented Carbon Dioxide During the Last Deglaciation

Researchers studied boron isotope records from marine sediment samples to reconstruct the history of ocean–atmosphere carbon dioxide exchange during the late Pleistocene and early Holocene. Credit: Rena Olson, CC BY-NC-SA 2.0 (bit.ly/ccbyncsa2-0)

During the late Pleistocene epoch, ice sheets advanced and retreated in tandem with changing atmospheric carbon dioxide levels. Researchers have long sought to understand the complex processes that modulate rising and falling carbon dioxide concentrations—a line of research with important implications today as levels reach highs not seen since roughly 3 million years ago in the Pliocene, when the Arctic was forested.

The world's oceans are a major carbon sink today, collectively absorbing as much as a third of the carbon dioxide humans have pumped into the atmosphere since the Industrial Revolution. In a new study, *Shao et al.* further constrain the role of oceans in driving atmospheric carbon levels during the glacial cycles of the late Pleistocene.

The work builds on previous research that used boron isotope records as a proxy for ocean surface chemistry, which gives scientists insights into the exchange of carbon dioxide between the sea surface and the atmosphere. Researchers have measured boron isotopes extracted from planktonic animals locked in marine sediment cores to reconstruct oceanic pH in the tropical and North Pacific, the Indian, and the Atlantic Oceans, but data from the southwestern Pacific, a major carbon sink today, were lacking.

To address this, the authors analyzed boron isotopes from specimens of the planktonic foraminifera *Globigerina bulloides* found in two sediment core samples collected from Chatham Rise off the east coast of New Zealand to obtain a boron isotope–based pH reconstruction for the area. The cores provided a record of oceanic conditions dating back at least 25,000 years, to the late Pleistocene. The team found that pH was about 8.2 during the Last Glacial Maximum, when ice sheets covered most of North America, Europe, and Asia. The pH then fell between 16,500 and 14,000 years ago before rising again to 8.1 at the end of the Pleistocene and into the early Holocene. The results indicate that this region of the South Pacific was venting carbon dioxide as the ice sheets were retreating. The team noted that similar results have been obtained from the South Atlantic, suggesting that both the South Pacific and the South Atlantic Oceans were carbon sources, not sinks, during the last deglaciation.

The authors integrated their results with previously published boron isotope records from around the globe to create a more complete picture of carbon dioxide exchange over the past 25,000 years. They found widespread outgassing of carbon dioxide, particularly during the last deglaciation, which could be explained by an increase in upwelling of the gas from the deep ocean, according to the authors. The result is intriguing, they say, as none of the records in the data set are from the high-latitude Southern Ocean, where most carbon from the deep ocean first contacts the atmosphere. However, the researchers also note that the sites sampled may be biased toward upwelling regions.

The study fills an important gap in boron isotope–based reconstructions of the ocean-atmosphere carbon dioxide exchange throughout the last deglaciation. A better understanding of this exchange in the past could provide insights about impacts that rising atmospheric carbon dioxide levels will have on climate today. (*Paleoceanography and Paleoclimatology,* https://doi.org/10.1029/2018PA003498, 2019) **—Kate Wheeling,** *Science Writer*

Skywatchers Spy Rippling Waves in the Northern Lights

Finding new forms of Earth's aurora—the colorful light display resulting when charged particles from the Sun interact with the magnetosphere—is rare. However, with improved digital photography and communications, researchers and citizen scientists have recently collaborated in making new discoveries, including last year when STEVE, a pinkish optical emission produced by subauroral ion drifts, was revealed.

Now *Palmroth et al.* have identified a new type of emission. Citizen scientists recorded the sight at multiple locations in Scandinavia in digital photographs near the 2018 fall equinox. These fluorescent ripples in the atmosphere, here named dunes due to their rolling shape, recur every 45 kilometers at a height of around 100 kilometers.

The researchers developed a parallax-based method to show that the emissions are indeed an atmospheric phenomenon, perhaps related to previously detected atmospheric phenomena at lower latitudes. After their original discovery, researchers and citizen scientists organized a coordinated campaign to confirm and quantitatively analyze the previous sightings. (*AGU Advances*, https://doi.org/10.1029/2019AV000133) **—Mary Hudson**

Optical dunes—numbered ripples—captured by digital photography on 7 October 2018 at 17:40:59 UT in Latilla, Finland. The field of view is toward the northwest, and the dunes are numbered with magenta circles. They extend equatorward toward the zenith, away from the bright arc appearing below them in the photograph, which is due to electrons striking the atmosphere to the north. Credit: Palmroth et al., 2020, https://doi.org/10.1029/2019AV000133

Slow Slip By Any Other Name

Much like the parable about blind men each characterizing an elephant by feeling different parts, we have identified different ways that faults can slip slowly by using different observation techniques. At the surface, this is known as fault creep. Immediately after an earthquake, this is known as postseismic slip, or afterslip. In the interval between earthquakes, geodetic networks capture episodic slow slip events classified by varying size, duration, and magnitude.

In a commentary, *Jolivet and Frank* suggest that these different classifications are artifacts from how and when they were discovered. They instead point out that there is no evidence for different physical causes of slow slip. They note that, much like their more obvious earthquake cousins, the slow slip events we observe happen on all temporal and spatial scales and are part of the same intermittent, clustered process. (*AGU Advances*, https://doi.org/10.1029/2019AV000126) **—Tom Parsons**

Why Does Ocean Warming Pattern Matter?

Uneven ocean surface warming under nearly uniform greenhouse gas forcing is one of the most fundamental and intriguing questions in climate dynamics. Recently, researchers have recognized the effect on the global mean warming and hence on climate sensitivity.

Xie reviews the key features of ocean warming patterns and their formation mechanisms and discusses their implications for radiative feedback and climate sensitivity. One of the challenges is the inconsistency between the simulated and observed warming pattern in the tropical Pacific, confounding the estimation of climate sensitivity from observations.

Such a discrepancy highlights the need for communication between two seemingly distinct communities: those that study ocean-atmospheric dynamics that focus on spatial patterns and those that study climate sensitivity, where the original emphasis was on the planetary energy budget and radiative feedback. (*AGU Advances*, https://doi.org/10.1029/2019AV000130) **—Sarah Kang**

POSITIONS AVAILABLE

Atmospheric Sciences

Atmospheric Scientist, The Savannah River National Laboratory. The Savannah River National Laboratory is seeking versatile and highly motivated candidates to participate in the ongoing development of an Earth Systems Modeling program within SRNL's Atmospheric Technologies Group (ATG). The ATG conducts applied research aimed at improving atmospheric, surface water, and contaminant fate and transport modeling for customers in emergency response, national security, and international nuclear nonproliferation. Currently, the ATG is pursuing a strategic initiative to develop an earth systems modeling program focused on aerosol/cloud modeling and terrestrial carbon science.

The successful candidate will be expected to develop a research program in earth systems modeling with a focus in either 1) cloud/aerosol interactions (which may include the study of production and fate of biogenic aerosols in the southeast U. S.); or 2) terrestrial carbon cycling (which may include the study of carbon fluxes across different spatial scales and biodiverse landscapes in the southeast U. S.). Available modeling and instrumentation resources operated by SRNL and the ATG includes local High-Performance Computing clusters, a network of operational meteorological towers which includes carbon and moisture measurements from a 30m forest flux tower at SRS and a 330m Tall Tower near Beech Island, SC, a Scanning Particle Mobility Spectrometer, a WindCube LIDAR, a ceilometer, as well as a network of pyranometers and rain gauges. The successful applicant may also be expected to collaborate on projects conducted by other ATG scientists and engineers.

Qualifications: The applicant should possess a PhD in atmospheric science, meteorology, or other science or engineering discipline with at least 3 years experience related to one of the target areas of expertise. Familiarity with the DOE Office of Science's modeling and research initiatives is desirable; in particular, a candidate with experience using the E3SM model is preferred. The successful candidate must possess excellent written and oral communication skills, willing to present their work at professional conferences and government forums, and comfortable interacting with program managers from potential U. S. government sponsors.

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Ocean Sciences

Research developing Metrics of Transient Ocean Tracers and Water Mass Transformations. The Princeton University AOS program, in collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) and the Department of Energy's Program for Climate Model Diagnosis and Intercomparison (PCMDI), seek an energetic and enthusiastic postdoctoral or more senior scientist. A research position is available focused on process-oriented ocean studies using theory, modeling, and observations. The goal of this research is to develop metrics of transient tracer distributions and water mass transformations in ocean models and observations. Of particular interest is how these metrics can further elucidate pathways of ocean ventilation, heat, carbon uptake, and guide the development and improvement of global ocean and earth system models. Knowledge gained through understanding these processes will

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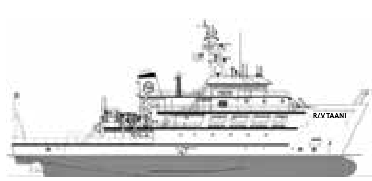

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Howdy, folks!

My name is Chris Spencer. I am a senior research fellow at Curtin University and am currently exploring the jungles of Ghana with Ph.D. student Janne Liebmann. We are in search of migmatite over 2 billion years old to evaluate the potential connection between the rise of atmospheric oxygen and changes in the chemistry of continental crust.

One of the challenges of finding outcrops in the jungle is, well, the jungle. But if you are willing to bushwhack for miles, you will be rewarded with not only an outcrop that can be sampled but also some very nice views. Lucky for us, the jungle provides some very nice fruits, and generous farmers are willing to let us partake of the few cacao pods left following their recent harvest.

—**Chris Spencer** (@travelinggeologist), Curtin University, Bentley, W. A., Australia

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