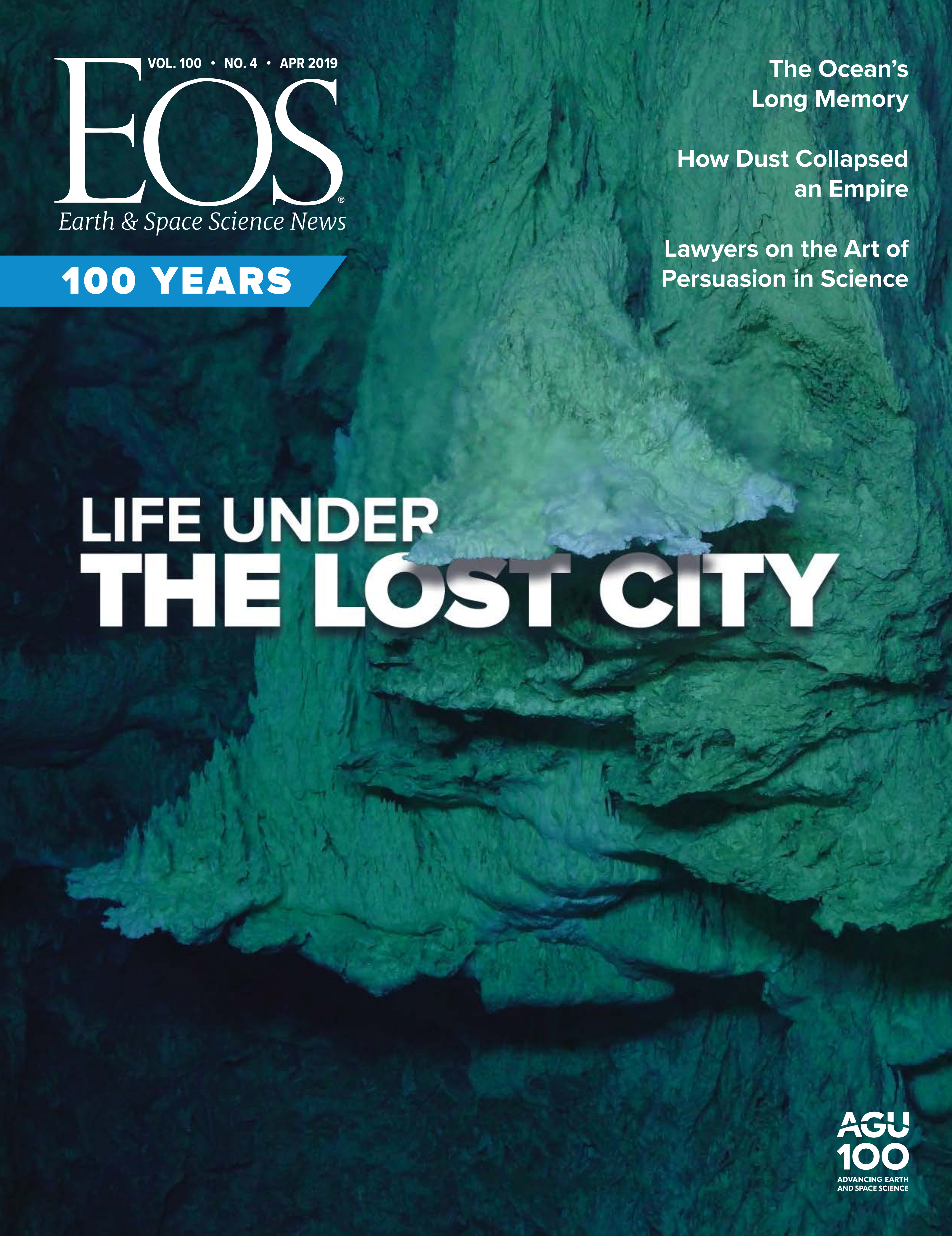

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EOS

Earth & Space Science News

100 YEARS

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How Dust Collapsed an Empire

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LIFE UNDER THE LOST CITY

AGU 100

ADVANCING EARTH AND SPACE SCIENCE

How Did We Get Here?

The shells of tiny ancient sea organisms hold the evidence that underpins one of the newest fields in the Earth sciences. In the 1950s, Cesare Emiliani at the University of Chicago was learning how to measure stable isotopes in invertebrates and use those data as a proxy to make conclusions about environmental factors. One day he turned that study to ancient foraminifera taken from sediments in the ocean floor. The oxygen isotopes he found in their shells told him that the ocean was once much warmer—that, in fact, the ocean changed over time. Paleoceanography was born.

In April, as AGU continues its Centennial celebrations, we're looking at this nascent but critical field, which has already proved so prolific it's expanded into two major components. AGU launched its *Paleoceanography* journal in 1986, and as it embraced the growth and evolution in the field, changed its name to *Paleoceanography and Paleoclimatology* last year. "We now use, in addition to fossils, a broad and growing range of stable isotope compositions, trace element concentrations and organic biomarkers in fossils and sediments as quantitative proxies for a growing number of environmental properties," wrote journal editor in chief Ellen Thomas when she announced the change in *Eos*. "In our present time of environmental change, it is, more than ever, important to use proxy data on Earth's past in order to evaluate Earth's future, thus making our past a key guide to our future."

Paleoclimatologists know better than anybody that understanding Earth's past is necessary for understanding what's happening to the climate today—and why the recent warming can't simply be explained by natural cycles. As a result, this young field has been uniquely shaped by the challenge and urgency of communicating its findings to the public. It's no surprise that a recent workshop for scientists to learn lessons in persuasive communication from lawyers was funded by the National Science Foundation (NSF) Paleoclimate Program (p. 18).

We know that however our society reacts to that information in the coming decades, the consequences will be reflected in our environment for a very long time. For this reason, one important topic of study right now is determining how much heat is stored in the oceans. A recent study used data collected by the HMS *Challenger* expedition, which launched in 1872, beginning the modern era of the study of oceanography. Comparing the temperature observations with those taken today shows that the Pacific Ocean is still cooling in response to the Little Ice Age during the 14th to 19th centuries. This direct evidence of the ocean's "long memory" means that modern climate models—most of which only use data from the beginning of the Industrial Revolution—need to incorporate ancient signals and that the effects from modern warming will be seen throughout the planet for a long, long time (p. 4).

Cesare Emiliani's revolutionary work continues today through programs such as the core drilling conducted aboard the *JOIDES Resolution* vessel and that of NSF's Paleo Perspectives on Climate Change, which is currently soliciting proposals that will provide data on Earth's past climate sensitivity to specific variables.

At AGU and *Eos*, we continue to support the work of and listen carefully to the information learned by paleoceanographers and paleoclimatologists because every time we learn more about our past, we learn a little bit more about our future.

Heather Goss, Editor in Chief

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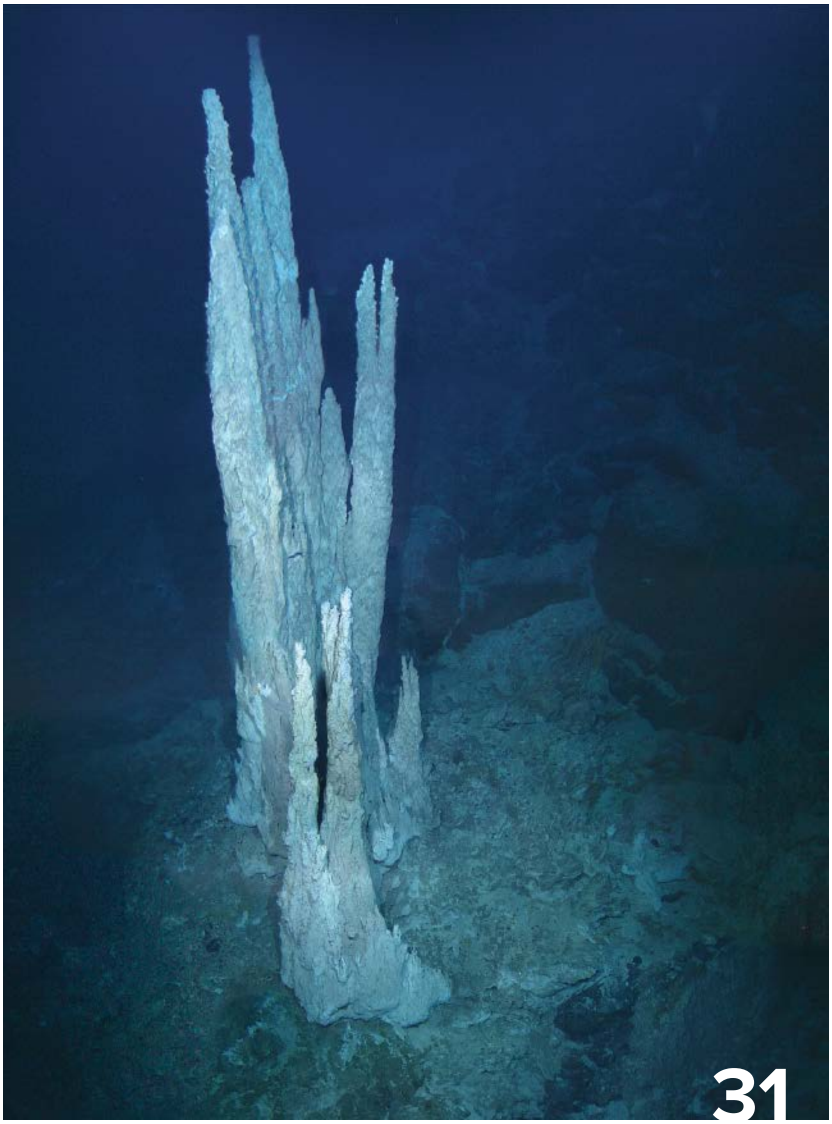
Christine W. McEntee, Executive Director/CEO



Cover Story

On the Cover

The carbonate chimneys that make up the "Lost City" in the Mid-Atlantic Ridge are the largest hydrothermal vent structures in the ocean.
Credit: Billy Brazelton/Return to the Lost City 2018 Expedition

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EOS CENTENNIAL COLLECTION

Scientists Discover Evidence of Long "Ocean Memory"

The world's first oceanography expedition, which set sail in 1872, is still uncovering new insights today.

In a study published in January in *Science,* researchers analyzed thousands of measurements from the HMS *Challenger* expedition, the scientific voyage that sailed around the globe from 1872 to 1876. The data revealed that the deep Pacific Ocean is still cooling from a dip in global temperatures that chilled surface waters several centuries ago.

Waters take so long to reach the depths of the Pacific that "they are still responding to the cooling trend that marked the entry into the Little Ice Age," said first author Jake Gebbie of the Woods Hole Oceanographic Institution in Woods Hole, Mass. The findings could improve climate models and may offer a clue into how future oceans will respond to modern global warming.

Data Taken by Hemp Rope

Understanding the ocean's history through past changes in climate can help scientists pinpoint just how much heat is stored in the oceans, a hot topic of current research.

Earth's climate cooled globally between the 14th and 19th centuries in what's known as the Little Ice Age, causing temperatures to dip roughly half a degree Celsius by some estimates. Past research has uncovered evidence of the Little Ice Age across the globe; it crops up in ice cores, tree rings, corals, sediments, and cave formations.

In the latest study, the researchers pulled data from the *Challenger* expedition, which "marks the beginning of modern oceanography," said Gebbie. The scientific expedition took top to bottom measurements from the world's oceans for 4 years, often using thermometers tied to hemp ropes. The new research compared the temperatures with modern-day measurements and ran an independent model using 2,000 years of climate records to search for cooling trends.

A Chilling Trend

Gebbie and his collaborators found a signal of cooling in the Pacific in both the measurements and the model. The model calculated that the Pacific deep waters have cooled by 0.02°C over the past century. The long-term trend in the data matches up "pretty closely" with what the model predicted, said Gebbie.

Taken together, the results reveal that the deep Pacific is still slowly being replaced by waters from the Little Ice Age, which are causing the deep to cool down. Although the decrease in temperature may not seem like much, Gebbie explained, "when you sum up that temperature change over such a big volume of the Pacific Ocean, it actually adds up to a lot of energy." The cooling trend is enough to offset one quarter of the heat gained in the surface of the ocean during the 20th century.

This offset is not enough to overwhelm the steadily increasing global warming signal in the surface ocean, he notes, but will help researchers better constrain how much heat has been taken up by the ocean.

Gebbie believes that the latest results could be helpful for climate modelers. "Most comprehensive climate models are started from equilibrium at some time near the beginning of the Industrial Revolution," Gebbie noted. "What this study shows is that there's still some influence from ancient signals that originated from the surface before the Industrial Revolution."

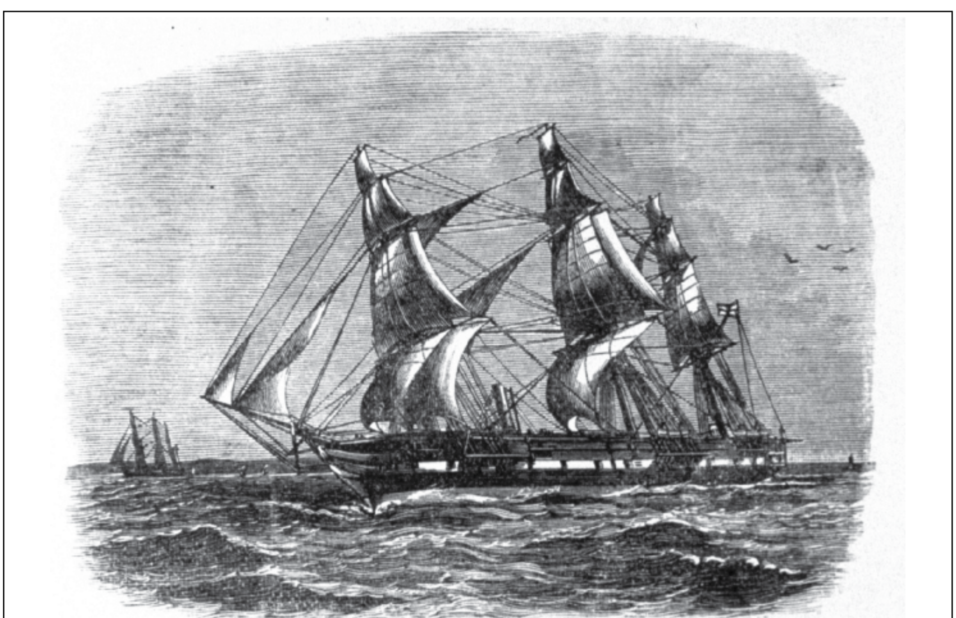
Ocean Memory

Timothy DeVries, an assistant professor at the University of California, Santa Barbara who was not involved in the study, said that these results are important because "it reminds us of the long memory of the ocean." Scientists who measure ocean temperature trends will "take note of these results" and begin scouring their field measurements for these signals, DeVries said.

"Long memory in the climate system is both a fascinating phenomenon and also a major difficulty in understanding the ocean state today," said Carl Wunsch of Harvard University, who is acknowledged in the paper. "This paper is, to my knowledge, the first one to document direct, plausible evidence that the deep ocean 'remembers' long-ago climate states."

The latest results hint at future consequences of present-day climate change. "The signal of modern warming will more quickly overwhelm the previous signals," Gebbie said. Once the present-day warming reaches the depths, he added, "it will take several hundred to even a thousand years for that signal to be removed."

"Whatever we're doing today at the surface will have consequences for a long time," Gebbie said.

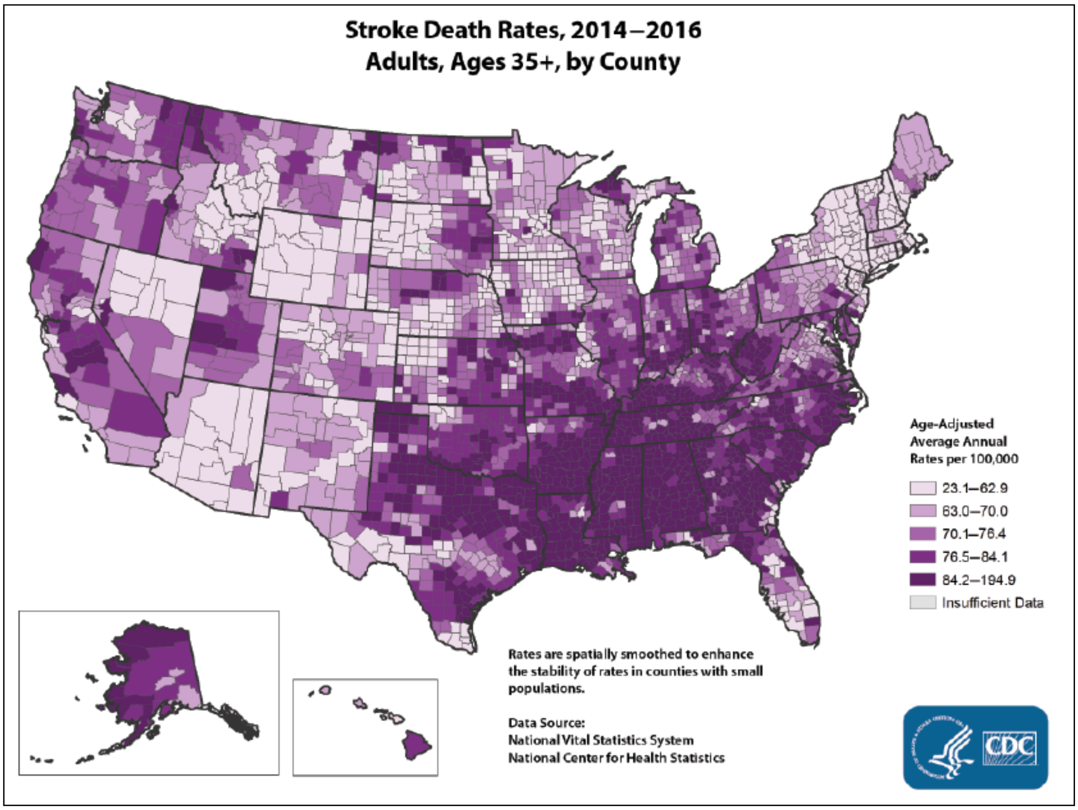


H.M.S. Challenger under Sail, 1874.

National Oceanic and Atmospheric Administration/Department of Commerce

By **Jenessa Duncombe** (@jrdscience), News Writing and Production Intern

Stroke Deaths Rise, Life Expectancy Falls with Polluted Air



This map shows the average rate of stroke deaths for adults in the United States from 2014 to 2016. The data are grouped by county and shaded darker purple in areas with higher rates of stroke deaths per 100,000 residents. The stroke belt spans the southeastern region of the country, roughly from eastern Texas to Virginia. Credit: U.S. Centers for Disease Control and Prevention

People living in regions with a high level of fine-grained air pollutants have shorter life expectancies and an increased rate of death from a stroke, according to new research. The study, which surveyed counties across the United States, also found a link between poor air quality and higher levels of poverty and reduced access to affordable healthcare.

In almost half of the areas surveyed "the annual average [pollution] was at a level considered acceptable. However, 51 percent of counties had an annual average exceeding" that limit, said Longjian Liu in a press release. Liu is a medical doctor and an associate professor of epidemiology and biostatistics at the Dornsife School of Public Health at Drexel University in Philadelphia, Pa. "To reduce the risk of stroke, clinicians should consider their patients' likely exposure to air pollution along with other risk factors," he said.

Liu presented these preliminary results in February at the International Stroke Conference in Honolulu, Hawaii.

The Stroke Belt

The researchers gathered air quality data from more than 1,550 U.S. counties from 2005 to 2010 from the U.S. Environmental Protection Agency (EPA). They focused on annual average levels of $PM_{2.5}$, a category of breathable particles around 30 times smaller than the width of a human hair. $PM_{2.5}$ is a main cause of hazy or smog-filled air, and past research has connected it with heart disease and respiratory illnesses. Liu's team found that 51% of the counties surveyed had annual average $PM_{2.5}$ levels that exceeded the EPA's air quality standard limit of 12 micrograms per cubic meter.

The team also gathered county data on stroke mortality, overall life expectancy, poverty rate, rural population percentage, and the number of primary care physicians per 1,000 residents from the U.S. Centers for Disease Control and Prevention. When they compared $PM_{2.5}$ levels with health and demographic data, the researchers found that higher annual levels of $PM_{2.5}$ were significantly correlated with both stroke mortality rate and life expectancy in men and women. Populations that breathe polluted air experience higher rates of death from strokes and have shorter life expectancies, the study concluded.

Poor air quality hit hardest in counties with a higher percentage of people living below the poverty line and counties with fewer physicians per capita. Those factors are markers for whether residents have ready access to an affordable health care provider who can treat the effects of air pollution, the researchers said.

When the team mapped out which regions experienced the strongest effects, it found that people living in southern states had the highest rates of stroke death and the lowest life expectancies due to high $PM_{2.5}$ levels, followed by those living in the Midwest, Northeast, and West. The intersection of poor air quality, lower income, and fewer doctors in southern states may help explain a phenomenon called the "stroke belt," an 11-state region where nearly 8.5 times as many people die from a stroke than in other areas of the United States.

Higher annual levels of $PM_{2.5}$ were significantly correlated with both stroke mortality rate and life expectancy in men and women.

Cars in rush hour highway traffic driving in hazy air. Credit: iStock.com/ssuaphoto

Pollution Elevates Personal Risk

"Places that are usually high in air pollution and other types of environmental risk are also associated with low socioeconomic status areas, unemployment,…access to medical care, and utilization of medical care," Daniel Lackland, a doctor of public health and a professor of epidemiology at the Medical University of South Carolina in Charleston, explained in a press release. Lackland, who was not involved with this research, added that these demographic variables exacerbate lifestyle factors that increase the stroke risk from air pollution.

What can a person who lives in the stroke belt do? "Knowing that I'm in a high-risk area," Lackland said, "and knowing that I'm at high risk personally, that [should] be even more of an emphasis that I need to develop a healthy lifestyle."

On the basis of this research, Liu's team suggests that primary care physicians begin to take air pollution into account when assessing patients who are at risk of a stroke. "Clinicians can then encourage at-risk patients to take measures to reduce their exposure when possible," Liu said. "Avoiding major roadways during rush hour traffic, keeping car windows closed, and setting the air conditioner to circulate internal air" are a few options Liu suggested. Changing a commute to work or avoiding congested and industrial areas completely, however, might not always be feasible for low-income individuals.

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

EOS CENTENNIAL COLLECTION

Ancient Arctic Ice Cover Undone by Warming

Glacier researchers Simon Pendleton and Gifford Miller collect ancient plants preserved beneath an ice cap on Baffin Island in Arctic Canada. Modern warming has caused the ice to retreat and expose the material preserved beneath. Credit: Matthew Kennedy, Earth Vision Institute

The melting of ice caps and glaciers in the Canadian Arctic has exposed plants that died tens of thousands of years ago. Radiocarbon dating of the plants and surrounding rocks has revealed when the ice first crept over the plants and preserved the landscape beneath.

"Glaciers are in some ways purely reactionary to climate: It warms, they shrink. It cools, they grow," Simon Pendleton told *Eos*. "The plant ages and the radiocarbon in the rocks tell us that they've likely had continuous ice cover for the last at least 40,000 years." Pendleton is a geoscientist at the Institute of Arctic and Alpine Research at the University of Colorado Boulder and the lead author on the paper that reported these results in *Nature Communications* in January (bit.ly/under-ice).

In addition, the researchers found that the plants and landscapes are exposed today because "the most recent century of warming that we have experienced was greater than [that of] any century in the past 115,000 years," Pendleton said.

"Glaciers are in some ways purely reactionary to climate."

Delicate Dead Plants

The researchers traveled to Baffin Island in Nunavut, Canada, in 2013, 2014, and 2015 to study dead plants and rocks at the edges of its ice caps and glaciers. Glaciers on high-elevation, low-relief terrain like Baffin Island are useful for paleoclimate studies because they adhere to the rock rather than sliding and eroding the surface.

"They actually preserve the landscape underneath to a really high degree," Pendleton said. When the ice cap retreats, "those plants come out from underneath the ice in the exact same position that they went under the ice thousands of years ago." The team collected dead plants—mostly fragile mosses and lichen—from the edges of 30 ice caps and glaciers on Baffin Island.

Radiocarbon Ages

The researchers determined the approximate year the plants died using radiocarbon measurements. "Radiocarbon dating in organic material is based on the idea that living organisms—plants, you, me, anything that breathes—exchange CO_2 [carbon dioxide] with the atmosphere," Pendleton explained. "That CO_2 is a combination of ^{12}C and [radioactive] ^{14}C."

The amount of radioactive carbon left in dead organic material directly relates to when it died and stopped replenishing its levels of ^{14}C. Pendleton and his colleagues found that most of the plants died at least 40,000–50,000 years ago, marking the time span that those plants were covered by ice.

At nine of the sample sites, the team also measured the ^{14}C concentration in surface rocks. The radioactive carbon in surface rocks is caused by energetic particles from space striking the surface. Ice cover shields the rocks from these particles. "Basically, it's an on-off signal," Pendleton explained. "When the landscape is exposed, you're producing ^{14}C; when it's covered by ice, you're not."

The researchers compared ^{14}C measurements to models of radiocarbon concentration that depend on the ice cover thickness. This can reveal whether a rock was exposed after the glacier first expanded. They found that in eight of the areas, the ice that originally killed the plants 40,000 years ago never melted away—until now.

An ice cap on Baffin Island. Researchers collected preserved plant life from the edge of this ice cap and found that it had died more than 48,000 years ago. Credit: Gifford Miller, University of Colorado Boulder/INSTAAR

Undoing Consistent Ice Cover

"We know the Arctic is changing," Pendleton said. "We see it in shrinking sea ice and retreating glaciers and changing ecosystems. What we don't know is, When was the last time the Arctic was actually as warm as it is today?"

Ages from radioactive carbon can reach back only so far, Pendleton explained. The researchers wanted to know when Baffin Island last experienced warming similar to today's and thus when their field sites may have been ice free.

For this, they looked to ice cores collected in Greenland by other teams. The Greenland ice cores showed that the most recent time before the plants died that the Arctic had warming similar to today's was 115,000 years ago, during the Last Interglaciation.

"You can have a year here and a year there where the temperatures may be pretty warm or very cold," Pendleton said. "The climate system is naturally chaotic. But now what we're seeing is consistent warmth undoing this continuous ice coverage of the past 115,000 years."

Preserved ancient moss collected from the margin of a retreating ice cap on Baffin Island. Credit: Matthew Kennedy, Earth Vision Institute

Running Out of Time

"This is an exciting paper that documents the magnitude of recent warming in the Arctic," Meredith Kelly, a glacial geologist at Dartmouth College in Hanover, N.H., told *Eos*. Kelly, who was not involved with this research, said that the study "is amazing but alarming, since it shows that the recent melt is unprecedented in the Holocene. The small ice caps on Baffin Island are highly sensitive to temperature, and their retreat is emblematic of the Arctic cryosphere."

Kelly also said that using radiocarbon measurements from the plants and rocks, combined with ice core ages, is a promising research technique for paleoclimate and cryosphere research. "It's a relatively new methodology that could and should be applied in the Arctic and elsewhere to determine a more detailed record of past ice extents," she said.

Pendleton said that the team will return to Baffin Island in the near future and collect more samples from the ice caps. "So many of these small ice caps you're seeing are going to be gone in the next 10 years," he said. With time running out, scientists must "try and preserve that record, or at least access that record, before it's gone."

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

Volcanic Flank Collapse in Italy Tied to Ancient Tsunami

The volcano on Italy's Stromboli Island has been erupting since 1932. Credit: iStock.com/MaRabelo

The Italian island of Stromboli has long attracted residents and visitors, thanks to its mild climate, fertile soils, and picturesque views. But there's a sinister side to Stromboli: The steep flanks of its active volcano periodically slough off, creating landslides that tumble into the sea and trigger tsunamis. Now geoscientists and archaeologists have shown that one of these events in the 14th century was likely responsible for the rapid abandonment of the island. An enormous, deadly marine storm reported in Naples in 1343 was also probably due to the same tsunami waves, the researchers proposed. These findings suggest that southern Italy is at a higher risk of tsunamis than previously known.

Something Completely Different

Mauro Rosi, a volcanologist at the University of Pisa in Italy, and his colleagues excavated three trenches in the northeastern part of Stromboli to look for signs of ancient tsunamis. Working 170–250 meters from the present-day shoreline, the researchers didn't have to dig long before their machinery revealed something other than normal soil. "Below 1 meter, we immediately found something that was completely different," said Rosi. Three clearly defined layers of pebbles and black sand emerged, "closely resembling what you see when you go to the beach," Rosi said. This material, the researchers surmised, had been swept inland by tsunami waves.

> This research "sheds new light on the persisting hazard of landslide-generated tsunamis in the Tyrrhenian Sea."

To calculate approximately when these tsunamis occurred, the researchers used carbon-14 dating to age date charcoal fragments buried directly below the tsunami deposits. Rosi and his colleagues estimated that the three tsunamis inundated Stromboli between the 14th and 16th centuries. Focusing on the oldest and largest tsunami, the team found that no large, contemporaneous earthquakes were noted in historical records. The lack of a seismic event, paired with lava records showing a collapse of the volcano's Sciara del Fuoco (Stream of Fire) lava feature around 1350, suggest that the tsunami waves were triggered by the collapse of the flanks of the volcano, the researchers concluded.

Graves in the Rubble

Rosi and his colleagues also used archaeological evidence to show that the tile roof of a medieval church in northeastern Stromboli had collapsed right around the same time. They also found three graves containing human remains that were hastily dug in the collapsed tiles. Landslide-induced shaking might have irreparably damaged the church and killed people, the team proposed.

Further evidence of this tsunami might also be in literature. In November 1343, the writer Francesco Petrarca recorded a sea storm that pummeled the harbor of Naples, destroyed boats, and killed hundreds of people. It's entirely conceivable that a tsunami originating on Stromboli could have swept 200 kilometers north and rolled up the shoreline of the Italian mainland, Rosi and his collaborators concluded. Communities in southern Italy may be "exposed to a much higher tsunami hazard than previously thought," the researchers wrote in January in *Scientific Reports* (bit.ly/tsunami-stromboli).

This research "sheds new light on the persisting hazard of landslide-generated tsunamis in the Tyrrhenian Sea," said Max Engel, a geomorphologist at the University of Cologne in Germany not involved in the research.

Rosi has a long history with Stromboli—his doctoral thesis in the 1970s focused on the island—and he is looking forward to continuing fieldwork there. In the future, he plans to dig deeper in search of even older tsunami deposits to study how often large waves have struck Stromboli. Extracting history from layers of sediments is hard, however, Rosi admits. "The identification of past tsunami is not an easy task."

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

EOS CENTENNIAL COLLECTION

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Was the Akkadian Empire Felled by Dust?

Stalagmites in a cave in Budapest, Hungary. Credit: iStock.com/Obencem

Forty-two centuries ago, the flourishing Akkadian Empire—spread across modern-day Iraq, Turkey, and Syria—suddenly disappeared. Paleoclimatologists and other geoscientists now have one possible explanation. Using precisely age dated chemical measurements from a stalagmite collected in a cave in Iran, researchers found an abrupt uptick in dust at that point in history. This heightened dust activity, which persisted for 300 years, might have made for uncomfortable living conditions and difficulties in farming, the researchers suggest.

Everything Just Disappears

Archaeologists have long been baffled by the abrupt abandonment of northern Mesopotamian settlements roughly 4,200 years ago. "There's this specific point in time where everything just disappears [from the archaeological record]," said Stacy Carolin, the paleoclimatologist who led this research while at Oxford University in the United Kingdom and is currently at the University of Innsbruck in Austria. Sediment cores obtained from the Gulf of Oman have suggested that increased dust activity in Mesopotamia might have been the culprit, but the imprecise ages of marine records make it difficult to definitively link the geophysical and archaeological evidence, Carolin said. "Unless you know the exact timing… you can't say anything about a cause and effect relationship."

Carolin and her colleagues—including geochemists and members of the Iranian Cave and Speleology Association and the Geological Survey of Iran—have now analyzed the chemical composition of an 18-centimeter-long, semitranslucent stalagmite from Gol-e-Zard (Yellow Flower) cave near Tehran to look for signatures of dust. Because stalagmites slowly build up over time as dissolved minerals percolate through rock and drip from cave ceilings, they're like clocks recording local environmental conditions. Using uranium-thorium radiogenic age dating, Carolin and her team found that their stalagmite started growing about 5,200 years ago. They estimated an age uncertainty of 31 years for their measurements, far more precise than the centennial-scale resolution of other studies.

Dust for 300 Years

Carolin and her collaborators found an uptick in magnesium, a component of dust, in the stalagmite beginning 4,260 years ago (in a twist of geophysical convention, all dates are referenced as years before 1950). This dust likely derived from the alluvial plains of the Tigris and Euphrates Rivers—that is, the location of the Akkadian Empire—and was transported by prevailing winds, the researchers suggest. They concluded that high levels of dust might have caused the Akkadian Empire settlements to be abandoned. "Dry, arid conditions could have been detrimental to agricultural settlements," Please make DQ narrower to make for better line spacing. "The dustiness may have made living conditions unbearable as well."

The stalagmite records exhibited heightened dust activity for the following 290 years, the researchers showed, remarkably consistent with the 300-year interval of abandoned settlements revealed in the archaeological evidence. These findings were published in January in *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/NAS-evidence). The data are suggestive of a link between the geophysical and archaeological records, but it's hard to know for sure, said Carolin. "The idea that there's a relationship between climate and society is a provocative one."

Other researchers are supportive of a real cause and effect correlation, however. This work "provides another line of evidence supporting the idea of a link between climate variability and societal change," said Matthew Lachniet, a paleoclimatologist at the University of Nevada, Las Vegas who was not involved in the research.

Carolin is currently analyzing other Iranian stalagmite samples that afford a deeper look into the past. She and her colleagues are looking at climate change over ice age cycles on the timescale of centuries. "We are interested in reconstructing the climate state of this region… when our human ancestors were migrating out of Africa and into Asia through southern Iran."

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

An SOS Call for Ocean Health and National Security

Sen. Sheldon Whitehouse doesn't just think that the administration's push to construct a wall along the U.S.-Mexican border in the name of national security is a bad and trumped-up idea that triggered the recent government shutdown.

Whitehouse, a Democrat from Rhode Island, thinks that the security threat along the U.S. southern border pales when compared with the security threat that the United States and other nations face from the decline in health of the world's oceans. That decline, caused by climate change, population growth, overfishing, and other threats, is leading to increasing competition and conflict over marine resources.

"When [President Donald] Trump moves on to another topic, he'll be talking about something completely different, and this political episode is likely to pass," Whitehouse told *Eos* at the launch of the Stephenson Ocean Security (SOS) Project in January. "The mounting problems in the oceans are only going to build into worse and worse security concerns, ones that our military and defense experts have warned us about now for 5–6 years," Whitehouse said. He was referring to warnings including the Pentagon's 2014 Quadrennial Defense Review, which describes climate change as a global threat multiplier.

Comparing the security issue along the U.S.-Mexican border with ocean security issues, Whitehouse told *Eos*, "One is, I think, temporary, political, and largely rhetorical. One is deep, abiding, and potentially catastrophic."

Ocean Security Project Is Launched

The SOS Project, which is an initiative of the Center for Strategic and International Studies (CSIS), a Washington, D.C.-based policy research organization, focuses on the connection between ocean health and global security and the need to support sustainable development to manage global marine resources and reduce conflicts. The project plans to highlight key aspects of ocean security. Among them are identifying current and potential marine resource conflicts—whether they relate to fisheries, mineral rights, or territorial disputes—and possible solutions.

"In a world that's ever more crowded and a world that is ever more competitive, sustainability needs to be at the core of our national, foreign, and security policies in a way that I don't think it has been to date," project director Whitley Saumweber said at the January launch event.

Ocean security combines traditional concepts of maritime security with the principles of conservation and sustainable use of marine resources, according to Saumweber, who was President Barack Obama's director for ocean and coastal policy on the White House Council on Environmental Quality. "Over the long term, unless you're thinking about sustainability, you are not secure in the maritime sphere. So it's not just a conservation solution but a vital element of soft power and a critical alternative to the more exploitive path," he said.

"There is no better time to talk about the needed integration of sustainability and national security in the marine space."

In an interview with *Eos*, Saumweber said that "the world is changing out from under our feet" in many ways, including from the dramatic impact of climate change on the oceans, a shifting geopolitical dynamic and the rapid ascent of China, and the Trump administration's "views on America's place in the world, which have allowed other nations to step into places where we were previously a larger presence."

"There is no better time to talk about the needed integration of sustainability and national security in the marine space," Saumweber said.

South China Sea and Arctic Ocean Case Studies

Saumweber explained that the launch event focused on two initial SOS projects that look at sharply contrasting areas of the ocean. One project focuses on the South China Sea, an area crowded with fishing vessels, many of which may be involved in illegal, unreported, and unregulated fishing. There China is asserting its dominance in "an incredibly

Fishing boats in the South China Sea near the Vietnamese coast. Credit: Paul Hampton/Shutterstock

crowded space with incredibly complicated debates around jurisdictions and boundaries and resource use and without any real effective mode of collective governance," Saumweber said.

The other initial SOS project looks at the currently relatively unexploited Arctic Ocean, which already has strong international governance structures in place, including the intergovernmental Arctic Council and a new international agreement to prevent unregulated commercial fishing in the central Arctic Ocean.

In the Arctic, "we have the opportunity to run an experiment, if you will, and think about the lessons that we have in the South China Sea of what happens when you have a crowded space with heavy exploitation and little to no governance," he said. "Well, what happens if we can set up that kind of regime at the start? What happens if we can be conscious about where this all might end up?"

Sen. Sheldon Whitehouse (left) with Stephenson Ocean Security Project director Whitley Saumweber at the 9 January launch of the project. Credit: CSIS

Climate Change Threats to the Oceans

At the CSIS event, Sen. Whitehouse focused on the threat of climate change to the oceans, noting that they annually absorb more than 9 zettajoules of excess heat energy due to climate change and carbon emissions. He said that the added heat the oceans absorb "is equivalent to four Hiroshima-sized nuclear bombs exploding in the ocean every second, with all of the thermal energy of that release captured by the ocean."

Whitehouse sharply criticized "the nefarious political activities" of the fossil fuel industry. The industry "maintains a very large and complex armada of false-front organizations designed both to obscure the hand of the fossil fuel industry and to propagate junk and false science to counter the legitimate science that the world knows" about climate change, he said. "Although the climate-denial apparatus has won unseemly influence in Congress now, it will surely lose the test of time."

Whitehouse said that the administration is doing "reasonably well" at some "specific and localized levels" regarding the oceans, "where common sense and factuality continue to exist." He said, for instance, "I don't think the denial operation has done a very effective job at infiltrating NOAA [the National Oceanic and Atmospheric Administration] and trying to shut down its scientific efforts."

However, Whitehouse added that the administration is doing poorly in many other areas. "The extent to which this administration has been—to put it very bluntly in the terms the Founding Fathers would use—corrupted by an interested party"—the fossil fuel industry—"is almost unprecedented in our history."

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

Deaf Students Feel the Universe's Vibrations in New Workshop

A purple and green aurora lit up the sky above Delta Junction, Alaska, on 10 April 2015. Deaf students felt the vibrations of sonified aurora data in a new workshop that featured the vibrations of the universe. Credit: Sebastian Saarloos

A new workshop brought the vibrations of the universe to Deaf students, a group often overlooked in informal outreach activities. Astronomers and teachers at a school for Deaf children partnered to design an activity that transformed cosmic phenomena into vibrations that students could feel and could connect with visuals and a scientific narrative.

"It's the beginning of trying to think of scientific outreach with a much broader appeal, where everyone is capable and must have access to public outreach of science," Mario De Leo-Winkler, an astronomer and director of the National System of Researchers of Mexico, told *Eos*.

When he began looking into astronomy outreach activities for children with physical disabilities, De Leo-Winkler found that there were many activities designed for blind people, who could not see the stars, but few designed specifically for Deaf children.

"We all like the stars," he said. "If that was enough—if looking through a telescope or interacting with things related to science or to astronomy in general was enough—then we would all be scientists or we would all be astronomers. You need an extra push as a citizen to be enticed or enamored with science."

Making Astronomy Data Vibrate

According to recent surveys, over 5% of the world's population are Deaf or hard of hearing, but this community represents only about 1% of recently awarded science and engineering doctorates. This is partly due to the scarcity of Deaf-accessible science, technology, engineering, and mathematics (STEM) courses in higher education, De Leo-Winkler explained. The number of Deaf-accessible STEM and astronomy-related outreach and research programs has grown in recent years, and De Leo-Winkler wanted to create one in his own backyard.

De Leo-Winkler and other astronomers at the University of California, Riverside decided to create their own outreach activity in partnership with the California School for the Deaf, Riverside (CSDR). The team decided to focus on developing an activity that uses the sense of touch to convey information. Research into brain development has shown that in people who are born Deaf or who lose hearing later in life, the brain rewires itself to process vibrations in the absence of sound through a phenomenon known as neuroplasticity.

The researchers gathered recordings of Earth and astronomical phenomena that produce distinct sounds or that vary with time. For data that were outside the range of human hearing—about 20–20,000 hertz—they used an algorithm to shift the sounds into that range.

For nonauditory data sets, the researchers used a technique called sonification to transform the data into sounds and vibrations the students could experience.

CSDR teachers gave their expertise and guidance to the astronomers when selecting sounds that would produce detectable and distinguishable vibrations. They also developed American Sign Language (ASL) interpretations for unfamiliar astronomy terms in the accompanying narrative.

The team held the workshop in a multisensory sound lab at CSDR. The lab converts sound into other mediums, such as vibrations and light, that can be experienced by Deaf individuals.

The brain rewires itself to process vibrations in the absence of sound through a phenomenon known as neuroplasticity.

"We're giving the explanation, we're showing the imagery, and we're producing the vibrations at the same time," De Leo-Winkler said.

Vibrations of the Universe

The researchers held two workshops in the multisensory sound lab for CSDR students in grades 3–8. They collected feedback from participants after the first workshop and altered their set of vibrations, visual materials, and verbal and ASL narratives in the second workshop in response to that feedback.

The students first learned some introductory astronomy in their classrooms before participating in the workshop. The workshop presenter then introduced students to the idea that sounds and vibrations are connected and gave examples that students might be familiar with, like thunderstorms or pots of bubbling water. The presenters explained that everything in the universe produces energy and that energy can be converted into sounds or vibrations that they could feel.

The workshop activity took the students on a journey from Earth outward to the edges of the solar system and beyond with 19 different vibrations. Some of the vibrations they experienced include Earth's auroras, the vibrations of the Sun, and radio emissions from Saturn recorded by the Cassini spacecraft (listen to the accompanying audio files at bit.ly/Eos-vibrations).

"We're opening the door for others to be able to explore for themselves what has been done and to think out of the box."

Eighty-three students participated in the two workshops and provided overall positive feedback about the experience. The team analyzed the survey responses and published the results in February in the *Journal of Science Education and Technology* (bit.ly/astronomy-deaf).

Opening the Door

This workshop focused on astronomy phenomena, but the techniques could easily be adapted to other STEM disciplines, such as physics, stem cell research, or genome mapping, De Leo-Winkler said.

"I think the possibilities are limitless," he said, "as long as you have a clear interpretation of the information that you want to transfer to the students and as long as it's fun."

The team has made all of its sound files and presentation materials freely available online at bit.ly/astronomy-vibrations.

"We're opening the door for others to be able to explore for themselves what has been done and to think out of the box," De Leo-Winkler said. "We invite people to take it in, to use it, to reimagine it, and to follow some of the steps and create new and innovative things."

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

Universities Can Lead the Way in Supporting Engaged Geoscientists

Geoscientists address society's challenges by engaging with nonscientists of all ages. Universities can play a vital role in providing support, guidance, and resources for these efforts. Credit: Karin Higgins, Strategic Communications, University of California, Davis

Geoscientists play a critical role in addressing societal challenges related to natural hazards, climate change, the environment, energy, and resource issues. Many geoscientists who recognize this critical role put their knowledge into action by engaging with local communities and beyond, and we are called upon by public leaders to do more of this work [e.g., *Lubchenco et al.,* 2015].

Engaging with societal challenges requires more than just a one-way transfer of facts. It necessitates multidirectional dialogue with those outside the research community based on shared values and understanding [*Meadow et al.,* 2015]. Universities benefit from this type of engagement through the rigorous use-inspired research it generates, as well as from better community relations, higher-quality teaching, and service learning opportunities.

Unfortunately, at many universities, engagement is still viewed as an optional professional activity, having a lower priority than research, teaching, and university service [*Whitmer et al.,* 2010]. This perception stands in opposition to a growing understanding that engagement is a necessary ingredient in actionable science: Researchers cannot and should not craft usable knowledge all on their own [*Clark et al.,* 2016]. Training and encouraging individual geoscientists to engage the public is necessary, but insufficient, to address the critical societal challenges that involve the geosciences.

How Do We Fix This Disconnect?

We suggest something different: Universities should play a central role in both bottom-up cultural change and top-down support for public engagement. Geoscientists are educated in and often employed by universities, and universities can coordinate existing resources and build new capacities to amplify geoscientists' collective impact.

We recognize that motivating and enabling scientists to create a culture of engagement cannot happen in a vacuum—support and opportunities must come from a university's institutional and administrative levels. Universities must also evolve to incentivize such engagement.

To fix the disconnect, university-based geoscientists should use faculty and student governance structures to create change that strengthens the culture and formalizes support for public engagement.

What Is "Engagement"?

Public engagement describes "intentional, meaningful interactions that provide opportunities for mutual learning between scientists and members of the public," according to the American Association for the Advancement of Science (AAAS). In other words, engagement includes all of the activities that scientists do to bring their work into the world around them and the ways that scientists do better by learning from people beyond academia.

Engagement activities can include communication with the public, providing input into policy making, citizen science, and research cooperation. Each of the authors has been recognized as a public engagement fellow by the AAAS Leshner Leadership Institute, and we each take our own approaches to engagement based on what works best for our research topics and personal style.

For us, engagement activities include working with national and local parks on environmental monitoring and restoration projects that involve hundreds of volunteers, building relationships with local and state leaders to improve the resilience of climate-sensitive communities, and working with policy makers worldwide to help inform the negotiation and implementation of international treaties to address toxic pollution. We also spend time translating science for state and federal decision makers and designing research projects in collaboration with stakeholders.

> Universities should play a central role in both bottom-up cultural change and top-down support for public engagement.

Five Core University Capacities That Support Public Engagement

Universities can bring scientists together in ways that transcend disciplinary boundaries, spawning innovative ideas for tackling societal challenges. Solutions to such problems require integrative, multidisciplinary perspectives, broad collaborations, and strategic engagement with specific public audiences.

We propose that universities develop five core institutional capacities to support public engagement. These capacities are not unique to geoscience engagement, but they can catalyze transformation when combined and directed at large-scale interdisciplinary challenges.

- **Creating networks** of scientists from across disciplines working on public engagement to provide peer-mentoring support and collaboration on existing and new initiatives
- **Developing best practices**, informed by literature on science communication and outreach, to train, educate, advise, and support faculty and students
- **Convening stakeholders** to collaborate with academics on projects, events, and engagement strategies toward shared goals (stakeholder groups can include concerned citizens, nongovernmental organizations, industry representatives, and government officials)
- **Establishing incentives** such as merit pay, workload modifications, and tenure and promotion credit to support developing engagement skills and to recognize high-quality engagement activities
- **Facilitating regular evaluation** of public engagement activities and processes, using evidence-based approaches to improve the quality of engagement and university support

To build these core institutional capacities, universities could integrate best practices, expertise, and support that may already exist scattered throughout each university, allowing universities to coordinate, leverage, and elevate existing resources. One approach is to create centers with professional public engagement staff that provide a one-stop shop for students, faculty, and staff. However, universities should tailor their approach to their unique needs and contexts.

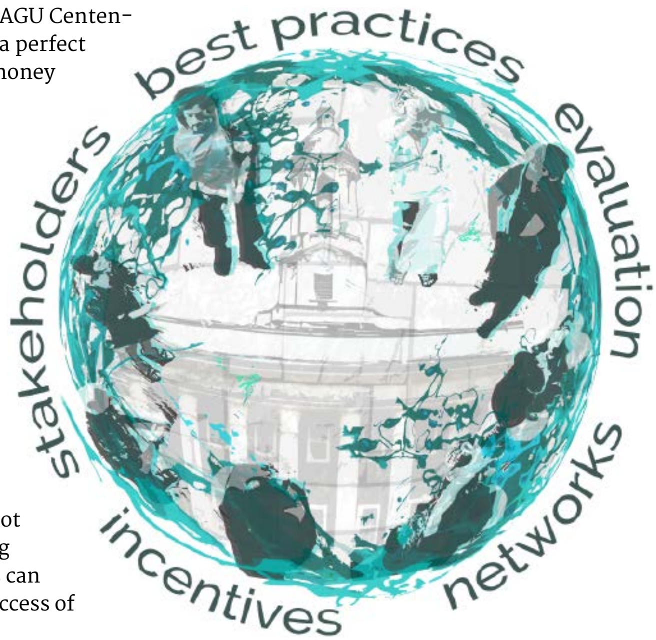
Effective Engagement Requires Funding, but It Won't Break the Bank

Universities need to make long-term commitments to engagement, with sustained support from administrators. In addition, students, faculty, staff, alumni, and local communities can work individually and collectively to build a case for why resources for public engagement are critically important.

Building engagement capacity requires resources, but engagement is not a zero-sum game, and resource requirements can be modest. For example, universities can help build partnerships with community groups, making it easier for individual faculty to institute collaborations. They can offer small seed grants to faculty and students who seek to connect to the public. The AGU Centennial Celebrate 100 grants are a perfect example: Small amounts of money can jump-start engagement activities.

The investment pays off: Universities benefit when their scientists are ambassadors who publicize the return on investment of scientific funding. Scientists can leverage engagement initiatives to pursue meaningful activities with broader impact, and they can build bridges beyond the university to solve problems.

Institutional change does not have to take an all-or-nothing approach—incremental steps can demonstrate the value and success of university investments.



Universities can support their faculty, staff, and students—and advance their missions—by embracing five core capacities to support public engagement. In this way, the university forms the central pillar that enables a swirl of public engagement activities by many members of the university community. Credit: Bethann Garramon Merkle

Give Engagement Formal Structure and Support

Systemic change requires supporting and recognizing team-based and long-term efforts that build to significant outcomes, not just recognizing a few stellar individuals or events within a university or professional society. To facilitate collective action by many geoscientists, formalized infrastructure supporting engagement must be in place.

For example, universities often have Centers for Teaching and Learning to help faculty and others improve teaching; these centers offer training sessions, provide targeted individual assistance (e.g., evaluating individual teaching efforts by observing classes), and connect faculty to research in education and evaluation. Engagement centers could fulfill similar needs, such as providing training in communications, making connections to experts in policy and law, or helping organize stakeholder engagement workshops.

> Systemic change requires supporting and recognizing team-based and long-term efforts that build to significant outcomes.

Geoscience faculty and students can, individually and collectively, push departmental and university administrations for formalized support structures. Department chairs and tenure stream faculty, who have greater access to power within university structures, could lead the charge for institutional change, but all members of the university community should be empowered to advocate for change through departmental committees, student government, and unions.

The National Science Foundation and other funders value public engagement as a "broader impact." Organizations like the National Alliance for Broader Impacts provide examples of engagement successes that scientists can use as a jumping-off point. But networks within institutions can also facilitate idea exchange, local knowledge, and in-person training and support so that researchers can better maximize engagement efforts.

Rather than being informal and ad hoc, engagement can be prioritized if university administrators create a formal space for ideas to grow. Through such a space, university-based networks can grow as individual scientists across the campus find each other.

The collegial atmosphere has an added benefit: Just like the way research collaborators pool together to discuss a negative result or a failed experiment, universities can sup-

Geosocial scientists can collaborate with policy makers to support smart decision-making in coastal regions like this Maryland wetland. Credit: Ariana Sutton-Grier

port scientists in learning from and responding to engagement attempts that are not always positive.

Lessons Learned from Existing Successes

Building university-based public engagement capacity enables geoscientists to work alongside colleagues from other disciplines, learning from and developing improved practices across a broad range of science-society interactions.

Geoscientists already work, in part, within existing models that institutionalize support for public engagement on sustainability challenges [*Parris et al.,* 2016]. Such models include Cooperative Extension, Sea Grant Extension, state water resources research institutes, and climate impact–focused Regional Integrated Sciences and Assessments (RISA) centers. These sustained and successful programs promote evidence-based decision-making, facilitate cogeneration of ideas, and support translation of knowledge into action. They build long-term relationships between university and decision-making communities. Staff and faculty alike are involved with public engagement, the work is financially supported, and engagement is incorporated into merit and promotion metrics.

These programs are shaped by the goals of scientists, communities, and state and regional policy makers. University-based geoscientists could build upon lessons from these existing models to advocate for long-term support across a broader range of issues.

Similarly, over the past several years, AGU has expanded trainings and programs, such as Sharing Science and Thriving Earth Exchange, to encourage members to engage with communities and decision makers [*Vano et al.,* 2017]. AGU could also play a role in advancing university initiatives, and university administrators and geoscience faculty and students could work together with AGU on these initiatives. However, professional societies cannot replace all of the core capacities and human power that universities can leverage.

Expected Transformation

New public engagement initiatives should be inherently collaborative and multidisciplinary. In particular, public engagement initiatives

> Societal challenges are too important to leave engagement to individual scientists acting alone or to after-hours efforts.

could facilitate greater interaction between geoscientists and social scientists, recognizing vital human components within the Earth and environmental challenges facing society.

Just as multidisciplinary research collaborations can take extra time to realize their full potential, university structures must recognize that relationship-building and public engagement activities often require patience and careful tending before they bear fruit, particularly when engaging with marginalized communities. Successful and transformative public engagement produces benefits even when it may not generate awards, media coverage, or viral Internet attention. Engagement helps guide research approaches that are sensitive to public needs, and it translates results into knowledge that benefits communities, society, researchers, and academic institutions.

Societal challenges are too important to leave engagement to individual scientists acting alone or to after-hours efforts. Universities, along with organizations like AGU, need to lead the charge to amplify individual efforts. By developing university capacities to connect, train, support, and reward public engagement, geoscientists can enhance their collective impact in addressing societal challenges.

Acknowledgments

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EOS CENTENNIAL COLLECTION

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Being Persuasive: Lessons from Lawyers That All Scientists Need

The greatest uncertainty in our planet's future lies in what next steps we take on climate policy. As scientists, our contribution is to improve understanding of how climate systems function. We build on established research, make new discoveries, and provide facts to the global community. But simply presenting facts is not enough to inform the public's beliefs, change behaviors, or influence positions on policy [*Kahan et al.,* 2012].

In this atmosphere of urgency, we must do more than be messengers. Research on science communication offers helpful tips such as reducing complexity, getting straight to the point, and minimizing jargon [*Somerville and Hassol,* 2011; *Hassol,* 2008]. Here we look to another source for lessons on persuasive communication.

In summer 2017, we participated in the Expert Witness Training Academy's Effectively Communicating Science workshop hosted by the Mitchell Hamline School of Law in Saint Paul, Minn., and funded by the Paleoclimate Program at the National Science Foundation. Over an intensive weeklong training, 2 dozen scientists joined law students in a mock trial [*Thorstad et al.,* 2017]. Each participant practiced the roles of lawyer and expert witness. Law faculty coached us in the trial's main components: opening statements, direct examination, cross-examination, and closing arguments.

Talk about being out of your comfort zone. The lawyer's role was unfamiliar, to say the least. What did we know about delivering an opening statement? How are cross-examinations structured? When do we yell "Objection!"?

During this training, we learned strategies that lawyers use to communicate—specifically, to persuade juries of their client's position. Scientists do not aim to sway others toward a subjective stance, but we too need to convince our audience of the robustness (or, as lawyers might argue, the incontrovertibility) of our findings while remaining honest and objective.

To be more convincing, scientists should consider the following four communication strategies for oral presentations based on courtroom techniques. These strategies can help scientists be more engaging and relatable and will put them in a better position to effectively convey key facts about the pressing issues of our time. We present these strategies using examples from the role-playing exercises and mock trial we participated in as part of the Expert Witness Training Academy.

1. Speak to Your Audience's Values

Identify your audience, and then tailor your message and delivery to it. Scientists are accustomed to some of this: We target readers and journal editors each time we submit a manuscript. We reference previously published articles and use consistent terminology to avoid alienating the journal's audience.

But when we write journal articles, we know that our readers are familiar with the background and conventions of the topics under discussion. Our readers already agree with us on the same basic premises, and together we find the same types of methods and evidence to be convincing. So not only are we tailoring our message to journal editors and readers, but also we know that we're starting our discussion with the same set of values.

> Consider revealing your underlying message up front, returning to it throughout your presentation and at the end for maximum impact.

The trick, then, is finding which aspects of your research resonate with a general—or even a skeptical—audience's values. When appealing to those audiences, find ways to link your science to universal values such as safety, family, and financial stability. To be an effective expert witness and communicator, you must make your listeners care.

We turn now to an example from our expert witness workshop. One participant began her opening statement with a question for the jury: "Have you ever witnessed a natural disaster?"

Immediately, the expression on the jurors' faces changed. She continued, "What if you found out afterward—after your home had been destroyed or you lost loved ones—that it wasn't natural at all?"

With this appeal to her audience's values, she had the jury's undivided attention.

2. Lead Your Listeners with the Facts

When questioning expert witnesses, lawyers begin with short, general questions that gradually become more targeted. The sequence is carefully crafted to highlight information supporting their position. When questioning is done well, the lawyer draws out key facts supporting his or her position in a clear, stepwise fashion so the jury can easily follow along.

Here scientists must be cautious not to cherry-pick information and must be sure to present all available information objectively, acknowledging gaps in understanding. But by building upon the facts step by step and explaining what scientific uncertainty means in real terms, scientists can craft a more understandable message, as in this direct examination:

Lawyer: *Based on your expertise, did weather modification cause the rain observed in Falls County?*

Witness: *No. The procedure could not have produced that much rain. The amount of rain produced depends on how much product is used.*

Lawyer: *Given the amount of product you used in this instance, how much rain did you predict?*

Witness: *I filled the generators with only enough solution to produce 0.25 inch of rain per hour, maximum. The rain observed in Falls County reached 3 inches per hour. The generators simply did not have enough solution to produce the rain observed.*

Scientists need to lead listeners down the path to their conclusions. When conveying your message to an audience with different backgrounds and expertise, it is essential to meet your audience where they are. Don't tell the entire story all at once: Introduce evidence piece by piece so the information builds slowly and sequentially, and you'll lead them to a more compelling conclusion.

3. Consider It a Performance

Like it or not, how you say something is as important as, if not more than, what you say. Your words will not contribute as much as your tone, body language, and attitude.

Consider choreographing your movements. They should be deliberate, not distracting. Plant both feet on the floor, balancing your weight equally to prevent swaying. Square your shoulders toward your audience and draw your elbows away from your body—

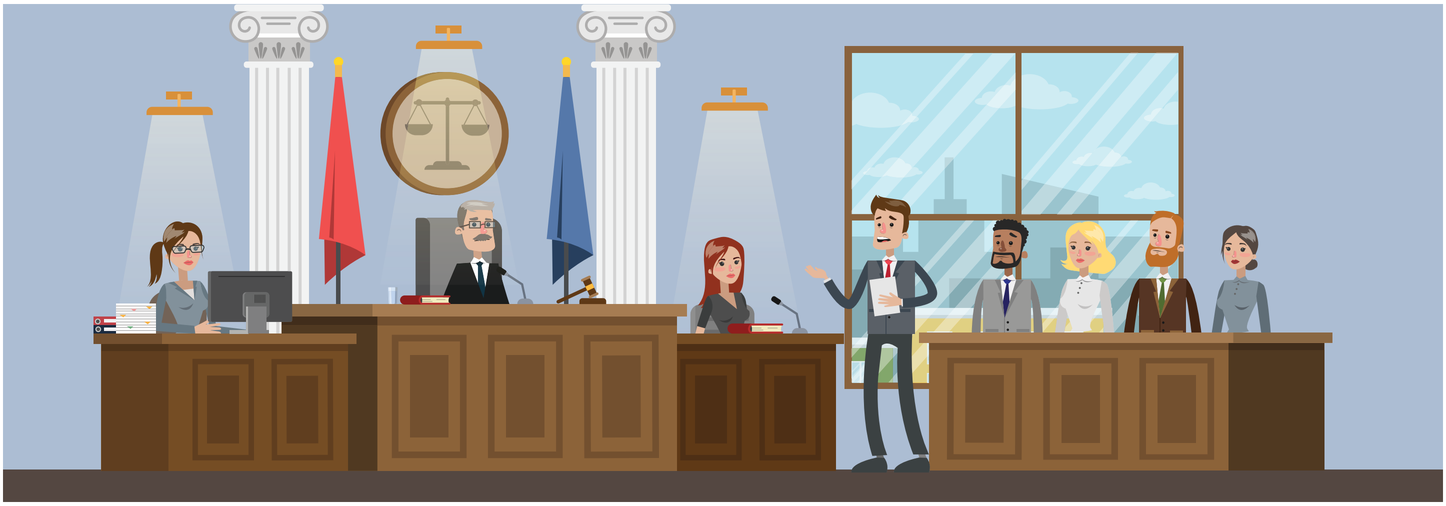

Illustration by Artinspiring/Adobe Stock

don't be afraid to take up more space. Use hand gestures, or move in a way that helps emphasize key points. When you present a contrasting perspective, move to the other side of the room or change where your body is facing to signal the shift. Does this seem like acting? Fight your resistance to performing—you're more likely to come across as engaging and enthusiastic, not insincere.

I performed my closing statement with these points in mind: I began in the center of the room. I faced the jury and clasped my hands. I moved toward the plaintiff, my client, recapping our position. Then I walked to where the defense team sat, turned my back to them, and listed the ways the defendant had erred, counting with my fingers. I pointed to the defendant when I said key words: negligible, wrongful, liable. To conclude, I walked back to the plaintiff, reclasped my hands, and asked the jury to rule in our favor.

4. Maximize Your Impact Through Repetition

Your audience is most likely to remember your first and last statements. This point should motivate scientists to craft memorable and concise introductions and conclusions.

Begin with a hook, something intriguing to catch your audience's attention: a thought-provoking image, a question, or a startling statistic. Consider revealing your underlying message up front, returning to it throughout your presentation and at the end for maximum impact.

Listening to our mock trial jury deliberate at the conclusion of our trial, we were struck by which pieces of information the jurors found most persuasive or even remembered at all. Jurors forgot facts presented earlier in the case. Long-winded or confusing scientific explanations did not convince them. But jurors did recall points we made clearly and repeatedly and even echoed phrases and terms from the closing arguments.

Don't overestimate the audience's ability to follow along: They are probably hearing these facts for the first time. Unlike journal readers, this audience cannot reread a confusing paragraph to make sure they follow your point. Emphasize the main point by saying it slowly; let it sink in. Repeat key points throughout your presentation. Recall the common adage "Tell me what you are going to tell me, tell me, then tell me what you told me."

Wrapping It All Up

Now we'll take our own advice and tell you what we've told you. We have presented four ways scientists can use courtroom strategies to help audiences understand, remember, and engage with science. Like many scientists, we don't often practice being persuasive—we tend to think that proven facts and robust methodologies will speak for themselves.

Yet scientists are increasingly finding that this is not enough to convey findings that have potentially dire consequences for the planet and our well-being. And it's no secret that better communication is necessary. We are now seeing institutional support at the national and international levels for science communication reform that goes beyond supplying information.

The Intergovernmental Panel on Climate Change recently published a comprehensive handbook its first communication guidance for report authors—featuring advice to "connect with what matters to your audience" [*Corner et al.*, 2018, p. 5]. The *National Academies of Sciences, Engineering, and Medicine*'s [2017] guidance underlines the challenges of addressing your audience's perceptions, beliefs, and potential misunderstandings when conveying science.

We clearly need better ways to connect society to science. By sharing our experiences going from lab to courtroom, we've highlighted communication strategies that are urgently needed by scientists to effectively inform policy and engage public opinion.

Acknowledgments

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SCIENTISTS INVITED TO COLLABORATE IN OCEAN OBSERVING MISSION

By Rosemary Morrow, Lee-Lueng Fu, Francesco D'Ovidio, and J. Thomas Farrar

Sea level is sea level, no matter where you go, right? Not necessarily. The Moon's gravitational pull, ocean currents, melting glaciers, and a host of other factors ripple and distort the surfaces of the world's oceans. Water levels in lakes, rivers, reservoirs, and other inland bodies are constantly changing as well, in response to floods, droughts, and human water use.

The Surface Water and Ocean Topography (SWOT) satellite mission, due to be launched in 2021, will map the elevation of water surfaces on Earth at a resolution that has not been possible before. This mission aims to improve estimates of sea surface elevations and the volumes of water stored in lakes, reservoirs, wetlands, and rivers around the world.

SWOT is scheduled to map the entire globe between 78° north and south latitude over the course of 3 years. Before it settles into its main orbit, covering Earth's surface every 21 days, the first 90 days of the mission will be flown in a "fast-sampling" phase, revisiting each area once daily.

We are inviting members of the international ocean science community to participate in this unique fast-sampling phase. We encourage you to create programs to deploy in situ assets in the

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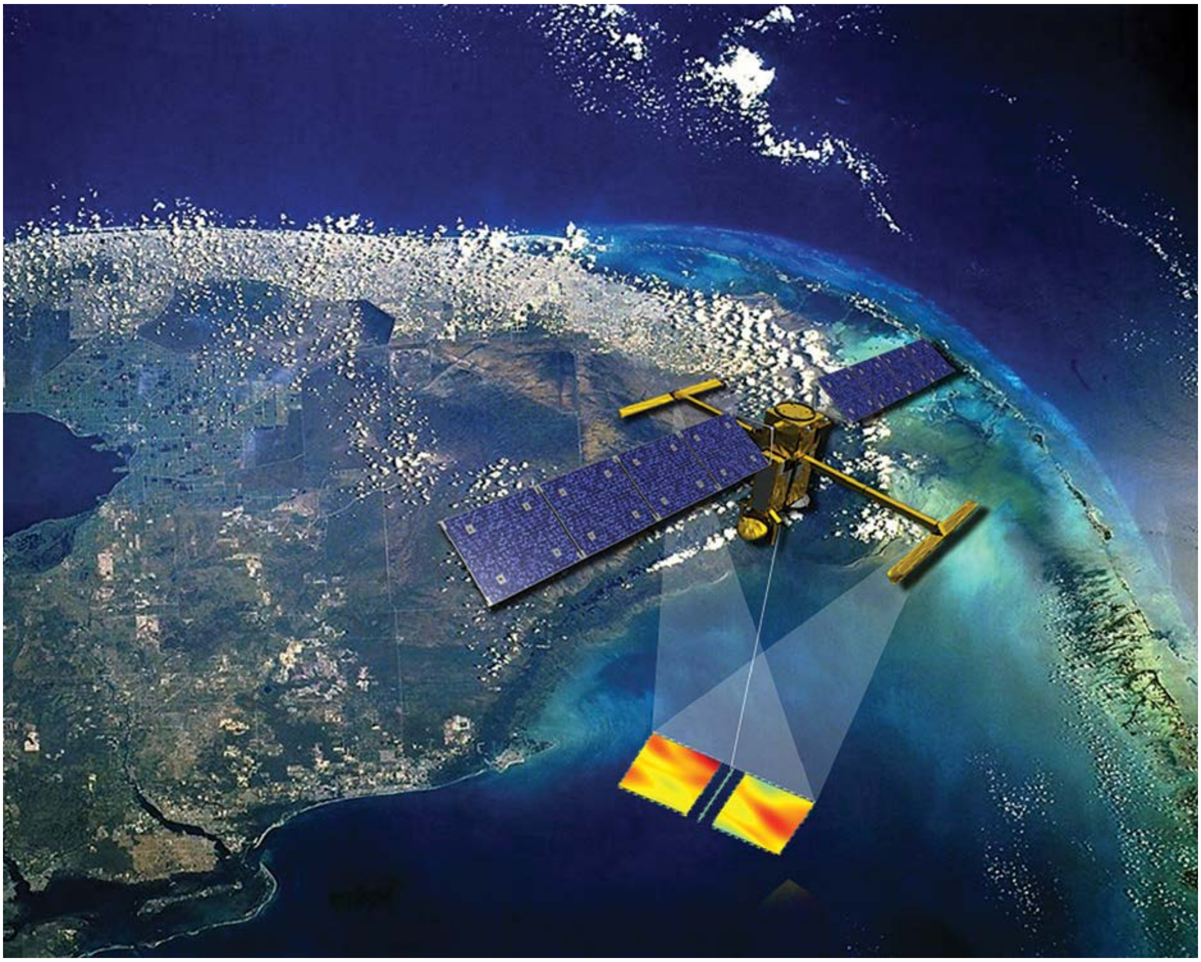


Artist's rendering of the future SWOT satellite making sea surface height observations, even through clouds. Off-nadir radar interferometers gather data over two 60-kilometer-wide swaths at once, with a conventional nadir altimeter in between. Credit: CNES

regions covered by the SWOT fast-sampling orbit to provide a global series of experiments with fine-scale ocean campaigns, as well as ground-based data for comparison with SWOT's daily 2-D sea surface height data.

A High-Resolution Look at the World's Oceans

Today's multimission satellite altimeter maps show sea level undulations, from large eddies up to basin-scale or global variations. We cannot resolve the smaller eddies with diameters less than 75 kilometers because their signal gets lost in the noise. These unresolved 75-kilometer-wide eddies have a spectral wavelength of 150 kilometers; this defines the minimum spatial wavelength that we can resolve today.

SWOT will rely on a satellite altimeter that will use radar interferometry to make high-resolution (~2-kilometer) measurements over two 50-kilometer-wide swaths of water at once, with a conventional nadir altimeter in the gap in between.

This new SWOT measurement will extend the 2-D resolution of ocean surface topography down to between 15 and 45 kilometers in wavelength, detecting small eddies with diameters of 7–20 kilometers , depending on ocean surface conditions. This advance will offer researchers new opportunities to study the oceanic dynamic processes at these scales over the global oceans [*Fu and Ubelmann,* 2014].

SWOT aims to bring new insight into ocean processes at scales of 15–150 kilometers in wavelength that have typical temporal scales of hours to weeks [*Fu and Ubelmann,* 2014]. A number of dedicated local in situ campaigns have provided insight into these rapidly evolving submesoscale dynamics (e.g., the Lateral Mixing Experiment (LATMIX) and the Ocean Surface Mixing, Ocean Sub-mesoscale Interaction Study (OSMOSIS)) and the internal wave dynamics (e.g., internal wave experiment (IWEX), Ocean Storms). Globally, our current knowledge on the fine scales is based largely on untested simulations of high-resolution circulation models. SWOT will address this observational gap and provide an unprecedented opportunity to study the surface signature of these motions and their interactions.

These fine-scale processes are important in the generation and dissipation phases of ocean mesoscale eddies, and they provide both sinks and sources for the ocean's kinetic energy at larger scales. They also act as one of the main gateways that connect the interior of the ocean to the upper layer: The active vertical exchanges linked to these

These fine-scale processes act as one of the main gateways that connect the interior of the ocean to the upper layer.

scales may have important impacts on the local and global budgets of heat, carbon, and nutrients. Ocean stirring can be a main controller of oceanic fronts and plankton diversity and thus of the ocean ecosystem services. SWOT is therefore positioned to play a key role in studying the ocean climate system and in biogeochemical cycles [*Mahadevan,* 2016].

Internal Tides and Gravity Waves

A major challenge and opportunity offered by SWOT's fine-scale sea surface height (SSH) observations is to study the interaction of these balanced ocean motions (driven by Earth's rotation, wind, and buoyancy effects) with the internal tides and internal gravity waves that stir and circulate water beneath the ocean's surface. Whereas a large part of the internal tide is predictable, the internal wave continuum is not.

Modeling studies suggest that the spatial scales at which balanced motions are clearly separated from internal waves in SSH vary geographically and seasonally [*Qiu et al.,* 2018]. Balanced motions tend to dominate in the middle to high latitudes, and internal waves are prominent in the weakly energetic eastern basins and tropical regions. Adequate observation of these processes made simultaneously with SWOT and in situ systems should allow progress on testing methodologies to separate these two entangled motions and to understand their interactions.

A Quick Look at Short-Lived Events

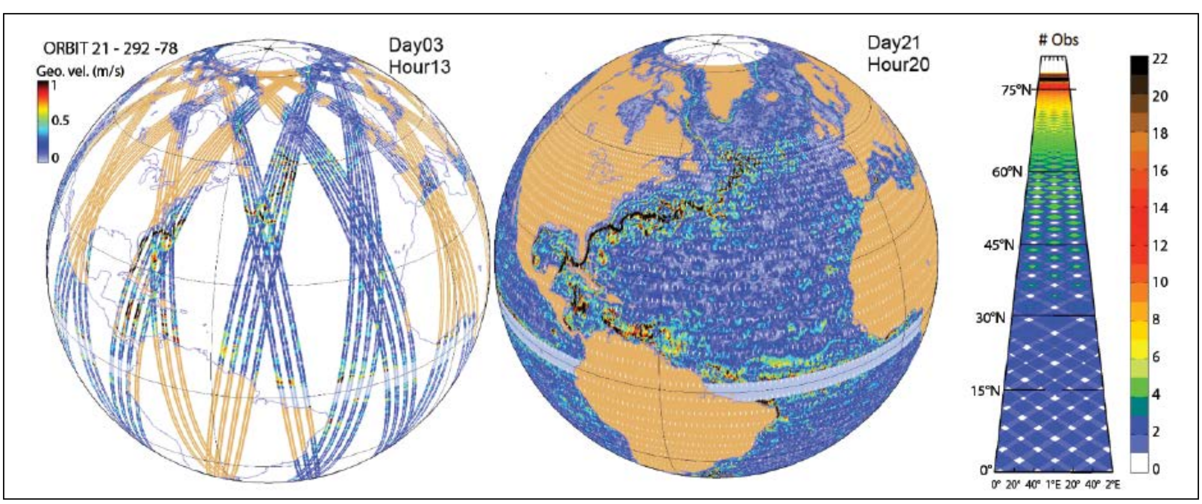
Given the width of the measurement swath, it will take SWOT 21 days to map Earth's entire surface at latitudes lower than 78°. (In the Northern Hemisphere, the 78th parallel circles just north of the coasts of North America and Europe; in the Southern Hemisphere, it passes through Antarctica's coastal regions and the Southern Ocean.)

In its 3-year science orbit, SWOT will loosely cover the global oceans (Figure 1, left) after 10.5 days, then shift westward and fill in the gaps to achieve full coverage after 21 days (Figure 1, middle).

Because of the swath coverage, the number of repeat observations at a given location during the 21-day repeat orbit varies with latitude, from two repeats at the equator to two to four at the midlatitudes to more than six at the high latitudes (Figure 1, right). This rather coarse temporal sampling presents a challenge for the study of the small-scale, rapid ocean processes that have timescales comparable to or shorter than the sampling intervals.

To catch a glimpse of these short-lived processes, the first 90 days of the SWOT science mission will be flown in a fast-sampling phase that revisits specific areas once per day. This phase will begin after a 90-day commissioning phase for engineering checkout and adjustment. Details of the various orbits are available online (bit.ly/SWOT-details). The fast-sampling phase (January to March

Fig. 1. SWOT's nominal orbit coverage up to 78°N and 78°S after 3 days (left) and the full 21 days of a complete cycle (middle). Color shows the modeled surface currents for each track. Geo. vel. indicates surface geostrophic velocity (with the speed of currents in meters per second). (right) The number of observations at a given latitude (shown here for northern latitudes, but the same applies to the south) during the 21-day repeat period. Credits: (left and middle) C. Ubelmann, CLS; (right) JPL/NASA



2022) is intended for process studies with a reduced coverage, providing observations in the Northern Hemisphere winter and Southern Hemisphere summer (Figure 2). SWOT measurements are not impeded by clouds, so the synoptic maps of sea surface height provided by SWOT will track fine-scale circulation features at daily intervals (twice daily at crossovers) during this fast-sampling phase.

Comparing Snapshots from Earth and Space

The speed of SWOT's measurements poses a challenge to researchers attempting to compare the mission's results with in situ measurements from the surface: SWOT will cover a distance of 150 kilometers in about 20 seconds, providing a nearly instantaneous snapshot of SSH over a 120- × 150-kilometer area. In order to disentangle the substantial contributions of high-frequency motions (such as internal waves) to SSH, we need to observe the 2-D in situ dynamic height on hourly timescales.

Wang et al. [2018] presented a basic design of an in situ observing system involving an array of 20 station-keeping underwater gliders to determine hourly dynamic height over scales of 15–150 kilometers. Alternatives are to use moorings for continuous sampling, combined with fast underway CTDs (instruments that measure electrical conductivity, temperature, and depth), gliders, or profiling floats. To characterize the ocean pressure and velocity field in four dimensions (three spatial dimensions and time), we would need more in situ assets. SWOT's fast-sampling phase will also open opportunities for designing in situ adaptive sampling strategies.

Although SWOT's 2-D radar interferometric technique will reduce the measurement error by more than an order of magnitude compared to today's 1-D along-track altimetry missions, SWOT's actual spatial resolution will vary spatially and temporally, depending on the relative strength of ocean signals and the magnitude of measurement errors. Studies have predicted that SWOT's resolution may approach 35–45 kilometers in low-energy regions or in high surface wave regions.

Coupling Data Sources Yields Big Payoffs

Since the SWOT measurement performance and the oceanic fine-scale signals vary geographically and seasonally, our understanding of the oceanic variability at 15- to 150-kilometer scales would greatly benefit from in situ observations made at different locations during the 90-day fast-sampling phase. Such an ambitious undertaking can be accomplished only through coordinated international campaigns and contributions. The payoff would be tremendous in advancing our understanding of the key fine-scale dynamics of the ocean governing the energy budget and the biophysical processes of the ocean circulation, as well as its role in the climate system.

Diverse in situ deployments covering multiple crossover regions during the 1-day fast-sampling phase would help unravel the complicated dynamic processes contributing to these SWOT SSH snapshots to achieve a truly global fine-scale ocean dynamics experiment.

We encourage the international ocean science community to join us in this unique opportunity by deploying in situ assets in different regions covered by the SWOT fast-sampling orbit. Such in situ efforts would require external funding, but the SWOT mission would enthusiastically welcome these collaborative validation efforts. These projects could be proposed in coordination with the mission's next science team (NASA's Research Opportunities in Earth and Space Science and Centre National d'Etudes Spatiales' Terre, Océan, Surfaces Continentales, Atmosphère issued a request for proposals in February 2019, with selection in late 2019.) The next science team starts in 2020, about 1 year prior to the mission's launch (approximately October 2021).

The preliminary science data from the SWOT mission will be made available to the mission's science team in a timely manner during the fast-sampling phase to facilitate comparisons of the in situ observations with SWOT observations. The in situ results will contribute to the initial calibration and validation of the mission observations, as well as to SWOT's Adopt a Crossover global experiment on fine-scale ocean processes. We encourage interested ocean scientists to contact any of the authors listed below for further information.

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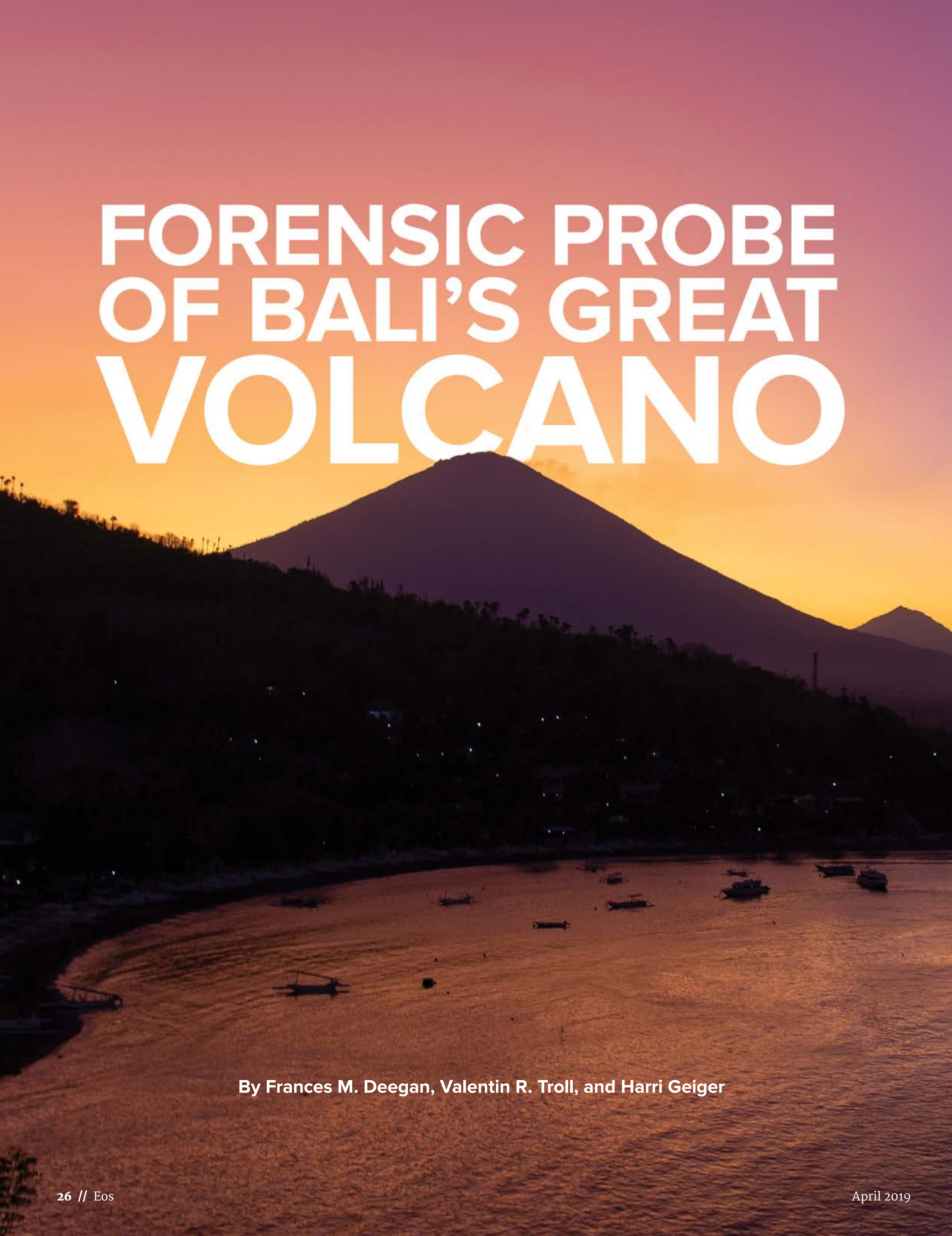
FORENSIC PROBE OF BALI'S GREAT VOLCANO



By Frances M. Deegan, Valentin R. Troll, and Harri Geiger

New evidence helps explain Mount Agung's frequent eruptions.

In November 2017, the world's eyes were focused on the tourist island of Bali, Indonesia, as Mount Agung volcano erupted for the first time since 1963 [*Gertisser et al.*, 2018]. Locals refer to Gunung Agung, the Bahasa Indonesian term for "great mountain," as Bali's great volcano. This latest Balinese eruption and the ensuing ashfall required some 150,000 people to evacuate the area and caused airline flight disruptions and widespread anxiety.

However, the 2017 eruption was tame compared with the climactic 1963 crisis, in which fast flowing, glowing hot debris avalanches killed at least 1,100 people. Sulfur-rich gas emitted to the stratosphere during the 1963 event also caused global temperatures to dip by 0.1°C–0.4°C [*Self and Rampino*, 2012].

Now that Agung has shown signs of reawakening, it is imperative that scientists understand its inner workings. Our international research team has taken on this challenge. We collected evidence from chemical analysis of volcanic crystals, which now enables us to reconstruct the magma storage network beneath Agung [*Geiger et al.*, 2018].

We found magma storage areas at both mantle (~20-kilometer) and shallow crustal (~5-kilometer)

A view of Mount Agung on 26 September 2018. Earlier that day, the Indonesian government issued a warning that an eruption was imminent. Credit: Øystein Lund Andersen/oysteinlundandersen.com

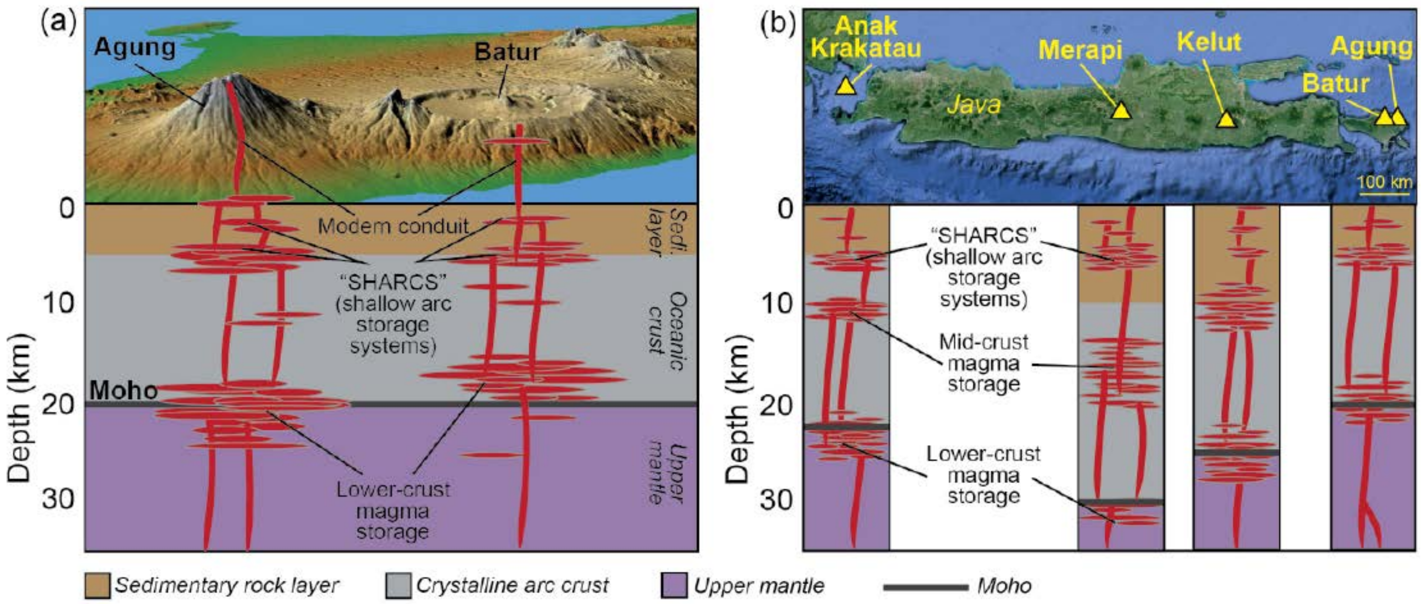


Fig. 1. (a) Schematic of Batur and Agung volcanoes with their underlying magma plumbing systems based on data by Geiger et al. *[2018] (map courtesy of NASA). (b) Magma plumbing at Anak Krakatau (Sunda Strait), Merapi (Central Java), Kelut (East Java), and Agung and Batur (Bali) based on data presented by* Geiger et al. *[2018] (map courtesy of Google Earth). Note the ubiquitous presence of shallow arc storage systems (SHARCS) throughout the region. Moho refers to the Mohorovičić discontinuity, the boundary between Earth's crust and mantle.*

depths beneath Agung. This type of multilevel plumbing system may be typical of Indonesian volcanoes and could cause magma in shallow reservoirs to become enriched in silica and volatile compounds containing sulfur or hydrogen, thus promoting the frequent explosive eruptions observed in the region.

Volcano Forensics

A research team from Sweden, the United States, and Italy collected rock samples from the infamous 1963 lavas of Agung, as well as from the 1963 and 1974 eruptions of Agung's "twin sister," Batur. These lava rocks look bland, but when we investigate wafer-thin slices of them under a microscope, a whole world of different crystal types and sizes is revealed.

Most of the crystals are close to one fifth of a millimeter across, but some can be as large as 1 millimeter. These crystals contain a rich archive of information about magmatic processes under and within Agung volcano. The most common minerals in Agung and Batur lavas are pyroxene and plagioclase feldspar, whose chemical composition varies as a function of the pressure and temperature under which they crystallized.

Micrometer-scale chemical data gathered from these minerals can thus be used to calculate their approximate depths of crystallization [*Putirka*, 2017]. In this way, scientists can make inferences about where magma is stored under a volcano and make predictions about how eruptions are fed, supplied, and, in some cases, sustained for considerable time.

Volcano forensics—studying minute crystalline components of volcanic rocks—has been very useful for investigating Agung and Batur [see *Geiger et al.*, 2018]. Scientists learned that before the devastating 1963 eruption, magma was stored at multiple levels beneath the volcano, within an interconnected network of melt pockets (Figure 1). One of the main storage levels was at the crust-mantle boundary some 20 kilometers beneath the island's surface. This is likely the region where magma produced by partial melting of Earth's mantle meets the lower crust and enters large magma reservoirs. The reservoirs probably form at this boundary level because of the

Before the devastating 1963 eruption, magma was stored at multiple levels beneath the volcano, within an interconnected network of melt pockets.

Lavas from Agung on Bali contain numerous crystals, such as this pyroxene surrounded by plagioclase feldspar (viewed under a polarizing microscope; field of view is approximately 3 millimeters). These crystals are held in a groundmass (or matrix) made of tiny, barely perceptible crystals (microlites) and glass (former melt).

density contrast between the mantle and the crust. Mantle-derived magma is basaltic—rich in magnesium and iron and relatively poor in silica—but it is relatively hot, and subduction zone systems often introduce volatiles into the magma. This magma delivers a flush of new volume, heat, and volatiles into the plumbing system, sending shock waves through the crust, which scientists can detect seismically in the form of deep crustal earthquakes.

The other major storage level detected at Agung lies within the top 5 kilometers beneath the volcano. A 2012 study used interferometric synthetic aperture radar (InSAR) to observe deformation indicative of a magma body at just a few kilometer's depth [*Chaussard and Amelung,* 2012], and the existence of a shallow magma body has now been confirmed using petrological methods [*Geiger et al.,* 2018].

When magma is stored in the top portions of Earth's crust, it cools and crystallizes, changing the composition of the remaining melt so that it becomes more viscous and enriched in alkali elements and silica (e.g., basaltic andesite or andesite composition). Silica-enriched magma, in turn, can dissolve greater amounts of water than basaltic magma, but neither magma type can keep a lot of volatiles in solution under the relatively low pressures of the upper crust. These elemental and volatile enrichments in shallow-level magma reservoirs can be further modified by interaction between magma and hydrous crustal rocks or fluids and, in so doing, promote conditions favorable for explosive eruptions.

Shallow Arc Storage Systems

Crystal-based volcano forensics helps scientists to assess magma storage levels and to evaluate the likelihood of future explosive eruptions. Other studies using thermobarometry and InSAR data have revealed that multilevel plumbing systems are likely present under other Indonesian volcanoes such as Anak Krakatau, Mount Merapi, and Mount Kelut (Figure 1). These observations suggest that shallow arc storage systems (SHARCS) are a widespread phenomenon in the Sunda subduction system.

The challenge with shallow magma reservoirs is that it remains very difficult to predict when an eruption will occur. It is important to monitor these volcanoes for

Kelut volcano in East Java exhibited only a few days of increased shallow crustal seismicity prior to a short but extremely explosive eruption.

signs of unrest, such as increased seismicity, that might indicate magma or gas movement in the plumbing system. For example, concurrent deep and shallow earthquakes may indicate replenishment of the shallow plumbing system from depth.

In the case of the Agung 2017–2018 events, seismic data from the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) initially revealed earthquakes at depths greater than 20 kilometers, which then migrated upward, signaling reactivation of the shallow magma storage system. In 1963, by contrast, the plumbing system at Agung was ripe for a major explosive event, possibly because of the nature of the evolved magma in the shallow crustal magma chamber and the rate and intensity of basaltic injections, which led to a larger and sustained eruption.

In fact, repeated injections of basaltic magma from deep in Earth into high-level andesitic magma bodies might have caused magma mixing and violent expulsion of volatiles from solution prior to the devastating 1963 eruption of Agung [*Self and Rampino,* 2012], as determined by evidence from magma chemistry, crystal zoning patterns, and observations of partly dissolved crystals.

However, processes such as cooling, fractionation, and possibly magma-crust interaction can oversaturate the volatiles in SHARCS, which can cause eruptions from shallow reservoirs that are not heralded by deep seismicity. These processes can cause apparently sudden, erratic explosive eruptions, as likely exemplified by the 2014 Valentine's Day eruption of Kelut volcano in East Java. This volcano exhibited only a few days of increased shallow crustal seismicity prior to a short but extremely explosive eruption [*Cassidy et al.,* 2016]. Another example is the brief but explosive eruption at Merapi in June 2018.

Our research group is currently analyzing recently obtained crystal-scale isotope data. We anticipate that information from these studies and other such emerging volcano forensic techniques will reveal more clues for better understanding the processes and resulting behavior of arc volcanoes like Agung in the near future. Stay tuned!

Acknowledgments

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SEARCHING FOR LIFE UNDER THE SEAFLOOR

By Gretchen L. Früh-Green and Beth N. Orcutt

Tectonic plate movements wrinkle and stretch Earth's crust, pushing up mountain ranges in some regions and spreading the crust in other regions until it splits. Along mid-ocean ridges, slow spreading under the right conditions can expose rocks from the lower crust and upper mantle. Seawater percolating through cracks and fractures in exposed mantle rocks oxidizes the minerals in these rocks, releasing ions and chemical compounds into the nearby seawater.

These rock reactions excite scientists because they may produce nutrients for subsurface

Limestone towers, known as The Lost City, on the floor of the Atlantic Ocean. Credit: D. Kelley and M. Elend/University of Washington

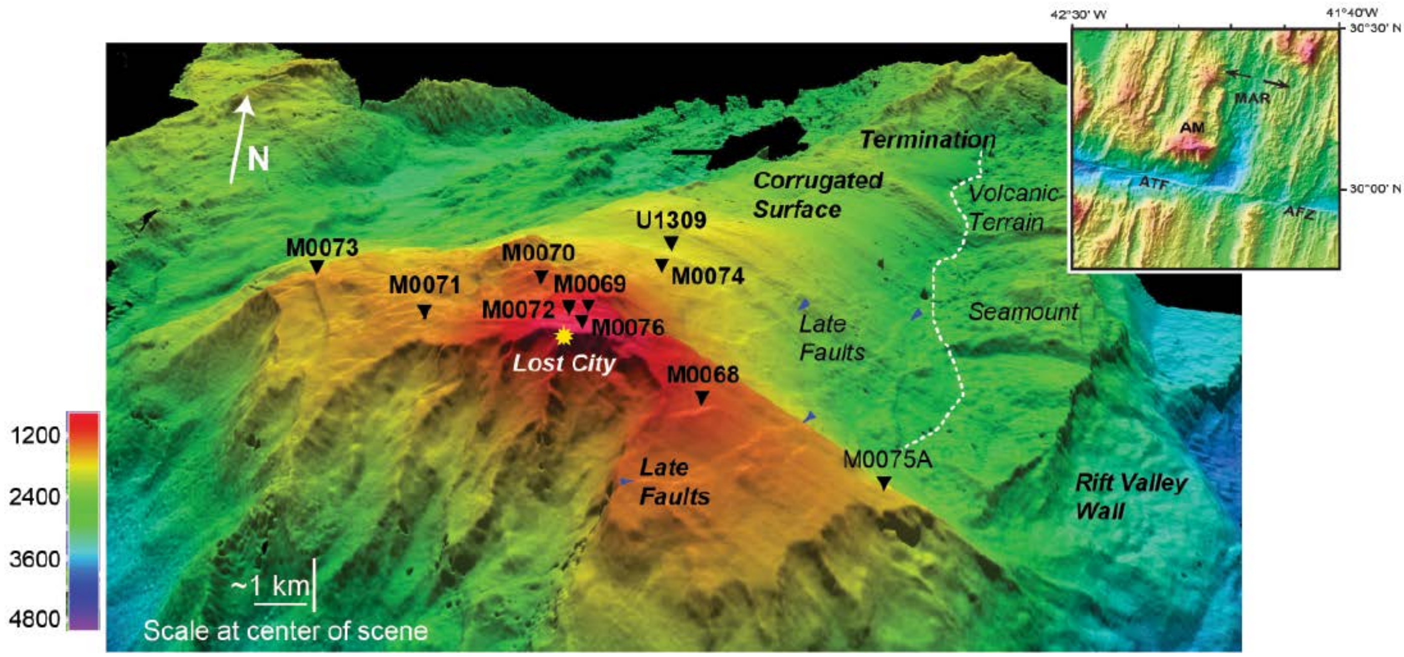

Fig. 1. Bathymetry of the Atlantis Massif: 3-D terrain model with a northward view of the detachment fault surface. Striations define the corrugated surface associated with detachment faulting. Also shown are late crosscutting faults (Late Faults), locations (black triangles) of the IODP Expedition 357 drill sites and IODP Site U1309, and the Lost City hydrothermal field. This map is based on new multibeam bathymetry of Atlantis Massif acquired at 50-meter resolution. The inset shows the location of the Atlantis Massif (AM) at the intersection of the Mid-Atlantic Ridge (MAR) and the Atlantis Transform Fault (ATF) and Atlantis Fracture Zone (AFZ).

microbial life in the depths of the ocean where sunlight doesn't penetrate. The conditions these reactions create may be analogous to conditions early in Earth's history or those that exist on other planets.

In late 2015, Expedition 357 of the International Ocean Discovery Program (IODP) set out to collect cores from across the Atlantis Massif, a prominent, nearly 4,000-meter-high underwater mountain on the Mid-Atlantic Ridge (Figure 1). The Atlantis Massif is one of the best-studied oceanic core complexes. Its exposed mantle-derived rocks react with seawater and produce methane- and hydrogen-rich, alkaline waters [*Karson et al.,* 2006; *Proskurowski et al.,* 2006]. Along the massif, where these warm alkaline waters exit through fissures in the seafloor, impressive white towers of carbonate rise up tens of meters, creating a distinctive environment that researchers have dubbed the "Lost City" [*Kelley et al.,* 2005].

IODP Expedition 357 aimed to gain a deeper understanding of the interlinked magmatic, tectonic, and mineral-forming processes that led to the exposure and alteration of mantle rocks. The expedition also investigated the types of subsurface life that make their homes in this extreme, alkaline, carbon dioxide–poor environment.

Pivotally, our team of researchers found organisms within mantle rocks in core samples we collected from the seafloor under the North Atlantic Ocean, as recently reported by *Früh-Green et al.* [2018]. Identifying the organisms in this ecosystem is a work in progress, but this biosphere may be larger and more diverse than we had previously understood.

Rock Reactions Create an Extreme Habitat for Life

The formation of slow spreading mid-ocean ridges is influenced by irregularly occurring magmatic activity and asymmetric crustal stretching along major faults. In some areas with this type of spreading, the upper crustal layers can split apart and lower crustal and upper mantle rocks can be pulled up to the surface in the gap, producing a domed structure referred to as a core complex.

Seawater can percolate through cracks and fractures in mantle rocks exposed in the core complex, causing iron- and magnesium-bearing minerals to be oxidized and hydrated in a process known as serpentinization, named after the serpentine minerals produced in the process (Figure 2). Serpentinization is a fundamental process that drastically changes the geophysical properties of the oceanic lithosphere and can produce alkaline fluids (pH 9–12) with high concentrations of hydrogen, methane, and formate ions (HCO_2^-), which could support microbial life.

Many Firsts for Ocean Drilling

Using seabed drills for the first time in the history of the international ocean drilling program, we cored 17 holes across nine sites. This was also the first time that seabed drills, usually a soft-sediment tool, were used to penetrate hard rocks on the seafloor. We recovered as much as 75% (in some cores) of shallow mantle sequences from the top 17 meters of a core complex detachment fault zone—an unprecedented level of recovery for hard-rock drilling [*Früh-Green et al.,* 2017; *Früh-Green et al.,* 2018]. Also new to the drilling program was a suite of sensors mounted on the seabed drills that measured dissolved methane and hydrogen, temperature, pH, and oxidation reduction potential

A first for ocean drilling: A custom-designed sensor package and Niskin bottles mounted on the British Geological Survey Rock Drill 2 (RD2) seabed drill allowed us to monitor in situ the formation fluids and to collect water samples after drilling. Credit: Susan Lang

during coring operations, providing real-time information about fluids in the basement.

We collected bottom water samples before and after drilling and analyzed them for dissolved hydrogen and methane levels to evaluate the influence of serpentinization in the region. Finally, a high-resolution multibeam bathymetric survey provided a picture of the surface of the detachment fault at the top of the Atlantis Massif, the Mid-Atlantic Ridge axis to the east, and the Atlantis Fracture Zone to the south. The survey revealed small-scale patterns, such as corrugations and striations, late-stage faults, and mass wasting (Figure 1).

Documenting a Heterogeneous Lithosphere

The cores we recovered preserved a variety of contacts between various types of rock, deformation features, and alteration characteristics. The cores highlight a highly variable distribution of magma-derived rocks with a range of alteration styles and extents of deformation. They also show that the rocks in this region have a high degree of serpentinization and alteration due to interaction with seawater or other fluids, which points to silica mobility and channeled fluid flow within the detachment fault zone.

We compared the coarse-grained, iron- and magnesium-rich gabbroic rocks recovered during this expedition with similar rocks recovered from the central dome of the Atlantis Massif during IODP Expeditions 304/305 [*Ildefonse et al.*, 2007]. The distribution of rock

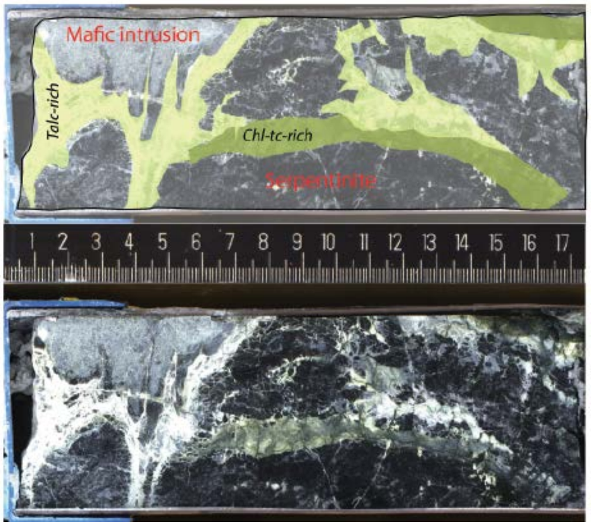

Fig. 2. Example of magmatic intrusion in a fully serpentinized harzburgite. Color overlays highlight the fluid-driven alteration at the contact between the mafic and ultramafic rocks (top). This true-color image shows white and green assemblages of talc (tc) and chlorite (Chl) that crosscut the previous texture (bottom). The ruler shows the depth of the core sample in centimeters. Reproduced with permission from Früh-Green et al. *[2017]. Credit: ESO (European Consortium for Ocean Research Drilling Science Operator)*

ODP Expedition 357 used seabed drills for the first time in the ocean drilling program. Here the RD2 seabed drill is deployed over the starboard side of the RRS James Cook. *Credit: Dave Smith*

types between the southern ridge and the central dome of the massif reflects variations in the distribution of magmatic melt within the oceanic core complex. Overall, comparison of the recovered rock types, crosscutting alteration and deformation relationships, and interpretation of the new bathymetric map provide a record of the history of this region: early gabbroic intrusion in the shallow mantle, progressive seawater infiltration with multiphase serpentinization and silica mobilization along the detachment fault zone [*Rouméjon et al.*, 2018], injection of dolerite dikes, and recent basalt volcanism.

In Situ Records of Active Processes

The complementary water sampling program and data from the custom sensor package on the seabed drills confirmed that seawater is still circulating through the mantle-derived rocks at the Atlantis Massif and that these rocks are still being altered to form serpentinite. The drill-mounted sensors registered increases in releases of methane and hydrogen that correlated with decreases in oxidation reduction potential at most sites [*Früh-Green et al.*, 2017].

This suggests that the drills penetrated horizons that released serpentinization-derived fluids and volatiles into the drilling fluid. We found elevated hydrogen and methane concentrations in most water samples, particularly at sites near Lost City. The elevated concentrations of volatile species reflect active serpentinization processes occurring within the subseafloor and the release of hydrogen and methane into bottom seawater.

We also designed and installed novel borehole plug systems to enable future sampling of the subsurface fluids and provide long-term information about fluid compositions and microbial processes. A U.S.-led research expedition visited these plugged holes in September 2018 with the remotely operated vehicle *Jason* (funded by the National Science Foundation) to further investigate the serpentinization and microbiological processes operating in this system.

Rock Reactions Fueling a Deep Biosphere

The gases that we found could support a subseafloor biosphere fueled by chemolithotrophic reactions; that is, the chemical alteration of the rocks could provide nutrients for living organisms. We sampled roughly 15% of the recovered core for microbiological investigation, and we were able to confirm the presence of life in this subseafloor environment through cell counts, which revealed cell densities on the order of 10–1,000 cells per cubic centimeter of rock [*Früh-Green et al.*, 2018].

We're currently evaluating the diversity of life and testing the range of metabolisms supported by reactions between fluid and rock in this subseafloor biosphere using a variety of laboratory incubations and analyses. Considering the extent of ultramafic environments on the seafloor and the longevity of seawater circulation during serpentinization, the ultramafic-hosted biosphere may be greater than previously appreciated, and these samples provide a first glimpse of the magnitude and diversity of this ecosystem.

Overall, IODP Expedition 357 proved a successful trial of using seabed drills for ocean crust drilling and provided unprecedented samples from an oceanic core complex to study crustal accretion, uplift processes, serpentinization, and the deep biosphere.

Acknowledgments

These results were made possible by the IODP Expedition 357 project managers (Carol Cotterill and Sophie Green), the Meeresboden Bohrgerät (MeBo) and British Geological Survey seabed drill teams, and the entire science party (N. Akizawa, G. Bayrakci, J.-H. Behrmann, E. Herrero-Bervera, C. Boschi, W. Brazelton, M. Cannat, K. G. Dunkel, J. Escartin, M. Harris, K. Hesse, B. E. John, S. Q. Lang, M. D. Lilley, H.-Q. Liu, L. Mayhew, A. McCaig, B. Ménez, S. Morgan, Y. Morono, M. Quéméneur, A. S. Ratnayake, S. Rouméjon, M. O. Schrenk, E. M. Schwarzenbach, K. Twing, D. Weis, S. A. Whattam, M. Williams, and R. Zhao). Figure 1 was prepared postcruise by Javier Escartin, Marvin Lilley evaluated the hydrogen and methane data, and cell count data were provided by Yuki Morono. We thank the captain and crew aboard the RRS *James Cook* as well as IODP, ECORD, and the ESO staff for their efforts and support during all phases of IODP Expedition 357.

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Advancing FAIR Data in Earth, Space, and Environmental Science

Kenton/depositphotos

Research and scientific discovery are rooted in a rich, fluid ecosystem of shared information that includes data, publications, software, physical samples, and a myriad of other research products. A combination of technological advances and increasing pressures on global resources is prompting a major shift in how data and research products are shared and valued in the Earth, space, and environmental sciences (ESES). This shift is complicated by legacy systems of communication, incentives, and cultural norms. Open sharing [*European Commission,* 2016] of data and research products will mitigate many of these challenges and enable new frontiers of discovery. Toward this goal, scientific publishers, geoscience data repositories, funders, and other stakeholders met in March 2018 as part of the Enabling FAIR Data project, funded by the Laura and John Arnold Foundation through AGU. By leveraging the FAIR principles [*Wilkinson et al.,* 2016]—findable, accessible, interoperable, and reusable—this emerging community is working together to ensure that data, physical samples, and software are treated as first-class research products to open new opportunities for ESES research.

Community Driven, Community Led

The Enabling FAIR Data project mobilized a community of more than 300 cross-sector leaders to improve data handling across the ESES. Building on the achievements of the Coalition for Publishing Data in the Earth and Space Sciences (COPDESS) initiative [*Hanson et al.,* 2015] and using the FAIR Data Principles as a framework, AGU partnered with Earth Science Information Partners (ESIP) and the Research Data Alliance (RDA) as primary data communities to generate new capabilities and connect with data experts. The value of the inclusive, community-driven approach was the vibrant and full picture of existing work painted by the array of participants. To address the ESES-specific challenges identified, we primarily amplified and connected existing pieces and then developed new materials where needed.

The first step in the community development process was bringing together a representative group to share their perspectives and work to find connections [*Stall et al.,* 2017]. International cross-community participants organized and developed charters around identified challenges and split into action groups to address these roadblocks to open and FAIR ESES data. The volunteer-led action groups were the following:

- Repository Guidance for Researchers
- Publishers in the ESES
- FAIR Resources and Training for Researchers
- Data and Digital Object Identifier Workflows and Handoffs
- Culture Change Through Credit
- Key Elements of Active Data Management Plans (DMPs)

The groups leveraged community venues at the ESIP Winter Meeting 2018 in Bethesda, Md., and at the GFZ German Research Centre for Geosciences, colocated with the RDA Eleventh Plenary Meeting in Berlin, Germany. Deeply embedded assumptions in the culture emerged from these discussions, beginning a process of "assumption wrangling." The work of shifting the culture to align with FAIR principles is ongoing.

Community-Based Support for Researchers

The action groups, over a period of 5 months, identified gaps in researcher support and then brought together international experts to develop the needed social and technical infrastructure to streamline researcher workflows:

- **Repository Selection Decision Tree for Researchers** [*Enabling FAIR Data Community,* 2018a] demonstrates the complexity researchers face to find the best possible repository for data.
- **Repository Finder Tool** enables identification of FAIR-aligned repositories where research data can be deposited. (A FAIR-aligned repository complies with the goals in the Enabling FAIR Data Commitment Statement specific to scientific repositories.) It was developed by DataCite, leveraging the Repository Selection Decision Tree and the re3data international registry of repositories. Usability testing was carried out by the ESIP Usability Cluster and DeveloperTown. Curation of repository records is by the re3data Editorial Board.
- **Author Guidelines for Data** [*Enabling FAIR Data Community,* 2018b] ensures that journal data policies are consistent for researchers publishing in ESES journals.
- **Data Management Training Clearinghouse** offers centralized access to training materials on FAIR Data Principles and other topics. It was developed by a collaboration between ESIP, the U.S. Geological Survey's Community for Data Integration, and DataONE. Additional funding was provided by the Institute of Museum and Library Services.

Helping Repositories Be FAIR

The ESES repository community offers diverse data expertise and services to support the wide range of ESES research communities. To better understand what is needed to achieve FAIR data in ESES repositories, an inventory [*Enabling FAIR Data Community,* 2018c] was designed and piloted by one of the action groups. The inventory provided a snapshot of repository status and readiness for trustworthy services in an otherwise opaque part of the data ecosystem. On the basis of the outcome, the Enabling FAIR Data project focused on FAIR's F and A: findable and accessible. Also, in response to the inventory results, a repository cohort has been established in partnership with CoreTrustSeal and the World Data System and supported by the Council of Data Facilities to advance the implementation of FAIR principles in ESES repositories.

The value of a community-based approach can also be seen in the group's ability to include prepublication outcomes from the European Union–funded Technical and Human Infrastructure for Open Research (THOR) project as a result of involvement from those project participants. The action team captured the complex connections between the submission process of a manuscript to a journal and the deposition process of data to a repository. The workflows [*Enabling FAIR Data Community,* 2018d] clarified the communication necessary to share common data citations to link publications with supporting data and other research products.

A Commitment from the Community

The researcher and repository tools adopted and developed by the project support a larger set of community-defined goals to implement open and FAIR data. The Commitment Statement galvanized this momentum in the ESES community. The statement reflects distinct stakeholder perspectives and roles and defines goals for each ESES stakeholder that collectively support open and FAIR data. Individual or organization signatories commit to achieving full alignment within 1 year of signing. Those interested in becoming a signatory should click the Sign On button provided with the Commitment Statement (see bit.ly/commitment-statements).

Repositories will strive to support researchers with open and FAIR data services and support scholarly publishing with services for data citation, persistent identifiers, and human- and machine-readable descriptions.

Publishers will strive to ensure that data and other research outputs supporting publications are openly accessible at the time of publication in a FAIR-aligned repository, no longer accept article supplements as the primary archive for data, adopt the Author Guidelines [*Stall et al.,* 2018] to provide a common expectation, and implement standard identifiers for authors, data, and research products.

Societies, communities, and institutions will strive to support open and FAIR Data Principles in their activities and policies and promote open and FAIR data activities as important criteria in promotion and tenure, awards, honors, etc.

Funding agencies and organizations will strive to promulgate open and FAIR Data Principles in their activities and policies; align DMP content, DMP review processes, and DMP enforcement with FAIR principles; and support the description of plans for sharing physical samples and software in DMPs.

Researchers will strive to make all research products (e.g., data, software, physical sample information, etc.) FAIR and open by depositing them in FAIR-aligned repositories, cite all research products created or reused in publications, and include a data availability statement in publications to specify where the research products that support the paper can be accessed.

Frequently asked questions with community-generated and community-vetted guidance toward open and FAIR data and research products are available at bit.ly/FAIR-data-faqs.

The First Step in an Important Journey

The community-driven Enabling FAIR Data project is advancing the culture shift needed in the ESES by bringing cross-sector stakeholders together to promote the common goals of open and FAIR data. The tools and guidelines identified, developed, and adopted by the community bring together ESES publications, data, physical samples, and software, but this is just a first step. Ongoing commitment from institutions, governments, funders, and researchers is necessary to ensure application of open and FAIR principles to data, software, and physical samples.

Fortunately, the Enabling FAIR Data project revealed an energetic, collaborative, and growing community that is ready to act, and the work thus far has empowered that community to make change. We are on our way to realizing a practical vision of open and FAIR data involving and benefiting the entire research community and the world.

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For a
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How Will Melting Glaciers Affect Streamflow?

Research suggests that climate change–induced melting of the Nisqually Glacier near Seattle, Wash., and other high-elevation glaciers will offset seasonal declines in streamflow until late in the 21st century. Credit: iStock.com/KingWu

Glacier retreat is an extensively studied effect of climate change, and the Pacific Northwest is a hot spot for climate change–induced glacier retreat, with 858 glaciers contained in an area of 466 square kilometers. Runoff from shrinking glaciers can both increase and decrease summertime streamflow in alpine regions, but climate change also affects snow accumulation, evapotranspiration, and other hydrological factors that influence streamflow.

Few studies have examined how all of these factors might interact to alter future streamflow as climate change progresses. New research by *Frans et al.* predicts differing timelines for the effects of melting glaciers on streamflow at high versus low elevations in the Pacific Northwest.

The authors investigated this interplay using a high-resolution computer model to predict glacier and streamflow dynamics between 1960 and 2099 for six river basins fed by glaciers in the Pacific Northwest. The model incorporates regional climate data and is calibrated with real-world observations of glacier size and streamflow.

The six selected river basins span a range of elevations and climates, allowing for comparison between settings—from a high-precipitation setting with low-elevation glaciers in the Olympic mountain range, for example, to a drier, continental climate in the Cascades. The researchers' analysis of the model projections shows that glacier retreat in all six basins will accelerate throughout the 21st century. However, the resulting effects on streamflow are projected to vary according to elevation.

At higher elevations, the model projects, glaciers will remain big enough for their meltwater to buffer large declines in seasonal snowfall until late in the century. At that point, high-elevation glaciers will have shrunk too much for continued melting to support historic summertime streamflow levels. However, lower-elevation glaciers are already small enough that they will stop enhancing streamflow as soon as 2020 in some regions.

These new findings could help clarify the potential effects of glacier retreat on water resources and ecology in the Pacific Northwest. The authors note that continued advancements in computing and in remote sensing techniques to measure glacier size will enhance future efforts to model the streamflow effects of shrinking glaciers. (*Water Resources Research,* https://doi.org/10.1029/2017WR021764, 2018)

—Sarah Stanley, Freelance Writer

More Evidence Humans Migrated to the Americas via Coastal Route

Broad consensus exists that humans initially migrated into the Americas via a land bridge that temporarily formed between Siberia and Alaska. Experts believe that their southward progress was then blocked by the Cordilleran ice sheet, one of two continental ice sheets that covered much of northern North America during the Quaternary glacial cycles. Genetic evidence indicates that migrations south of the ice sheet began roughly 16,000 years ago, but the path the nomads took around the retreating ice remains uncertain.

According to one hypothesis, the earliest migrants traveled along an interior corridor that opened between the receding Cordilleran and another even larger ice sheet to the east. But recent evidence indicates that this route may not have hosted enough resources for humans to cross it until about 13,000 years ago. A competing hypothesis proposes that the first humans migrated south along British Columbia's west coast. However, it's unclear exactly when this route became viable.

Darvill et al. present a dating chronology that provides new geological constraints on the timing of Cordilleran ice sheet retreat. The researchers gathered 32 samples from seven locales along British Columbia's central coast, a crucial portion of the proposed coastal migration route. The team used beryllium-10 cosmogenic nuclide exposure dating to estimate the length of time rocks have been exposed on Earth's surface since the last deglaciation.

Their results include data from bedrock, moraine, and glacial erratic samples and indicate that the ice sheet's westernmost margin began retreating about 18,100 years ago. This timing is earlier than previously thought and earlier than the time when the ice sheet's southern lobes reached their maximum extents. Because the new chronology suggests that at least some portions of British Columbia's west coast were ice free well before the interior corridor became viable and also more closely coincides with the available genetic evidence, this study bolsters the argument that the first humans migrated into the Americas along a coastal route. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL079419, 2018) **—Terri Cook, Freelance Writer**

Ancient Faults Amplify Intraplate Earthquakes

Although earthquakes that strike in the interior of tectonic plates can inflict widespread damage, the processes that drive this type of seismicity are still poorly understood. This is partly due to the lower rates of deformation occurring in these regions compared with those at plate boundaries. Researchers have proposed that intraplate deformation is concentrated along ancient faults inherited from earlier cycles of tectonic activity. But exactly how these inherited structures influence modern seismicity remains a topic of vigorous debate.

Tarayoun et al. have quantified the impact of inherited structural features on the deformation occurring within eastern Canada's Saint Lawrence Valley, a region that has experienced two full cycles of ocean basin inception and closure during the past 1.3 billion years. Using new episodic and continuous GPS data acquired from 143 stations, the team calculated surface deformation rates across the region and compared them with the rates predicted by models of glacial isostatic adjustment (GIA), the main process controlling deformation in the valley today.

A scientist sets up GPS equipment in La Malbaie, Que. Credit: Stephane Mazzotti

The results indicate that within the Saint Lawrence Platform (the geological province paralleling the Saint Lawrence River that is riddled with inherited, large-scale faults), the rates of deformation average 2–11 times higher than those measured in the surrounding provinces. And although the GPS-derived and GIA-predicted deformation rates generally agree in the surrounding provinces, the GPS-calculated rates are, on average, 14 times higher than those predicted by GIA models within the Saint Lawrence province. This result strongly suggests that this zone of inherited structures concentrates modern surface deformation.

This research offers compelling evidence that the Saint Lawrence Valley represents a zone of high intraplate deformation, controlled by forces linked to the region's postglacial rebound and amplified by inherited structures from earlier tectonism. As the first study to quantify the impact of structural inheritance on surface deformation, this groundbreaking research will help unravel the processes that control deformation, as well as the poorly understood earthquakes that occur in the center of tectonic plates. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1029/2017JB015417, 2018) **—Terri Cook, Freelance Writer**

How Ningaloo Niño Supercharges the El Niño–Southern Oscillation

Researchers find that a warm current in the southeastern Indian Ocean may be associated with supercharged ENSO events, which often correspond with major coral bleaching events. Credit: iStock.com/Rainer von Brandis

In 2011, a record-breaking marine heat wave off the west coast of Australia wreaked ecological havoc, bleaching coral reefs and causing massive fish die-offs. Scientists identified the cause of the destruction to be Ningaloo Niño, a warm surge within an ocean current that flows south from Indonesia. A new study reveals that Ningaloo Niño forms a positive feedback loop in the Pacific Ocean, a discovery that could help scientists predict the El Niño-Southern Oscillation (ENSO): periodic changes in sea temperature that can cause droughts, floods, and heat waves.

Scientists already knew that La Niña, the cold phase of ENSO, plays a key role in triggering Ningaloo Niño by stirring up winds and ramping up the flow of water from the Pacific Ocean into the Indian Ocean. They also knew that sometimes local events also produce a Ningaloo Niño entirely independent of La Niña. But they didn't know how the abnormally high temperature of this warm current influences currents in the tropical Pacific or how those currents, in turn, affect Ningaloo Niño.

To find out, *Zhang and Han* looked at data from the Hadley Centre Global Sea Ice and Sea Surface Temperature resource, a record of monthly satellite and in situ measurements of sea surface temperatures and sea ice concentrations around the globe. The researchers focused on the years 1940–2016 and also examined wind records from the same time period. They ran three computer simulations: a control, which used the climatological sea surface temperatures, and two experiments that mimicked sea surface temperatures to resemble Ningaloo Niño and Pacific La Niña.

The models showed that the warmer waters in the southeastern Indian Ocean strengthened the western tropical Pacific trade winds and cooled the waters of the equatorial Pacific regions. This cooling lowered atmospheric pressure at sea level and caused cyclonic winds to form over the southeastern Indian Ocean. In turn, the stronger trade winds and cooler Pacific waters enhanced the strength of Ningaloo Niño's warm current: a feedback loop.

These results indicate that Ningaloo Niño may play an unappreciated role in building up the strength of La Niña and has likely contributed to shaping the sea surface temperature patterns of several so-called super El Niños, including those in 1982 and 1997. According to the authors, ENSO forecasts could be more accurate if they took Ningaloo Niño into account. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL078579, 2018) **—Emily Underwood, Freelance Writer**

Gravity Waves Dance Above Antarctica in Winter

Measurements of temperature fluctuations in the middle and upper atmosphere taken above Antarctica's Arrival Heights observatory near McMurdo Station are helping researchers to better understand the properties of persistent gravity waves in Earth's atmosphere. Credit: Xinzhao Chu

Gravity waves are enormous vertical oscillations of air that propagate through the atmosphere like ripples in quiet water, and they are perpetually present in the Antarctic atmosphere. Because these waves can create air turbulence and affect weather and climate by transporting energy and momentum between atmospheric layers, researchers have diligently searched for their sources.

Any gravity wave source must be constrained by wave properties observed in the atmospheric layers between 50 and 115 kilometers above Earth's surface, where persistent gravity waves were first documented, and in the underlying stratosphere, where gravity waves have not yet been rigorously characterized. To help fill this gap, *Chu et al.* report the results of a detailed statistical analysis of gravity wave characteristics in the stratosphere. Their data, which span from 2011 to 2015, are derived from the first multiyear, year-round measurements of temperature fluctuations made using an iron Boltzmann lidar system at the Arrival Heights observatory near Antarctica's McMurdo Station.

The results document the strength and the rate of dissipation of waves between altitudes of 30 and 50 kilometers and show striking differences among the four seasons. The data clearly demonstrate that despite significant year-to-year variability, gravity wave dissipation is consistently more severe during the winter. The team also found that wave activity peaks in midwinter, when the station is situated deep within the polar vortex, and declines during spring, when McMurdo is located near the vortex edge.

This is the first study to document multiyear seasonal patterns in gravity wave activity in the upper Antarctic stratosphere—an important contribution to our understanding of Antarctic gravity waves. The results also serve as an observational benchmark for future research, provide a physical basis for improving the performance of general circulation models, and, ultimately, aid in the search for the sources of persistent gravity waves in Earth's upper atmosphere. (*Journal of Geophysical Research: Atmospheres,* https://doi.org/10.1029/2017JD027386, 2018) **—Terri Cook, Freelance Writer**

Organic Particles Affect Carbon Cycling in Boreal Waters

Towering conifers store much of the carbon in boreal forests, the vast wooded expanses in the Northern Hemisphere's circumpolar region, but a significant proportion is processed and transported through the ecosystem by inland waterways. Carbon perseveres in these bodies of water as dissolved organic carbon (DOC), organic matter in the submicrometer range, and as larger flecks of matter known as particulate organic carbon (POC). Only half of the aquatic carbon in boreal waterways eventually spills into the oceans; the remainder is consumed or lost before it reaches the sea. Much of this lost carbon escapes into the atmosphere as carbon dioxide (CO_2), resulting in significant aquatic emissions.

Although POC accounts for nearly half of the total flux of organic carbon in rivers around the world, the bulk of the research to date has focused on the role of DOC in the carbon cycle; questions remain as to how aquatic carbon degrades and transforms when it is in POC form. On the basis of its ubiquitous distribution in northern waters, however, larger-sized organic material may appear to be a vital cog in the boreal carbon cycle and an essential regulator of CO_2 emissions.

To better understand carbon transformation and the role of POC in boreal waters, *Attermeyer et al.* analyzed how carbon degraded in different aquatic habitats in Sweden's boreal forests. They sampled 30 water bodies, ranging from peat surface water to rivers to lakes. The samples spanned environments and water retention times, a variable that can dictate organic matter decomposition.

The researchers found that across all aquatic ecosystems, the degradation rates of POC were approximately 15 times higher than those of DOC. Furthermore, the half-life of POC was only 17 days, a remarkably short decay in comparison with that of other forms of aquatic organic matter. In addition, the rapid deterioration of the particulate matter correlated with a shift in the ratios of carbon to nitrogen, whereas the ratio stayed the same for DOC.

The rapid decay of particulate matter ran counter to the study's findings that the sampled waters maintained consistent POC levels, which suggests a continuous replenishment of the POC pool. The authors believe that dissolved matter may clump together to create bulkier particles as water flows downstream, and these larger particles are later counted as particulate matter. The loss of DOC along the aquatic continuum supported this determination.

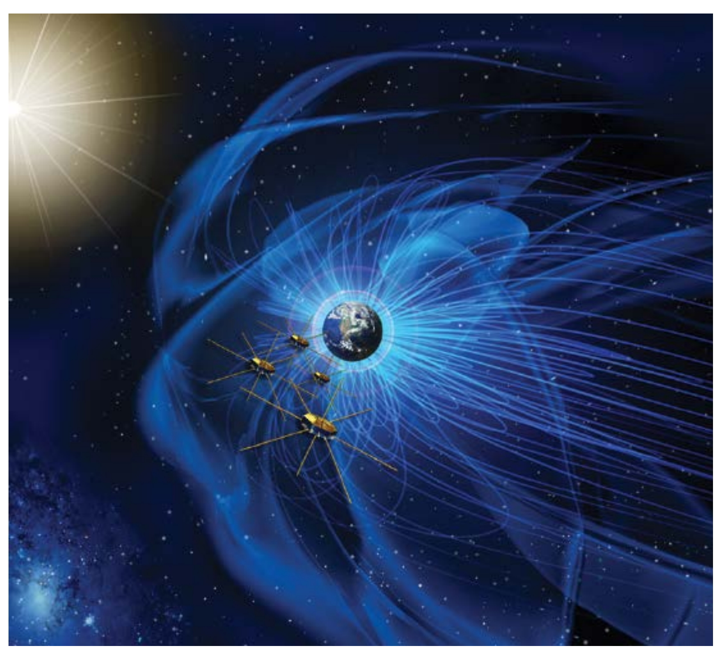
These results imply that particulate organic matter may play a more significant role in aquatic CO_2 emissions than previously thought. The findings also suggest that biogeochemical researchers should turn their attention toward particulate organic carbon, which is currently understudied. *(Journal of Geophysical Research: Biogeosciences,* https://doi.org/10.1029/2018JG004500, 2018) **—Aaron Sidder, Freelance Writer**

New Plasma Wave Observations from Earth's Magnetosphere

Plasmas are swirling mixtures of gas so hot that many of their constituent atoms have been stripped of their electrons, creating a dynamic field of both negatively and positively charged particles that are strongly influenced by magnetic and electrical fields. Plasmas account for more than 99% of matter in the universe and can disrupt satellite navigation systems and other technologies, but scientists are still working to understand the fundamental processes occurring within them.

Usanova et al. report new observations of plasma waves in the magnetosphere, the region surrounding our planet where Earth's magnetic field controls the charged particles. Using data from the FIELDS suite of instruments aboard NASA's Magnetospheric Multiscale satellites, they identified a series of electromagnetic ion cyclotron waves—high-frequency oscillations that can be divided into several bands on the basis of their vibrational frequencies—within the plasma sheet boundary layer during a 3-day period in May 2016.

In addition to measuring multiple harmonics of these waves in the oxygen frequency band, the satellite instruments also unexpectedly detected other accompanying waves, including higher-frequency broadband and whistler mode chorus waves that modulate at the same frequency. By presenting the first simultaneous observations of these various wave types, this study is likely to open up an entirely new area of inquiry into cross-frequency wave interactions at both electron and ion scales. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL079006, 2018) **—Terri Cook, Freelance Writer**



An artist's rendering of NASA's Magnetospheric Multiscale mission traversing Earth's magnetosphere. Credit: NASA

Unraveling the Origins of Australia's Ancient Mountain Chains

Australia's flat outback hides a secret: a series of ancient mountain chains known as the Tasmanides. A new synthesis of data has helped researchers unravel the geologic history of these features. Credit: iStock.com/CUHRIG

Eastern Australia's Tasmanides are a series of ancient mountain chains—now mostly eroded and underlying the country's flat outback—that record the long tectonic history of Gondwana's eastern margin. Convergence there has forged five separate mountain belts, all of which display large-scale, map view curvatures called oroclines. Although such bends appear to form in response to rotation around a vertical axis, the underlying processes associated with their development in this region are still poorly understood.

Abdullah and Rosenbaum are harnessing newly available data to investigate the origins of a large-scale orocline located at the transition between the southern Tasmanides' Delamerian Orogen and the Thomson Orogen in the northern Tasmanides. Through their analysis of borehole data, 2-D seismic reflection profiles, and gravity and magnetic potential field data, the researchers documented that the northern Tasmanides are underlain by thin crust that is separated from the southern Tasmanides by a distinctive, east-west trending shear zone. They also mapped a second shear zone that divides the northern Tasmanides from the abutting North Australian Craton.

Between the two shear zones lies the Thomson Orogen, whose crust is riddled with a series of basins the researchers attribute to Devonian back-arc extension that occurred in response to the retreat of a subduction zone trench along Gondwana's eastern margin. Because this extension coincided with alternating episodes of compression and extension in the southern Tasmanides, these findings suggest that the two regions experienced very different styles of tectonism during this period.

According to the authors, these different styles are most likely due to variations in the rate at which the trench retreated or advanced. In combination with slab tearing and its associated magmatism, they argue, these processes segmented the crust and ultimately resulted in the orocline's formation. *(Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1029/2018JB015724, 2018)

—Terri Cook, Freelance Writer

Interdisciplinary

Assistant Professor of Environmental Engineering

Marietta College in Marietta, Ohio, is seeking qualified applicants for a full-time, Environmental Engineering faculty position to begin in August 2019.

The new Environmental Engineering program at Marietta College will be affiliated with an ABET-accredited Bachelor of Science in Petroleum Engineering program, a Bachelor of Science Degree program in Geology and an Environmental Science, as well as an undergraduate minor in energy systems.

While professional development and scholarly achievements are valued, the primary focus is on undergraduate education, including classroom instruction, student advising, and student mentoring. Faculty members are expected to remain professionally active both within the department and through engagement with the broader profession. An interest in energy and environmental issues are especially desirable.

Successful applicants will have sufficient experience and expertise in environmental engineering to launch a range of required Environmental Engineering coursework, and will possess strong written and verbal communication skills. Required credentials include either of the following:

- An earned doctorate in Environmental Engineering or a closely related engineering or science discipline, OR

- An earned master's degree and professional engineer licensure which may also include certified environmental scientist

Professional experience is preferred.

Application Instructions: Review of Applications begins February 28, 2019 and continues until position is filled. Interested applicants should submit a cover letter addressing their industry experience and their interest in undergraduate education, resume/cv, and contact information for three professional references. All applications/resumes must be submitted through this online process at Marietta College-www.marietta.edu see Employment at bottom of web page. We regret that we are unable to accept applications or resumes submitted by mail, email, or fax. As you are submitting your application via this online process, please be sure to provide an accurate email address. You will then receive an acknowledgment indicating your application materials have been received.

Ocean Sciences

Biological Oceanography Assistant or Associate Professor

The Division of Marine Science in the School of Ocean Science and Engineering (SOSE) at The University of Southern Mississippi (USM) invites qualified applicants for a full-time, nine-month, tenure-track position in Biological Oceanography at the Assistant or Associate Professor level to begin in Fall 2019. SOSE includes two academic divisions, Marine Science, and Coastal Sciences, and several R&D centers including: Hydrographic Science Research Center, Center for Fisheries Research and Development, and Thad Cochran Marine Aquaculture Center. The Division of Marine Science is based at the NASA Stennis Space Center where Marine Science faculty benefit from close working relationships with a number of on-site federal agencies, including the Naval Research Laboratory-Stennis Space Center, the Naval Oceanographic Office, the Naval Meteorology and Oceanography Command, the USGS and NOAA, including the National Data Buoy Center.

Marine Science graduate and undergraduate programs extend across traditional marine science emphasis areas in biological, physical, chemical and geological oceanography, as well as hydrographic science and ocean engineering. Marine Science faculty and graduate programs are housed at Stennis Space Center, where the M.S. and Ph.D. degrees in Marine Science and the M.S. degree in Hydrographic Science are delivered. The Marine Science and Ocean Engineering B.S. degree programs are delivered at the USM Gulf Coast Campus in Long Beach, MS as well as at USM's main campus in Hattiesburg, MS. The Long Beach campus is in close proximity to the Port of Gulfport, which is the home port for USM's R/V

ARL DISTINGUISHED POSTDOCTORAL FELLOWSHIPS

The Army Research Laboratory (ARL) Distinguished Postdoctoral Fellowships provide opportunities to pursue independent research in ARL laboratories. Fellows benefit by working alongside some of the nation's best scientists and engineers, while enhancing the mission and capabilities of the U.S. Army and the warfighter.

ARL invites exceptional young researchers to apply. Fellows must display extraordinary abilities in scientific research and show clear promise of becoming future leaders. Candidates are expected to have already successfully tackled a major scientific or engineering problem or to have provided a new approach or insight, as evidenced by a recognized impact in their field. ARL offers five named Fellowships; three of these positions are open for the 2019 competition.

Fellowships are one-year appointments, renewable for up to three. The award includes a $100,000 annual stipend, benefits, and potential additional funding for the chosen proposal. Applicants must have completed all requirements for a Ph.D. or Sc.D. degree by the application deadline and may not be more than five years beyond their doctoral degree as of the application deadline. For more information and to apply, visit **www.nas.edu/arl.**

Online applications must be submitted by May 31, 2019 at 5 PM EST.

Point Sur and the recently opened USM Marine Research Center, that features a state-of-the-art fabrication lab, testing tank, and laboratory space.

Applicants must hold a Ph.D. in oceanography, biological oceanography, or a related field. Preference will be given to candidates with post-doctoral experience, and a demonstrated record of scholarship, service, grant development, communication, and commitment to diversity. For appointment at the Associate level, candidates should also have demonstrated a national or international reputation for excellence in their discipline. The successful candidates areexpected to develop and deliver courses in their field of specialization. The successful candidate should demonstrate the potential to contribute across disciplines and promote the continued interdisciplinary growth of the academic and research programs within SOSE. Applicants should submit a letter of interest outlining their qualifications for the position, including a research plan, teaching philosophy with a curricular plan, a curriculum vitae, and names and contact information of at least four references. Salary packages will be nationally competitive and commensurate with experience. Applications must be submitted online at https://usm.csod.com/ats/careersite/jobdetails.aspx?site=1&c=usm&id=624. For inquiries about the position, contact Donald G. Redalje, Chair of the Search Committee, at 1-228-688-1174 or Donald.Redalje@usm.edu. Review of applications begins 1 March 2019 and continues until the position is filled, with an anticipated start date of August 2019.

EOE/F/M/VET/DISABILITY

SFU SCHOOL OF ENVIRONMENTAL SCIENCE

ASSOCIATE PROFESSOR WATERSHED SCIENCES

The School of Environmental Sciences at Simon Fraser University, in Burnaby, BC, Canada invites applications for a **faculty position in watershed sciences.** The appointment will likely be at the **Associate Professor** level, but exceptional candidates at the **Assistant Professor** level will be considered.

The ideal candidate is a physical scientist interested in watershed-scale research questions, with an ability and interest in working collaboratively with other water scientists, such as those interested in biology and ecology. We welcome applications from highly motivated individuals in a broad range of fields related to physical watershed processes.

The deadline for applications is **May 1, 2019.**
For more information, please email **evschire@sfu.ca** or see our website:
http://www.sfu.ca/evsc/about/employment/faculty.html

Geological Oceanography Assistant Professor

The School of Ocean Science and Engineering (SOSE) at The University of Southern Mississippi (USM) invites qualified applicants for a full-time, nine-month, tenure-track position as an assistant professor in Geological Oceanography, broadly defined, to join the Marine Science faculty in the Division of Marine Science. The SOSE includes two academic divisions, Marine Science, and Coastal Sciences, and several R&D centers including: Hydrographic Science Research Center, Center for Fisheries Research and Development, and Thad Cochran Marine Aquaculture Center. The Division of Marine Science is based at the NASA Stennis Space Center where Marine Science faculty benefit from close working relationships with a number of on-site federal agencies, including the Naval Research Laboratory-Stennis Space Center, the Naval Oceanographic Office, the Naval Meteorology and Oceanography Command, the USGS and NOAA, including the National Data Buoy Center.

Marine Science graduate and undergraduate programs extend across traditional marine science emphasis areas in biological, physical, chemical and geological oceanography, as well as hydrographic science and ocean engineering. Marine Science faculty and graduate programs are housed at Stennis Space Center, where the M.S. and Ph.D. degrees in Marine Science and the M.S. degree in Hydrographic Science are delivered. The Marine Science and Ocean Engineering B.S. degree programs are delivered at the USM Gulf Coast Campus in Long Beach, MS as well as at USM's main campus in Hattiesburg, MS. The Long Beach campus is in close proximity to the Port of Gulfport, which is the home port for USM's R/V Point Sur and the recently opened USM Marine Research Center, that features a state-of-the-art fabrication lab, testing tank, and laboratory space.

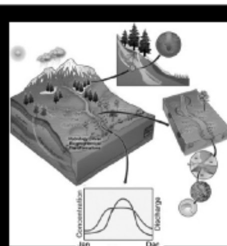
Applicants must hold a Ph.D. in earth science, oceanography, or a related field. Preference will be given to candidates with post-doctoral experience, and a demonstrated record of scholarship, service, grant develop-

Hydrologist

The Earth and Environmental Sciences (EESA.lbl.gov) of Berkeley Lab is advancing and integrating diverse expertise to accelerate scientific discoveries and their translation into scalable solutions that simultaneously sustain the Earth's environment and the growing need for energy and water resources.

We seek an outstanding Earth Scientist with a record of innovative research in hydrology. Aligned with EESA's 'Future Water' and possibly 'Sustainable Earth' strategic directions, we particularly encourage applicants who develop and utilize novel field methods and experiments with theory to advance understanding of multi-scale, multi-phase behavior of hydrological systems. Topics of interest include, but are not limited to: watershed response to extreme events and climate change; critical zone ecohydrology and hydrogeochemistry; aquifer storage and recovery; and bedrock flow and reactions relevant to subsurface energy strategies.

The position is open at the Research and Staff Scientist levels. The incumbent is expected to take advantage of world-class experimental facilities at Berkeley Lab and develop active collaboration with UC Berkeley. The incumbent may also be considered for leadership roles within EESA.



Berkeley Lab, located next to UC Berkeley, is part of the stimulating San Francisco Bay Area innovation ecosystem. The region is also recognized for offering a high quality of life, having both abundant natural beauty and exciting urban surrounds.

To apply online at **http://jobs.lbl.gov**, please select "Search Jobs", enter 86204 in the keyword search field, and follow the online instructions to complete the application process.

LBNL is an Equal Opportunity/Affirmative Action Employer.

BERKELEY LAB

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

NRC RESEARCH ASSOCIATESHIP PROGRAMS

The National Academy of Sciences, Engineering, and Medicine offers **postdoctoral and senior research awards** on behalf of 20 U.S. federal research agencies with facilities at over 100 locations throughout the U.S. and abroad.

We are actively seeking applications from highly qualified recent doctoral recipients and senior researchers. Applicants should hold, or anticipate receiving, an earned doctorate in science or engineering. Degrees from universities abroad should be equivalent in training and research experience to a degree from a U.S. institution.

Applications are accepted during four annual review cycles with deadlines of:
May 1, August 1, November 1, and February 1.

Awardees have the opportunity to:

- conduct independent research in an area compatible with the interests of the sponsoring laboratory
- devote full-time effort to research and publication
- access the excellent and often unique facilities of the federal research enterprise
- collaborate with leading scientists and engineers at the sponsoring laboratories

Benefits of an NRC Research Associateship award include:

- One year award, renewable for up to three years
- Stipend ranging from $45,000 to $80,000; higher for senior researchers
- Health insurance, relocation benefits, and a professional travel allowance

For detailed program information, visit **www.nas.edu/rap**, or send an e-mail to **rap@nas.edu.**

ment, communication, and commitment to diversity. The successful candidates are expected to develop and deliver courses in their field of specialization. The successful candidate should demonstrate the potential to contribute across disciplines and promote the continued interdisciplinary growth of the academic and research programs within SOSE. Applicants should submit a letter of interest outlining their qualifications for the position, including a research plan, teaching philosophy with a curricular plan, a curriculum vitae, and names and contact information of at least four references. Salary packages will be nationally competitive and commensurate with experience. Applications must be submitted online at https://usm.csod.com/ats/careersite/jobdetails.aspx?site=1&c=usm&id=597. For inquiries about the position, contact Davin Wallace, Chair of the Search Committee, at 1-228-688-3060 or davin.wallace@usm.edu. Review of applications begins 1 March 2019 and continues until the position is filled, with an anticipated start date of August 2019.

EOE/F/M/VET/DISABILITY

FACULTY OPENING ANNOUNCEMENT–INSTRUCTIONAL ASSISTANT PROFESSOR

The Department of Oceanography at Texas A&M University seeks an Instructional Assistant Professor (Non-Tenure Track) to lead efforts in the development and execution of online courses in the Ocean Data Science track of the online Masters of Geosciences (MGSc) degree program. The candidate is expected to transform and deliver courses on Ocean Observing Systems, Physical Oceanography, and Ocean Data Methods in a distance education environment. The successful candidate will work closely with the College of Geosciences Distance Learning Team, Department of Oceanography faculty and associated content experts to develop online course content material.

The Department of Oceanography is part of an alliance of Ocean Sciences at Texas A&M that spans the Marine Biology and Marine Sciences Departments at TAMU Galveston, the Geochemical and Environmental Research Group, the International Ocean Discovery Program, and Texas SeaGrant. This alliance of Ocean Sciences represents a unique concentration of educational and research resources. The capacity is greatly enhanced by close ties to the College of Geosciences Departments of Atmospheric Sciences, Geography, and Geology & Geophysics, as well as the Berg Hughes Center and the Texas Center for Climate Studies.

The successful candidate will be a motivated team member who is committed to our rapidly growing ocean observing science and education program. The candidate will actively collaborate with our faculty in his/her mission to develop and teach ocean-observing related courses for graduate and undergraduate students. Our strategic area of educational and research strength focuses on the long-term monitoring of the chemical, biological and physical conditions of the marine environment. The Department web site http://ocean.tamu.edu contains a full description of our program.

Review of applications will begin immediately and the advertisement will remain open until the position is filled. The anticipated start date is on or before June 1, 2019. The full-time position carries 9 months of salary with possibility of additional 3-month summer salary depending on availability of funds and the success of online courses.

Education and Experience

Required Qualifications:

• PhD in Oceanography, or closely related field;

• Higher Education teaching experience

Preferred Qualifications:

• PhD in Physical Oceanography

• Interest in Online Education and instruction (development and/or offering).

Knowledge, Abilities, Skills

Required Qualification

• Candidates must be comfortable with and proficient in using computer-based technology;

• Candidates must possess excellent written and verbal skills as demonstrated through publications and public speaking.

• Ability to work in a team setting with faculty colleagues and online course developers.

Preferred Qualifications:

• Knowledge of and proficiency using learning management systems, e.g., Blackboard, CANVAS.

• Self-motivated with a strong interest in online education and learning design practices;

Applications must include the following:

• A cover letter containing a statement of interest in this position;

• A statement indicating teaching philosophy and best practices, or a teaching portfolio (including syllabi and pedagogical materials developed by the candidate);

• A curriculum vitae; and

• Three references with complete contact information.

Electronic applications should be submitted to http://apply.interfolio.com/52944.

Information on applying for a faculty position is available at: http://ocean.tamu.edu/about

Information on online courses for the College of Geosciences is available at: https://geosonline.tamu.edu/

The Texas A&M System is an Equal Opportunity/Affirmative Action/Veterans/Disability Employer committed to diversity.

Questions regarding this position should be directed to: Dr. Steve DiMarco at sdimarco@tamu.edu.

NASA-USGS JOINT POST-DOCTORAL FELLOWSHIPS IN SILICON VALLEY

A two-year post-doctoral research fellowship to help solve national challenges using the power of two leading scientific agencies in the heart of Silicon Valley. Fellows will be co-advised by both NASA and USGS scientists.

OPPORTUNITY 1: Water from Orbit: Verified AI tools for detecting water resource changes from orbit
OPPORTUNITY 2: Hyperspectral instruments and techniques to map strategic minerals
OPPORTUNITY 3: Hyperspectral Data Products for Ecosystem Science and Natural Resource Management

• Postdoctoral hiring authority for a term Federal employee, with 2 years of provided funding
• Federal position with associated benefits
• Duty station will be USGS Moffett Field, California
• Base Salary is GS-12, Step 1 ($88,582 in 2019)
• Eligibility for US citizens with Ph. D. granted no more than 5 years before the Fellow's start date
• Advertised opportunities will ask for an 8-page research proposal, transcripts and any other documentation required (e.g. foreign degree accreditation)

To apply, go to **https://geography.wr.usgs.gov/InnovationCenter/fellowship.html**
• Deadline for Post-doctoral applications: **April 29, 2019**
• Notification of Awards: **July 01, 2019**
• Post-doctoral Fellow start dates: **August-December 2019**

For more information, contact Dr. Ian Brosnan, NASA, **ian.g.brosnan@nasa.gov**, or Dr. Jonathan Stock, USGS National Innovation Center, **jstock@usgs.gov**.

Dear *Eos*:

Colorful microbial mats composed of photosynthetic cyanobacteria (dark purple layers) and chemosynthetic microbes (white patches) thrive in the cold, oxygen-poor, sulfur-rich waters of sinkholes in Lake Huron. The carbon and oxygen cycles of these microbial ecosystems remain an enigma. Here, Joe Hoyt dives to monitor and sample field experiments set up to measure the changing composition of water overlying the microbial lakescape to quantify their photosynthetic, chemosynthetic, and respiratory roles using in situ sensors and follow-up analyses.

Cyanobacteria-dominated microbial mats such as these—prevailing in the shallow, oxygenless, sulfur-laden seas of the Proterozoic—may have oxygenated our planet during its youth. We are hoping that our exploration of these modern-day analogues will provide clues to the life-changing phenomena that began in the distant past.

—**Tony Weinke** and **Bopi Biddanda,** Robert B. Annis Water Resources Institute, Grand Valley State University, Muskegon, Mich.; and **Russell Green, Joe Hoyt,** and **Tane Casserley,** Office of National Marine Sanctuaries, National Oceanic and Atmospheric Administration, Silver Spring, Md.

Photo by **Tane Casserley**

View more postcards at
bit.ly/Eos_postcard