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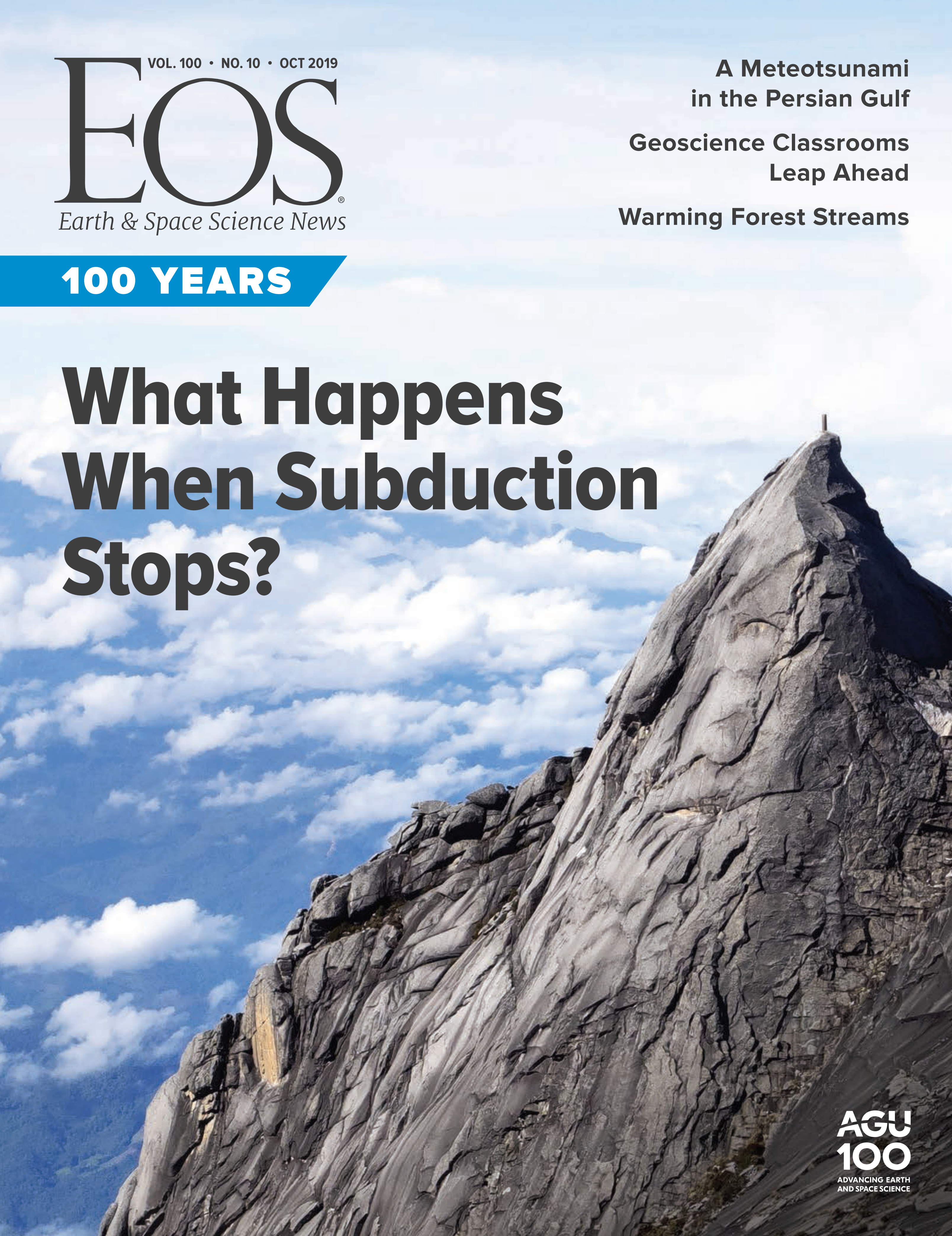

AGU 100

ADVANCING EARTH AND SPACE SCIENCE

AGU100 ADVANCING EARTH AND SPACE SCIENCE

AGU Celebrates the Members Who Participated in 2019 Congressional Visits.

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This Is How the World Moves

It didn't exactly crack open the world, the presentation Princeton University's Jason Morgan gave at AGU's Spring Meeting in Washington, D.C., in April 1967. However, Morgan's research leading up to the meeting had proved that there were, in fact, cracks in the world.

"It seems extraordinary that, in this hall packed with the best geophysicists and geologists in the United States, nobody got excited or even interested by the implications of Morgan's ideas. They were too new, too different from anything which had been done," wrote Xavier Le Pichon in the journal *Tectonophysics* in 1990, when he aimed to "reconstruct what happened during those exciting six months."

Morgan had, of course, proved the theory of plate tectonics through seafloor spreading measurements. "The evidence presented here favors the existence of large 'rigid' blocks of crust" that explained continental drift, he wrote in the conclusion of his landmark paper, "Rises, trenches, great faults, and crustal blocks," published in March 1968 in AGU's *Journal of Geophysical Research.* (Morgan's paper, held up in peer review, came several months after *Nature* published similar results from Dan McKenzie and Robert Parker, who were largely credited as the first scientists to verify plate tectonics. Le Pichon eventually found a copy of the outline Morgan had scrambled to finish the night before his 1967 talk—neither Morgan nor several colleagues had retained their copies. The document showed that Morgan should be credited for the feat.)

For AGU's Centennial, this month in *Eos* we're celebrating all the scientists who have been fascinated by the idea, since it was first proposed by Alfred Wegener in 1912, that the continents shift underneath our feet, constantly reshaping the planet.

Our cover story features scientists studying striking formations in Borneo. Mount Kinabalu (pictured on the cover) in the Malaysian state of Sabah is a spectacular example of plate tectonics at work. The granite mountain formed when magma rising from the active subduction zone below squeezed between two rock strata and then cooled rapidly—because of mechanisms still not entirely understood—about 7 million years ago. Several other strange landforms nearby were also created around this time, and then, about 5 million years ago, the subduction underneath Sabah just...stopped. The scientists, as they write, want "to understand why subduction ceased and how the landforms of Sabah may be related to deeper processes in the mantle." Read more about their work and the seismic network they've installed on page 18.

Some of our biggest questions about tectonics and seismic hazards could be answered if scientists could better understand the Alaska Peninsula subduction zone. On page 30, read about a large group of researchers who launched the Alaska Amphibious Community Seismic Experiment in May 2018, deploying a huge array of seismometers that stretch from onshore far out into the water, using innovative ocean bottom seismometers that work together to take integrated observations. The researchers collected their instruments in August and are making the data freely available as quickly as they are recovered.

What's next for the field of tectonics? We might ask Jacqueline Austermann of Columbia University. AGU's Tectonophysics section recently honored her with its Jason Morgan Early Career Award. Our hearty congratulations go to all the 2019 section awardees and named lecturers, as well as to AGU's Union medal, award, and prize recipients, and, finally, the warmest of welcomes to our 2019 class of AGU Fellows. We look forward to honoring your achievements in San Francisco at Fall Meeting 2019. See the announcements for all your distinguished colleagues starting on page 36.

With this much knowledge and passion among our members, we look forward to feeling the metaphorical ground shift beneath us soon once more.

Heather Goss, Editor in Chief

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Christine W. McEntee, Executive Director/CEO

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Cover Story

On the Cover

Mount Kinabalu in the Malaysian state of Sabah in northern Borneo.
Credit: rmnunes/Depositphotos.com

Features

Columns

Majority of YouTube Climate Videos Promote Nonconsensus Views

iStock.com/pressureUA

If an average Internet user opens YouTube to learn about climate change, they might search for "global warming" or "climate engineering" or simply "climate change." What videos will show up? A new study found that more than half of the videos that appear in climate-related YouTube search results promote views that oppose the scientific consensus on climate change.

"Searching YouTube for climate-science-and climate-engineering-related terms finds fewer than half of the videos represent mainstream scientific views," Joachim Allgaier, a senior researcher at Rheinisch-Westfälische Technische Hochschule Aachen University in Germany, said in a statement in July.

Fewer videos promoted outright climate change denial than those supporting the scientific consensus, but chemtrail conspiracy videos were the most numerous. "It's alarming to find that the majority of videos propagate conspiracy theories about climate science and technology," he said.

Overall, climate consensus videos were slightly more popular than nonconsensus videos. The study was published on 25 July in *Frontiers in Communication* (bit.ly/youtube-science).

A Powerful (Mis)information Platform

YouTube reports that nearly 2 billion logged-in users around the world access its platform every month. Science teachers and professors use YouTube videos to enhance curricula, and a growing body of research shows that YouTube can be a self-education tool outside the classroom.

But misinformation and conspiracies abound with climate science, particularly on social media, and it's unclear which videos might appear for typical Internet users who don't normally search for science videos.

To answer that question, Allgaier mined YouTube using 10 common climate-related search terms—for example, "climate," "climate change," "geoengineering," "global warming," and "chemtrails"—and used an online anonymity network so that searches would not be affected by past activity. He then evaluated the search results on whether the videos promoted the consensus view on human-induced climate change from the Intergovernmental Panel on Climate Change.

Of the 200 climate-related videos he analyzed, Allgaier found that 44.5% promoted the scientific consensus view and a further 2% were in a debate format that also included nonconsensus views. Only 8% of the videos focused on outright climate change denial.

The remaining 45.5% of videos focused on climate conspiracy theories about chemtrails. Chemtrail conspiracy videos dominated search results for "chemtrails" (95%), "climate manipulation" (75%), "climate modification" (95%), and "geoengineering" (90%) and also appeared in other search results.

People searching for information on climate mitigation strategies "won't find any information on these topics in the way they are discussed by scientists and engineers," Allgaier concluded. "Instead, searching for these terms results in videos that leave users exposed to entirely non-scientific video content."

When it comes to numbers of views, climate consensus videos (not including debates) hold a slight edge over the nonconsensus and conspiracy videos: about 2,300 more views out of more than 34 million.

Taking Back Climate Videos

Because YouTube decides which videos appear in a search and which videos it profits from in advertising, it should play a part in the solution, Allgaier argues.

"I think YouTube should take responsibility to ensure its users will find high-quality information if they search for scientific and biomedical terms, instead of being exposed to doubtful conspiracy videos," he said. The move would have precedent: Earlier this year, YouTube and other social media platforms removed advertising from anti-vaccine videos and categorized them as "dangerous and harmful" content.

Scientists and science communicators can play a key role too. "YouTube has an enormous reach as an information channel, and some of the popular science YouTubers are doing an excellent job at communicating complex subjects and reaching new audiences," Allgaier said. "Scientists could form alliances with science communicators, politicians, and those in popular culture in order to reach out to the widest possible audience."

> People searching for information on climate mitigation strategies "won't find any information on these topics in the way they are discussed by scientists and engineers."

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

The Dawning of the Age of Old Aquifers

As water moves from high in the sky to deep in the ground, it picks up chemical signatures that can tell researchers secrets about Earth, from the density of air pollution to global ice cover to what kind of rock the raindrops seeped through. Scientists can look at specific radioactive isotopes and reconstruct past climates and weather patterns recorded in stored groundwater.

In a paper published in August in the *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/pnas-aquifer), researchers leveraged an isotope of krypton (Kr) that can reach more than a million years back in time to discover the age of groundwater in the Negev desert in Israel.

Pairing krypton with other isotopes in groundwater, the researchers found two distinct ages and sources within the Nubian sandstone aquifer. They note that their method can be used to reconstruct paleoclimates from aquifers around the globe.

Arid Aquifers

Groundwater is an important resource for life on the planet, especially in arid regions. Replenishing, or recharging, groundwater requires that rainfall soak into the soil, traveling downward for storage in aquifers—a process that requires recurring wet periods.

"Groundwater can serve as a paleo-humidity, -precipitation proxy," said Reika Yokochi, a geochemist at the University of Chicago and lead author of the paper. By using groundwater as a record of past climate conditions, researchers can use that information to better predict how precipitation might change in the future.

In the Negev, Yokochi said, there is currently no groundwater recharge occurring. But in the geologic past, the area went through climate changes, including wetter conditions that renewed the aquifers.

Yokochi said that previous work in the Negev used carbon-14 (^{14}C) to date groundwater reserves to about 30,000 years. The problem with using ^{14}C is that the isotope extends back in time only 30,000–40,000 years, meaning that the age of older water remained a mystery.

Using the noble gas isotope ^{81}Kr solved this problem. Krypton-81 is found throughout the troposphere, where it mixes with raindrops.

"Once that water is isolated from the atmosphere [in the ground], there's no more supply, and it decays," Yokochi explained. "That's when the clock starts."

Yokochi said that ^{81}Kr, with its half-life of about 230,000 years, allowed the team to measure the age of aquifers that are up to 1.3 million years old—a huge extension from ^{14}C.

"Krypton isotope dating of groundwater is exciting, as it opens a new window into past

The aquifer beneath the arid Negev desert in southern Israel is no longer being recharged but once was fed by sources from the Mediterranean and the Atlantic. Credit: Mark A. Wilson, CC0 1.0 (bit.ly/ccby1-0) climatic conditions that was previously unavailable, or cloudy, with existing dating techniques," said Jennifer McIntosh, a hydrogeochemist at the University of Arizona not involved in the research.

"This is one of the few studies to use groundwater as a record of paleoclimate beyond the Last Glacial Maximum," said McIntosh.

Aging an Aquifer

Yokochi said that in the past, amassing enough krypton gas in a water sample required sampling about 200–300 liters. Bringing that much water back to a lab for analysis is "a lot to carry," so Yokochi said that she and her team used a field gas extraction device.

The team used atom trap trace analysis (ATTA) methods to measure krypton isotopes in the lab. The combination of field gas extraction and ATTA bolstered the team's ability to collect water from 22 wells in the eastern Negev.

"Everything became more efficient and fast," said Yokochi.

The researchers found that ^{81}Kr data revealed two distinct groundwater recharge dates: one less than 38,000 years ago and a much older wet period about 360,000 years ago.

Pairing this information with hydrogen and oxygen isotope data from the samples, the team found that the younger aquifer was recharged with water sources from the Mediterranean, whereas the older wet period brought precipitation from the tropical Atlantic.

"Knowing the source of the water helps scientists understand past climatic conditions that led to groundwater recharge and how vulnerable the aquifer is to future climate change," said McIntosh. "This information can be used to inform paleoclimate models and aid in water management decisions."

Other studies have used ^{81}Kr as a tracer, but Yokochi said that "this is the first case where we take a lot of data from a very small area, do the spatial distribution analysis, and talk about climate."

McIntosh said she anticipates—and is excited for—krypton isotopes to be widely used in future studies.

"Knowing how 'old' groundwater is helps water managers evaluate how much water they can extract without significantly depleting the aquifer," said McIntosh. "It can also help them determine how vulnerable the aquifer is to anthropogenic sources of contamination."

By **Sarah Derouin** (@Sarah_Derouin), Freelance Journalist

Paleontologists Peer Inside Billion-Year-Old Cells

Scotland contains an amazing array of wildlife: Puffins, Scottish wildcats, and orcas all make northern Great Britain their home. But paleontologist Eva Sirantoine and her colleagues weren't looking for any of these animals; the creatures they were interested in were much, much smaller. They had also been dead for nearly 1 billion years.

The picturesque sandstone outcroppings of northwestern Scotland's Cailleach Head Formation are studded with tiny gray phosphate nodules. To the casual observer, they might not look particularly special, but in fact, they contain exquisitely preserved microfossils of Precambrian cells.

The gray phosphate nodules in this sandstone contain microfossils of Precambrian organisms. Credit: Eva Sirantoine

In a recent study published in *Scientific Reports,* scientists from the University of Western Australia and Boston College report that they were actually able to peer inside these ancient cells (bit.ly/cells-preserved). Sirantoine said that by using scanning transmission electron microscopy combined with a technique called energy dispersive spectroscopy, the team was able to get an idea of the three-dimensional structure of the fossilized cells as well as to obtain information about the chemical composition of specific regions within them.

> "That's what I think is cool about this study—it opens up this new search image, this new place to go look and quest for other preserved fossils."

Sirantoine said that microfossils like these provide us with a window into the distant past. "Most fossils are not as good, so it's like having a bad camera with a bad lens: You get a blurred image, so you can't really tell what's in the picture. But when you get very nice fossil deposits like this one, you have a much sharper picture. Studying this well-preserved deposit gives you a better picture of what the diversity was like."

This group of billion-year-old microfossils contains what appear to be prokaryotic cells (cells without a nucleus) and one cell that appears to be eukaryotic (a more complex cell type that has a nucleus, like animal and plant cells). These fossilized cells were once part of an ancient lake ecosystem.

Preserved by Rare Earth Elements

The researchers think that the cells actively absorbed and retained the rare earth element (REE) phosphates monazite and xenotime. When the cells died, these REE phosphates precipitated rapidly, preserving the inner workings of the cells.

Sirantoine said that ancient microfossils can help us understand when and where eukaryotic cells developed and diversified, which was a major step in the evolution of life on Earth.

Alison Olcott Marshall, a paleobiogeochemist at the University of Kansas who was not involved in the study, said that this is an exciting finding. "The farther you go back in time, the fewer rock units there are that are likely to preserve signs of life.… So we all tend to cluster in the same units because there's only a limited number of targets. As scientists, we have a sort of search image for what kinds of rocks are good targets. These [samples from the present study] are rocks that wouldn't necessarily have been somebody's first place to think of to look. So that's what I think is cool about this study—it opens up this new search image, this new place to go look and quest for other preserved fossils."

By **Hannah Thomasy** (@hannahthomasy), Freelance Science Writer

EOS CENTENNIAL COLLECTION
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Wind-Triggered Ground Shaking Masks Microseismicity

The earthquakes that jolt us out of bed, the ones that trigger an instinctual urge to duck and cover, are powerful and potentially destructive.

But they're also rare: For every magnitude 7.0 temblor, roughly a million magnitude 1.0 earthquakes occur.

Earthquake detection algorithms must be able to accurately disentangle these numerous, low-amplitude seismic signals from other sources of ground shaking such as aircraft passing overhead and waves crashing into coastlines. Now researchers have analyzed the waveforms of wind-induced ground motion, work that will boost the performance of future earthquake detection algorithms, the scientists suggest.

Research on a Ranch

Christopher Johnson, a seismologist at the Scripps Institution of Oceanography in San Diego, Calif., and his colleagues collected data on a privately owned unused ranch situated atop the San Jacinto fault zone near Anza, Calif. Johnson and his team placed 40 geophones around the property's stands of vegetation, old structures, abandoned machinery, and defunct airstrip. The coffee can–sized instruments, anchored to the ground with a roughly 12-centimeter-long metal spike, recorded ground velocity measurements 500 times per second from 9 February through 17 March 2018.

The scientists wanted to better understand ground movement caused by wind energy being transferred into Earth through, for example, plant roots or building foundations. That's important, researchers said, because wind-induced ground shaking, which affects roughly the top kilometer of Earth's crust, is a source of noise in seismic records.

"We need to have a really good understanding of what all of these noise signals are," said Johnson.

Seismic records are increasingly being mined to find new fault lines and better understand how one earthquake triggers others.

> "We need to have a really good understanding of what all of these noise signals are."

To test how ground shaking was correlated with wind strength, the scientists also measured wind velocity using an anemometer mounted near the ranch's unused airstrip. They recorded an average wind velocity of roughly 2 meters per second and a maximum wind velocity of about 15 meters per second.

Researchers studied wind-induced ground movement near Anza, Calif. Credit: Christopher Johnson

Masquerading as an Earthquake

Johnson and his collaborators found that gusts of wind stronger than a few meters per second were linked to ground shaking characterized by earthquakelike waveforms. The team examined the vertical and horizontal components of the wind-triggered shaking and found a consistently larger signal in the horizontal direction. That's because the wind is pushing aboveground objects—like structures, vegetation, and machinery—with a shearing motion with respect to the ground, said Johnson.

Next, the researchers investigated the strength of the wind-triggered shaking at different locations on the ranch. They recorded the weakest signal on a hill and the strongest signal near a covered parking structure. These results make sense, said Johnson, because human-built structures are coupled to the ground through their foundations, which means that wind energy is efficiently transferred into the ground.

The scientists also found that wind-induced ground movement was sometimes strong enough to mask seismic signals arising from slipping faults. "About 6% of the day, there are wind-induced ground motions with amplitudes greater than what we're anticipating for microseismicity," said Johnson. That's bad news because much can be learned from these tiny earthquakes. "These tell a lot about the dynamics of fault zones and foreshock and aftershock sequences."

Shaking Deep Down, Too

The scientists recorded wind-induced ground motion not only in the geophones resting on the ground but also in a 148-meter borehole that had been previously drilled and instrumented with a seismometer.

"We can see that [the wind energy] is going into the ground," said Johnson. He and his colleagues published their findings in July in the *Journal of Geophysical Research: Solid Earth* (bit.ly/ground-motion).

These results are important, said Adam Ringler, a geophysicist with the U.S. Geological Survey at the Albuquerque Seismological Laboratory on Kirtland Air Force Base, N.M., not involved in the study. "By improving our understanding of how nonearthquake signals get recorded by sensors, we can improve our ability to detect small events and characterize them."

In the future, Johnson and his team want to place more geophones near the San Jacinto fault zone. "We've been focusing on small areas, but you could imagine putting them out over 20 kilometers," said Johnson. "They're quick and easy to deploy."

By **Katherine Kornei** (@katherinekornei), Freelance Science Journalist

Nearest Star System May Have a Second Planet

An artist's impression of Proxima b in orbit around the flaring red dwarf star Proxima Centauri, with two other stars in the background. Scientists suspect that there is also a larger, colder planet in this solar system. Credit: Ricardo Ramirez and James Jenkins, Department of Astronomy, Universidad de Chile

In 2016, astronomers announced the discovery of a rocky, habitable, Earth-sized planet orbiting Proxima Centauri, the closest star beyond our solar system. A recent analysis now suggests that Proxima might also host a larger, colder planet.

"We call it Proxima c," Mario Damasso, an astrophysicist at the Astrophysical Observatory in Torino, Italy, said about the potential discovery at a forum in April. "But it's only a candidate. That's very important to underline."

If confirmed, this planet would make Proxima Centauri our nearest multiplanet system and challenge our understanding of how rocky planets larger than Earth form. Damasso discussed Proxima c on 19 August at the Extreme Solar Systems IV conference in Reykjavík, Iceland. This discovery is currently under peer review in *Science Advances.*

Bigger, Colder, Farther Away

Astronomers found the 2016 planet, Proxima b, using radial velocity (RV) measurements of the host star, which showed a characteristic wobble from the planet's gravitational influence. Damasso and his team sought to validate Proxima b's existence by analyzing the same data using a different method. They took particular care when accounting for Proxima's stellar flares and spots.

"Stellar activity can hamper the radial velocity [analysis] because there can easily be present some signal from the stellar activity in the data," Damasso said.

After accounting for Proxima's stellar activity and Proxima b's radial velocity signal, the team noticed a periodic signal left over in the data. That signal suggested that a second planet was tugging on Proxima. To make the signal, a planet would need to be at least 6 times Earth's mass and orbit at about the same distance as Mars is from the Sun.

"This detection is quite challenging, particularly because it's made with only one technique," Damasso said. "And the orbital period is very long, so it takes a long time to collect more data."

"Is this planet habitable? Well, not really. It's quite cold," said team member Fabio Del Sordo, an astrophysicist at the University of Crete in Greece. "We estimated a surface equilibrium temperature of only 40 kelvins," which is −233°C. "So, clearly not habitable."

A Long Road to Confirmation

At the April forum, University of Hawaiʻi astronomer Lauren Weiss voiced concerns that a second Proxima planet might not be where or what the team thinks it is.

"In any system, you don't know what planets there are [that] you haven't found yet until you find them," Weiss said. "They are an unknown unknown, which makes it very challenging to accurately model and fit radial velocities."

She explained that the signal attributed to Proxima c could very well be a combination of other, weaker signals. "That maybe means that there are additional planets but not at the period at which [they're] announcing the candidate," she said.

Weiss recently told *Eos,* "I have seen no additional data supporting or falsifying the proposed orbit and minimum mass of the planet candidate Proxima Cen c" since the initial announcement in April.

With its currently calculated orbit, Proxima c would challenge our understanding of how planets that size form, Del Sordo said.

"Since low-mass stars are expected to host multiplanet low-mass systems, Proxima could certainly host other terrestrial planets we could not detect," Damasso told *Eos* about his presentation in Iceland. "Analyzing the available RV data with methods different from that

Proxima Centauri is only slightly larger than Jupiter and is much smaller, cooler, and dimmer than the other two stars in that system (Alpha Centauri A and B). Credit: European Southern Observatory, CC BY 4.0 (bit.ly/ccby4-0)

we used could reveal additional signals worthy of attention."

"Models tell us that super-Earths tend to form around the snow line, but Proxima c at the moment is quite distant from the snow line," he said. "It's possible that this planet migrated from somewhere else in the system."

"We plan to go on with radial velocity follow-up" as well as direct imaging with ground-based instruments, Damasso said. "This is a necessary step to do since the orbital period of the candidate is [about] 5 years long."

And with future astrometry data from the European Space Agency's Gaia mission, "we should be able to measure the mass with 5% accuracy, which is great news for us," Del Sordo said. "This will take place in a couple of years with the end-of-mission data."

When it comes to confirming Proxima c's existence, "it's going to be a long road," Weiss said.

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

Murders of Environmentalists Have Doubled in 15 Years

Environmental activists and defenders are killed at twice the rate that they were 15 years ago, according to a new study. Researchers found that more environmental defenders were murdered in countries with a weaker rule of law and where more land area was harvested.

"Environmental defenders help protect land, forests, water and other natural resources," Nathalie Butt, lead author of the study, said in a statement. "They can be anyone—community activists, lawyers, journalists, members of social movements, [nongovernmental organization] staff, and indigenous people—anyone who resists violence."

"As consumers in wealthy countries—who are effectively outsourcing our resource consumption—we share responsibility for what's happening," said Butt, who studies the ecological impacts of climate change at the University of Queensland in St. Lucia, Australia. "Businesses, investors, and national governments at both ends of the chain of violence need to be more accountable."

Environmentalists Dying Around the World

The study, which was published in *Nature Sustainability* on 5 August, analyzes reports of environmentalists' deaths around the world from the international environmental organization Global Witness (bit.ly/chain-of-violence).

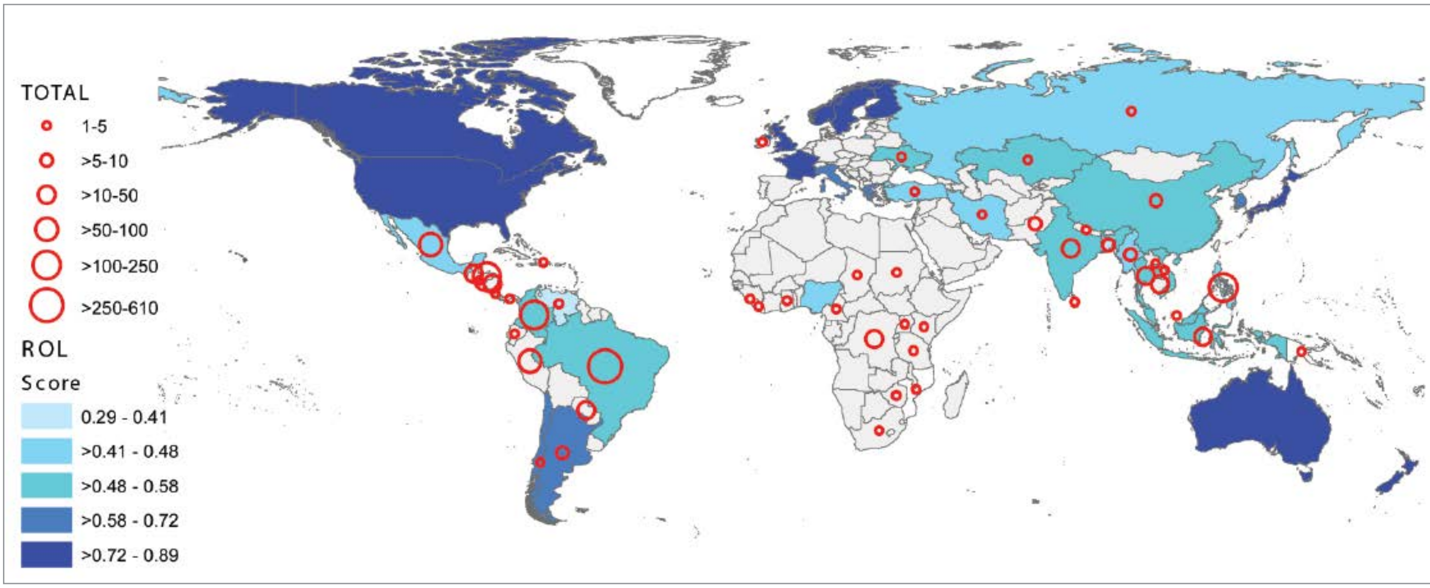
The researchers found that 1,558 people in 50 countries around the world were killed defending the environment between 2002 and 2017. "This is more than double the number of United Kingdom and Australian armed service people killed on active duty in war zones over the same period…and almost half as many as the number of U.S. soldiers killed in Iraq and Afghanistan since 2001," the study says.

During those 15 years, the rate at which environmental activists were murdered increased from two murders per week to four per week. The death toll in Brazil, the Philippines, Colombia, and Honduras represented about 71% of all environmentalists killed during that time period.

One particularly concerning finding is that about 40% of the murders in 2015 and 2016, and about 30% of the killings in 2017, were of indigenous persons. More indigenous people were killed defending their land and environment than were people of any other group.

"This is a phenomenon seen around the world: land and environmental defenders are declared terrorists, locked up or hit with paralyzing legal attacks, for defending their rights, or simply for living on lands that are coveted

Munduruku people hold signs with slogans like "Dam Kills!" during a protest of the Belo Monte hydroelectric dam in Brasilia, Brazil, in 2013. Munduruku and other indigenous Brazilian people argue that the dam will disrupt their way of living through deforestation and flooding and protested attacks against and murders of natives. Credit: EVARISTO SA/AFP/Getty Images



Researchers found that more environmentalists were killed (larger circles) in countries with lower rule of law (ROL) scores (lighter blue). Credit: Nathalie Butt

by others," stated Victoria Tauli-Corpuz, the United Nations Special Rapporteur on the rights of indigenous peoples.

Killing for Natural Resources and Getting Away with It

The researchers also gathered data from organizations that track rule of law and environment-related business sectors. They found that the mining, agribusiness, water resources, and logging sectors were tied to or suspected in the highest number of deaths. More deaths occurred in countries with higher corruption rates and a weaker rule of law.

What's more, murders of environmentalists were much less likely to have legal ramifications than were other murders: Homicides had an overall conviction rate of 43% in 2012, but the conviction rate was only 10% for the killings of environmentalists.

"Although conflict over natural resources is the underlying cause of the violence, spatial analyses showed corruption was the key correlate for the killings," Butt said. "In many instances, weak rule of law means that cases in many countries are not properly investigated, and sometimes it's the police or the authorities themselves that are responsible for the violence."

Criminalizing Environmental Activism

Global Witness released its 2018 report on attacks against environmental defenders on 30 July (bit.ly/gw-attack-stats). The organization found that 164 people were killed last year, an average rate of more than three per week.

On 22 May 2018, roughly 20,000 environmental protesters marched toward a Sterlite Copper mining plant in Tamil Nadu in southern India. The plant was linked to soil, water, and air pollution in the area. State police killed 13 protesters in what was the largest massacre of environmental defenders in 2018. Credit: Mksr2020, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

"Countless more were silenced through other tactics designed to crush protest, such as arrests, death threats, lawsuits and smear campaigns," the agency stated.

Mining and agribusiness remained the first- and second-deadliest sectors for environmentalists, but last year also saw a spike

> "Corruption was the key correlate for the killings."

in the number of deaths related to water resources. The 2018 report was released days before unrelated reports from the World Resources Institute on global water stress and from the Intergovernmental Panel on Climate Change on vulnerabilities in the land and food sectors.

Last year, Global Witness also tracked a rise in the criminalization of activism, including in the United Kingdom and Iran, a trend that the agency says has continued so far in 2019. The organization specifically called out Brazilian president Jair Bolsonaro and U.S. president Donald Trump for agendas that promote business over the environment and for policies that strip away environmental and human rights protections.

"It is a brutal irony that while judicial systems routinely allow the killers of defenders to walk free, they are also being used to brand the activists themselves as terrorists, spies or dangerous criminals," Alice Harrison, a senior campaigner at Global Witness, said in the statement accompanying the report. "Both tactics send a clear message to other activists: the stakes for defending their rights are punishingly high for them, their families and their communities."

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

EOS CENTENNIAL COLLECTION

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Earthquakes Shake Up Groundwater Systems

After an earthquake, regional streamflows will sometimes increase because of an influx of groundwater being released from aquifers. This phenomenon is well documented, but the details of the underlying mechanisms remain somewhat mysterious.

A new study looking at the effect of the 2011 Tohoku earthquake in Japan on groundwater systems in China is shedding some light on how Earth's subsurface can be affected by large earthquakes.

Groundwater systems often comprise layers of permeable rock called aquifers separated by low-permeability layers called aquitards. Previous studies have analyzed the effects of earthquakes on either aquifers or aquitards, but to date, nobody has quantified the effects of earthquakes on both aquifers and aquitards in the same groundwater system, said Zheming Shi, a hydrogeologist at the China University of Geosciences in Beijing and an author of a study published in May in *Water Resources Research* (bit.ly/wrr-groundwater-system).

"The commonly used tidal response models can only identify either aquifer or aquitard permeability, not both at the same time," Shi said.

Shi and colleagues took a different approach, combining a traditional tidal response model with an analysis of barometric pressure changes detected in a 2,600-meter-deep well near the Shunyi-Qianmen-Liangxiang fault zone, one of the largest fault systems in Beijing.

Scientists have been monitoring subsurface changes in this well—drilled into an aquifer in porous limestone that is capped by layers of impermeable mudstone, sandstone, and andesite—for decades as part of the country's extensive earthquake monitoring program. By comparing barometric pressures recorded 4 months before the 11 March 2011 Tohoku quake with data collected up to a year after the event, they found that the earthquake boosted the permeability of the aquifer by a factor of 6, whereas the permeability of the aquitard doubled.

"As far as I know, this is the first time that changes in both an aquifer and an accompanying aquitard have been quantified after an earthquake," said Michael Manga, a planetary scientist at the University of California, Berkeley who was not involved in the new study. Manga coauthored a commentary about the study's findings in June in *Water Resources Research* along with Steve Ingebritsen, a hydrologist with the U.S. Geological Survey (bit.ly/wrr-hydrologic-responses).

Earthquakes like the 2011 Tohoku earthquake in Japan can wreak havoc on local infrastructure like this, as well as increase the permeability of aquifers thousands of kilometers away. Credit: iStock.com/egadolfo

"Permeability is not usually thought of as a quantity that can change over time," Manga said. "When you drill a well, you measure the rate of flow and then that's the number you use" to describe the productivity of that well.

But during an earthquake, subsurface pressure changes, and new fracture networks and shifting gases and fluids can open new pathways for groundwater movement. The new study also demonstrates that these subsurface shifts are not permanent: As the area settled after the Tohoku event, detectable changes in the well returned to preseismic levels in about 4 months, Shi and his colleagues wrote.

A new study looks at the effect of the 2011 Tohoku earthquake in Japan on groundwater systems in China.

"This is a very clever study that's adding a lot to this discussion of how permeability can change in space and time," Ingebritsen said. "I think there's growing interest in this idea that permeability is a mutable property. I'd like to see more of these kinds of studies done in other wells in other geologic settings."

The work may also have implications for groundwater quality after an earthquake, Shi said. Increases in the aquitard's permeability may allow pollutants to find their way into groundwater supplies.

"The aquitard is a good indicator of the aquifer's vulnerability to pollution," Shi said. "If an earthquake causes changes in permeability in the aquitard, groundwater may move upward or downward, thus increasing the risk of groundwater contamination."

By **Mary Caperton Morton** (@theblondecoyote), Science Writer

First Persian Gulf Meteotsunami Spotted

Meteotsunamis in the Persian Gulf pose a danger to oil infrastructure and low-lying homes. Credit: iStock.com/Nikada

Earthquakes are a common cause of tsunamis, but the weather can also be a culprit when it comes to creating large waves. Scientists have now analyzed the first meteotsunami (a portmanteau of "meteorological tsunami") to hit the Persian Gulf. This event, which occurred in 2017, is troubling, the research team suggests, because so much infrastructure, including high-end resorts and oil- and gas-related equipment, dots the shoreline of this part of the Middle East.

Mohammad Heidarzadeh, a coastal engineer at Brunel University London, and his colleagues first learned about the 19 March 2017 meteotsunami through Iranian media outlets. "When we heard the news…it was a shock," said Heidarzadeh.

Seismic activity in the Persian Gulf isn't strong enough to generate traditional tsunamis, and a meteotsunami had never before been reported in the area. The event, which occurred at roughly 8:00 a.m. local time, killed five people, sank fishing boats, and sent water rushing about a kilometer inland.

Heidarzadeh and his collaborators have now used sea level data and air pressure records to analyze the waves and the weather conditions that created them. Using measurements from 12 tide gauges in the Persian Gulf, Heidarzadeh and his team found that waves as large as 2 meters from crest to trough—roughly 5–10 times larger than normal—rolled ashore in southern Iran. Unlike regular waves, which arrive every 10 or so seconds, the meteotsunami waves arrived every 15–20 minutes, the scientists calculated. The turbulent seas were remarkably localized, however, and affected only a roughly 40-kilometer section of coastline near the city of Dayyer.

Air pressure records from across the Middle East and satellite observations revealed the meteorological conditions that preceded the meteotsunami. Heidarzadeh and his colleagues found that a tropical cyclone had passed over the region shortly before the first waves were recorded. Such convective storms are characterized by updrafts and downdrafts, which trigger changes in air pressure that can cause meteotsunamis. "Atmospheric conditions over the [Persian Gulf] were highly favourable for the generation of meteotsunamis," the researchers concluded. Their study was published in July in *Pure and Applied Geophysics* (bit.ly/pg-extreme-waves).

"This certainly looks like a classic meteotsunami event and an extremely large one at that," said Gregory Dusek, a physical oceanographer at the National Oceanic and Atmospheric Administration's National Ocean Service in Silver Spring, Md., not involved in the study. "It would be valuable to collect a longer time series of water level observations to assess just how rare this type of event is in the Persian Gulf."

There's hope for predicting meteotsunamis in the Persian Gulf, Heidarzadeh and his collaborators suggest. Because weather systems tend to move from west to east, meteorological stations to the west of the inland sea—in Kuwait, Saudi Arabia, Bahrain, and Qatar, for instance—can be used to track conditions conducive to a meteotsunami. That's good news because roughly a third of the world's oil transported over water passes through this region, and waves that destroy critical infrastructure could spell "a disaster for the world's energy supply," said Heidarzadeh.

He and his colleagues are now creating computer animations of the 2017 meteotsunami. They're using these simulations to study how the waves propagated across the Persian Gulf, work that informs how meteotsunamis travel in shallow, protected bodies of water. "We really have to work on the full reconstruction," said Heidarzadeh.

By **Katherine Kornei** (@katherinekornei), Freelance Science Journalist

Uncontrolled Chemical Releases: A Silent, Growing Threat

Fishing operations in the Gulf of Mexico face a variety of challenges that originate close to home: hurricanes, leakage from offshore oil rigs, and fishing practices that deplete populations, to name a few. However, they also deal with problems that arise thousands of kilometers away. Record flooding in the U.S. Midwest during 2018–2019 has washed everything from Chicago sewage to pesticides and fertilizers from Iowa cornfields down the Mississippi River, fueling algae blooms and the resulting dead zones, including the one in the Gulf of Mexico.

This is just one example of how the uncontrolled release of household, industrial, and agricultural chemicals into the environment during natural disasters has become a significant, compounding impact of climate change. Large fluxes of petroleum and plastic-rich industrial waste, nitrogen-laden feedlot and human waste, and pesticide runoff, carried into the environment through the air, water, and soil, have the potential to meaningfully damage both ecological and human health [*Pierre-Louis et al.*, 2018; *Miner et al.*, 2018b].

These chemicals can be difficult to contain when a natural disaster damages storage structures. However, the effort to control chemical discharges is necessary: The cumulative impact of these chemical releases has the potential to raise background levels of toxic substances in the environment all over the world.

Texas National Guardsmen rescue a Houston resident after Hurricane Harvey in August 2017. Credit: Lt. Zachary West/Army National Guard

A Pervasive and Growing Problem

As the world observed after the radiation release from the Fukushima Daiichi disaster in Japan, human-made compounds introduced into the environment are possible to trace [*Anzai et al.*, 2012] but are difficult to control or fully remediate. Data from Munich Reinsurance, a company that tracks worldwide natural disasters, show an increase in all forms of natural disasters over the past 30 years. Meteorological and hydrological catastrophes specifically have seen greater increases as the climate has warmed, with events growing from fewer than 300 per year in 1981 to more than 600 in 2017. This translates to an international increase in hurricanes, strong monsoons or flooding events, and droughts.

In 2018, we saw noteworthy, large-scale, unrestricted chemical releases after a number of different natural disasters. Unprecedented summer flooding in Asia, India, the East Coast of the United States, the Philippines, and Sudan mobilized fecal matter, chemical runoff, and highway refuse, washing compounds out to sea and mobilizing toxins in the water, soil, and atmosphere [*Schwartz*, 2018; *Tabuchi and Kaplan*, 2017].

In the United States alone, over 860 cities use combined sewage overflow systems, which are designed to release untreated sewage into nearby water bodies during storm or flood events. These systems can release up to 700 million gallons of overflow per storm event [*Kenward et al.*, 2016]. Research has shown that a quantity of *E. coli* released into a watershed after a flood event can proliferate in the water for up to 3 months [*Kapoor et al.*, 2018], contributing to contamination of ecosystems and deterioration of human water resources.

In the fall of 2018, hurricanes in the American Southeast freed contained chemical effluent and feedlot waste pools into local ecosystems and the nearby ocean [*Pierre-Louis et al.*, 2018]. Although reports on the quantity of chemical releases from 2018's hurricanes are still coming out, we know that previous hurricanes in the American Southeast have released up to 10 million gallons of oil from in-ground storage systems. The U.S. Environmental Protection Agency (EPA) also counted 65,000 empty hazardous waste containers found after Hurricane Katrina [*Esworthy et al.*, 2006]. Levels of lead and arsenic in hurricane floodwaters have been repeatedly documented to be above acceptable limits. These elevated levels can affect the well-being of returning residents, compromise the health of near-ocean ecosystems, and take an economic toll on fishing communities [*Appel*, 2005; *Manuel*, 2006].

Nonflood events can also release toxic chemicals into ecosystems through direct atmospheric transport. Atmospheric transport of ash from wildfires like those in California can move household cleaning products, toxic chemicals from building materials, soot, and petroleum by-products substantial distances through the air [*Johnston*, 2018; *Young et al.*, 2004].

When summer fires destabilize a region's topsoil, winter rains can carry both ash and chemicals downstream, affecting the chemical composition and baseline toxicity of the soil and watershed. In the case of recent California wildfires, the cascading impacts were as small as a change in the taste of regional wines [*Noestheden et al.*, 2017] and as large as chemical transports to glaciers thousands of kilometers away [*Miner et al.*, 2018a].

A Cascading Series of Events

These documented cases illustrate that the cumulative impact of uncontrolled environmental chemical releases during natural disasters can create slow and steady increases in background environmental contaminations to well above current levels. A rise in background toxicity may carry significant long-term health risks, including cancer, impaired reproduction, and immune system damage [*Birnbaum,* 2013; *Kortenkamp and Faust,* 2018].

As hazardous chemicals move through soil, water, and air and into biota, the potential for toxic biomagnification and bioaccumulation increases. Bioaccumulation, the absorption of chemicals into fat tissue, increases the odds that chemicals released during a past event will move through the human and natural ecosystems for generations, being transmitted through breast milk or the consumption of fish and game, for example [*Bergonzi et al.,* 2011]. The large quantity and range of chemicals released in uncontrolled quantities can leave a legacy of contamination, leading to long-term health impacts for both humans and animals.

Tracking the Toxins

Although the EPA and the European Environment Agency, among others, are making efforts to monitor and record chemical releases, further research and real-time geographically enabled data products are needed. Models that incorporate up-to-date data with geospatial mapping would enable efficient response from agencies and could be incorporated into existing monitoring programs.

Combining geospatial data with field sources or citizen science programs would allow for the development of a digital platform for tracking toxic releases, much like easily accessible weather tracking apps. There is a clear precedent for working together across agencies and scale—after Hurricane Irma, nearly 43,000 volunteers came forward to help those affected in Florida.

In addition to on-the-ground resources, cohesive digital tools could help us understand the spread of toxins after a release while building a data-driven case for incorporating the protection of vulnerable facilities into national response plans. Integrating digitally enabled big data with applied Earth science and field monitoring can allow both the public and private sectors to plan for and reduce the long-term impacts of uncontrolled chemical releases.

Some of the greatest challenges of this century could emerge from the secondary and tertiary impacts of climate change, putting strains on global resources. Meeting these challenges requires governments and risk managers to streamline the process between identifying emergent climate risks and adequately responding. This, in turn, relies on prioritization of accessible, digitally enabled planning tools and systems-based science. Even as the world negotiates how to move forward with the Paris Agreement, these silent impacts of climate change will continue to multiply and compound.

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An Evolutionary Leap in How We Teach Geosciences

The content and skills that we teach our geoscience students benefit from developments in the knowledge and practices of the many research fields within the geosciences. In much the same way, what and how we teach should be informed by research on geoscience teaching and learning itself—this has always been true. However, geoscience education research is now entering a new stage and is poised to take an evolutionary leap [*Arthurs,* 2019]. If we make this leap successfully, teaching practice and student learning will reap the benefits.

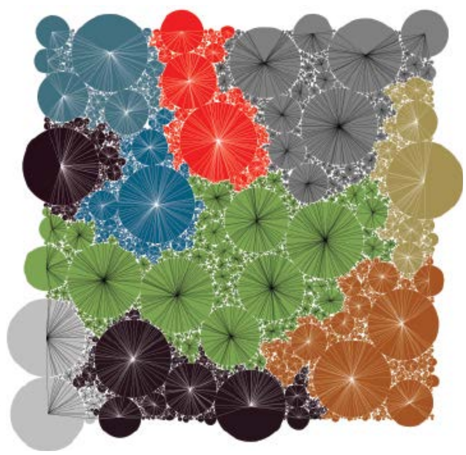
The idea that geoscience education research (GER) should inform the ways in which geosciences are taught is not new. *Eos* has been a venue to share several GER advances, such as in how geoscientists think and learn [*Kastens et al.,* 2009], methods for teaching geoscience to large classes [*Butler et al.,* 2011], and helping students develop spatial reasoning skills [*Davatzes et al.,* 2018].

One next step in this process, the AGU Council's formation last year of an Education section, reflects the value that AGU members place on teaching and learning about Earth. Education is at the core of nurturing the next generation of diverse Earth scientists, as well as growing public understanding of how Earth science is relevant to everyday lives and how it helps address pressing problems facing humanity.

Grand Challenges for Geoscience Education Research

Recently, more than 200 geoscience educators and researchers engaged in an important community-building and research-strengthening process, which spanned a year and a half. Through a series of National Science Foundation–funded activities, they defined a set of priority research questions, or "grand challenges," on 10 themes relevant to undergraduate geoscience education.

Grand challenge exercises have been essential steps in other geoscience communities, including tectonics research [*Huntington et al.,* 2018] and scientific ocean drilling. When done well, they enable a community to identify research needs and opportunities going forward. This is what the GER community has accomplished. The result is A Community Framework for Geoscience Education Research [*St. John,* 2018], a prioritized research agenda and a catalyst for action.



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Addressing Stubborn Problems

The questions guiding future research on undergraduate geoscience education span a web of topics. These include research on how students learn geoscience content, their development of workforce-necessary skills, and our ability as instructors to design and implement curricular pathways for the success of all students [*St. John,* 2018]. Within these areas are stubborn problems that will require action at multiple scales [*St. John and McNeal,* 2017], from case studies to large, multi-institutional studies, conducted by diverse teams of researchers.

Here we give three examples of stubborn problems in the modern landscape of undergraduate geoscience teaching and learning. Each example highlights needs and opportunities to tackle challenging teaching and learning questions of our time by rethinking our assumptions, drawing from new empirical data, and applying social science theories and methods to topics that matter to geoscience educators.

1. Overcoming Obstacles to Learning High-Stakes Science

Climate change is one of the most widespread geoscience challenges facing society today. This is an example of "high-stakes science," which requires a broad response by a scientifically informed populace to avoid potentially costly and disastrous outcomes.

Compounding the problem and stalling possible solutions is the disconnect between the public and scientific understandings of climate change. Psychologists *Weber and Stern* [2011] attribute this disconnect to two fundamental factors. First, climate change is intrinsically difficult to understand because of its multiple drivers, consequences, and feedbacks, as well as its operation across different spatial and temporal scales. Second, scientists and nonscientists develop their understandings of the natural world in different ways. Scientists base conclusions and recommendations on data and logic, but for nonscientists, feelings and values often override systematic observations and measurements of climate phenomena.

It is our job as geoscience educators to break down that complexity and help students experience how science works. Social science research tells us that success likely requires learners to overcome serious obstacles [*Paasche and Åkesson,* 2019], such as the tentacles of fake news, groupthink, and failure to think critically [*Pennycook and Rand,* 2019].

Currently, there is no consensus in the social science community on how to overcome these obstacles. However, GER efforts to advance climate literacy are under way [e.g., *McNeal et al.,* 2014; *Buhr Sullivan and St. John,* 2014]. In particular, work by *Cook et al.* [2017, 2018] shows promising results for teaching students how to critically analyze claims about climate change and inoculate them against climate misinformation.

These efforts are only the start to closing the gap between the public and scientific understanding of the high-stakes science of climate change. GER is uniquely qualified to address this challenge by integrating knowledge about how the Earth system (i.e., the climate system) works with knowledge about the theories and methods of social science research.

2. Complex Problem Solving Isn't What It Used to Be

When many of us were undergraduates, a "problem" was often a textbook-style exercise with a single correct answer. This answer might have been printed in the back of the textbook, and we could solve the problem using a technique that had been explicitly taught in class.

In today's undergraduate geoscience courses, students are increasingly being asked to grapple with complex, ill-structured problems at the intersection between Earth and human systems. Such problems have no single correct answer and no predetermined pathway toward solutions. Proposed solutions may involve values or ethics as well as science and technology. Such work has been called convergent science because solutions for problems must be converged on from different directions. This convergence is difficult to teach and learn.

However, we must teach convergent science, because geoscientists have scientific expertise and valuable perspectives needed to address a range of economic, environmental, health, and safety challenges [*Aster et al.,* 2016]. Research is needed on how societal problems, such as confronting climate variability, ensuring sufficient supplies of clean water, and building resiliency to natural hazards, can serve as effective contexts for teaching and learning in the geosciences.

Some help comes from a recent review paper by *Holder et al.* [2017], which provides a conceptual model to guide students in solving ill-structured problems. This model, which was calibrated against 11 empirical, classroom-based research studies, identifies elements of successful guidance. These elements include real-world relevance, collaboration among problem solvers, requiring students to analyze and interpret data, and the possibility to explore more than one pathway to a solution. The geoscience education research community has only begun to explore the forms of coaching and scaffolding that can help individuals who struggle with these types of problem-based curricula.

Understanding how we can help students find and solve Earth science–related problems that they care about in an information-rich society is a high priority for GER. One way we can make progress is by studying the problem-finding process itself. Defining authentic problems is not easy, but it is the first critical step to solving them.

Investigating this process will involve studies on how skilled geoscience problem solvers do their work, how learning occurs during problem solving, and what pedagogical approaches nudge students toward tackling problems as experts do. In addition, people from different backgrounds may perceive and prioritize different problems; therefore, inclusion is especially important in GER around problem solving and in problem-based learning.

We are beginning to explore forms of coaching and scaffolding that can help individuals struggling with these types of problem-based curricula (e.g., synthesis work by *Holder et al.* [2017]). This research direction is critical because we anticipate that people who learn to identify and solve convergent science problems as students will carry that skill set and habit of mind into their personal, civic, and professional lives.

The changing landscape of information technology (e.g., big data, emerging technologies, access to a wide variety of tools, rich multimedia) also affects the kinds and quantities of resources that are available for problem solving. Students must learn to navigate this rapidly changing space, identifying and harnessing resources (e.g., tools, data, models, experts, collaborators [*Ebert-Uphoff and Deng,* 2017]) that can be brought to bear on the convergent problems.

Employers articulate the importance of using data to solve problems, of learning to work on problems with no clear answers, and of managing the uncertainty associated with addressing these types of problems. However, the most effective strategies for learning how to manage and extract solutions from large data sets are not clear; therefore, this too is among the priorities for geoscience education researchers.

3. Learning Success and Essential Engagement

Another set of obstacles to learning is often overlooked. Imagine a situation in which a student who did poorly on the last exam comes to your office and asks, "How can I better study for the next one?" You ask, "What did you do to prepare for the last exam?" The student's response is typical of many introductory college students: "I reviewed the PowerPoint slides and looked at my textbook."

Research from the social sciences has shown that students' ability to reflect on what they know, what they don't know, and what they need to do to improve is vital to the learning process, as are their emotions, attitudes, and beliefs. Research addressing these factors in a geoscience context may be the key to strengthening the foundation of our undergraduate courses.

Results of GER are promising: We have a preliminary understanding of what drives some introductory geoscience students to learn new content [*van der Hoeven Kraft,* 2011] and to study for exams [*Lukes and McConnell,* 2014]. However, we need to learn how these factors affect students' abilities to advance from geoscience novices to geoscientifically literate citizens or to practicing geoscience experts.

In addition, the pathways and identities of students may affect their emotions, motivations, and engagement in our courses. These in turn affect the likelihood of their being attracted to and thriving in the geosciences. Given how geoscience touches the lives of all people, it should also be a field that is representative of all people, but that is not yet the case.

Because geoscience is the least diverse field in science, technology, engineering, and math [*Sidder,* 2017], with little improvement in diversity over the past 4 decades [*Bernard and Cooperdock,* 2018], expanding underrepresented minority participation is perhaps the most stubborn problem in geoscience education. Social science theories newly applied to the geosciences [e.g., *Callahan et al.,* 2015, 2017; *Wolfe and Riggs,* 2017] are likely going to be key to developing recruitment and retention strategies for implementation at the individual and programmatic levels.

What Can I Do?

Geoscience education research on these and other grand challenges identified in the framework will strengthen the geosciences as a whole by feeding back into what and how we teach. This goal has the underlying assumptions that research results are effectively shared with educators and are used to reform teaching practice. These actions cannot be left to chance—they will require expanding and sustaining dialogue between educators and researchers and increasing support for GER across programs and departments.

AGU members must be part of this effort. At the individual level, talk with your colleagues who do GER about questions on teaching and learning that matter to you. Invite geoscience education researchers to your department as seminar speakers. At the society level, the dialogue can be scaled up by hosting forums where educators can pose questions and talk directly to GER experts and where GER experts can ask questions of educators.

One online model for this is the Research + Practice Collaboratory, an organization that experiments with ways to support mutual cultural exchange between researchers and practitioners. Another model, which can be embedded in conferences, is the Geoscience Education Research and Practice Forum.

In addition, AGU publications can invite researchers to submit short summaries of new findings and their practical implications for teaching topics that align to that journal's focus. Geoscience teaching excellence is a shared goal of geoscience educators and geoscience education researchers, and now is the perfect time to engage in a disciplinary movement forward.

Acknowledgments

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The Fate of Borneo's Plunging Tectonic Plates

Scientists installed a dense seismic network to investigate what happens when subduction stops.

By Simone Pilia, Nicholas Rawlinson, Amy Gilligan, and Felix Tongkul

Walking around Kota Kinabalu, the capital of the Malaysian state of Sabah in northern Borneo, you cannot help noticing the imposing bulk of Mount Kinabalu. Rising to an elevation of 4,095 meters (13,435 feet), it is among the highest mountains in Southeast Asia; it towers over the surrounding Crocker Range (Figure 1), which reaches higher than 2,000 meters.

Mount Kinabalu is made of granite that was emplaced within Earth's crust 7–8 million years ago [*Cottam et al.*, 2010, 2013]. The mountain is a sheeted laccolith-like body; that is, it initially formed when a mass of magma intruded between two existing rock strata, causing the overlying layers to rise into a dome shape. After the granite was emplaced, it cooled rapidly; scientists have interpreted this cooling as a reflection of both the granite's adjustment to ambient crustal temperatures and its relatively rapid exhumation toward Earth's surface. The processes responsible for

The Sun peeks over a ridge near the top of Mount Kinabalu in northern Borneo. Credit: Amy Gilligan

Sabah is an ideal location to study the process of subduction termination, which is one of the more poorly understood stages of the global subduction cycle.

this rapid cooling and how this granitoid body rose so quickly to such spectacular heights remain enigmatic.

Mount Kinabalu is not the only puzzling geological landform in Sabah. Travel across the Crocker Range to the southeast of the state, and you will encounter circular basins that rise up from the surrounding landscape. The most spectacular of these is Maliau Basin (Figure 1), which is around 30 kilometers in diameter and is encircled by an imposing ridge up to 1,500 meters high. The basin's shape, clearly visible in satellite imagery and digital elevation maps, may at first suggest an impact crater, but closer inspection reveals that the interior contains a thick sequence of river delta sediments that were deposited at sea level 10–15 million years ago. What caused the uplift of southeastern Sabah and the preceding 10 million years of subsidence, and how were these unusual basins formed?

The answers to these questions may be found in the postsubduction setting of northern Borneo. As recently as 5 million years ago, subduction stopped along the eastern margin of Sabah for reasons we do not fully understand. The mantle processes and changes in the regional stress field associated with such an event likely conspired with

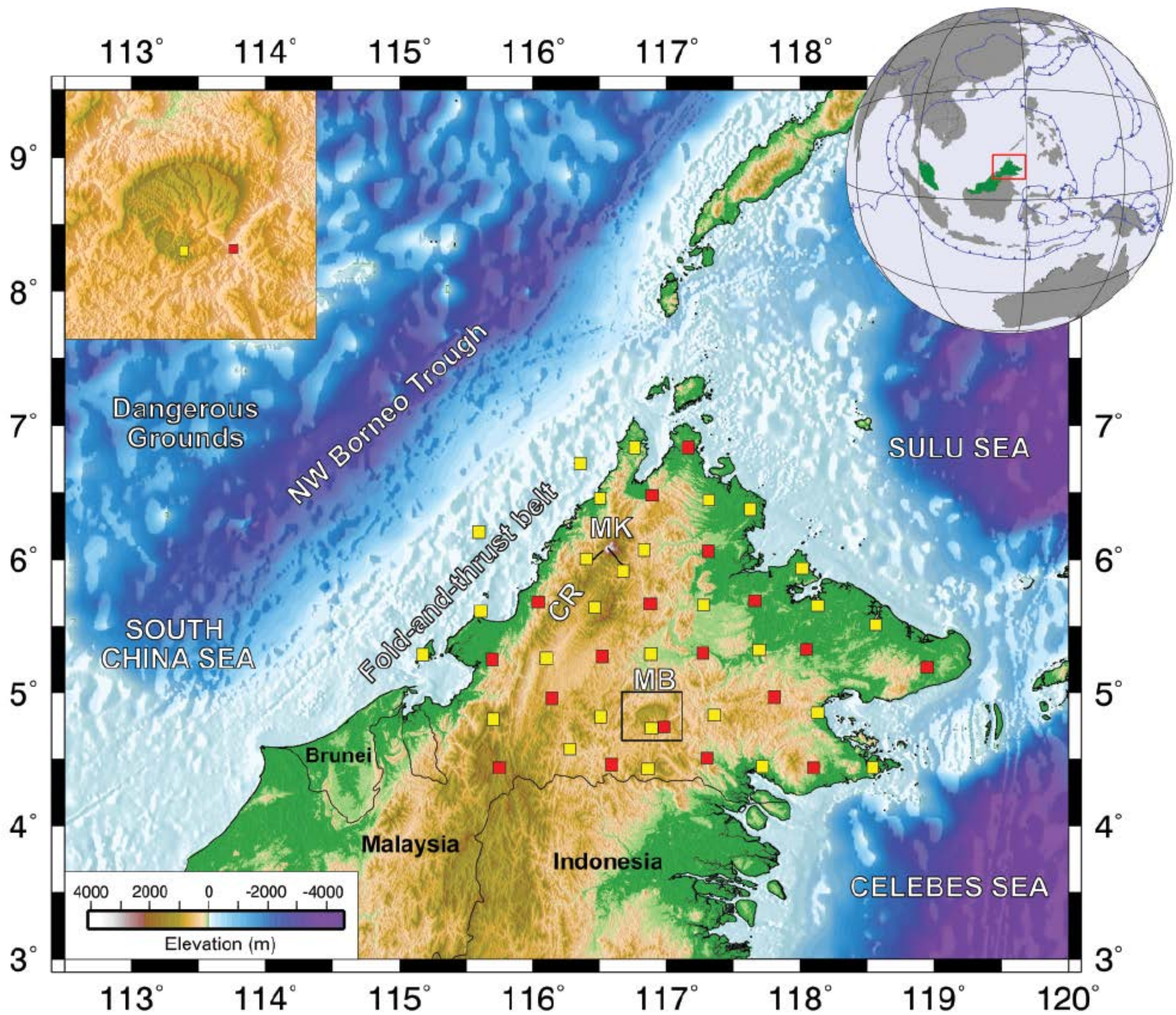
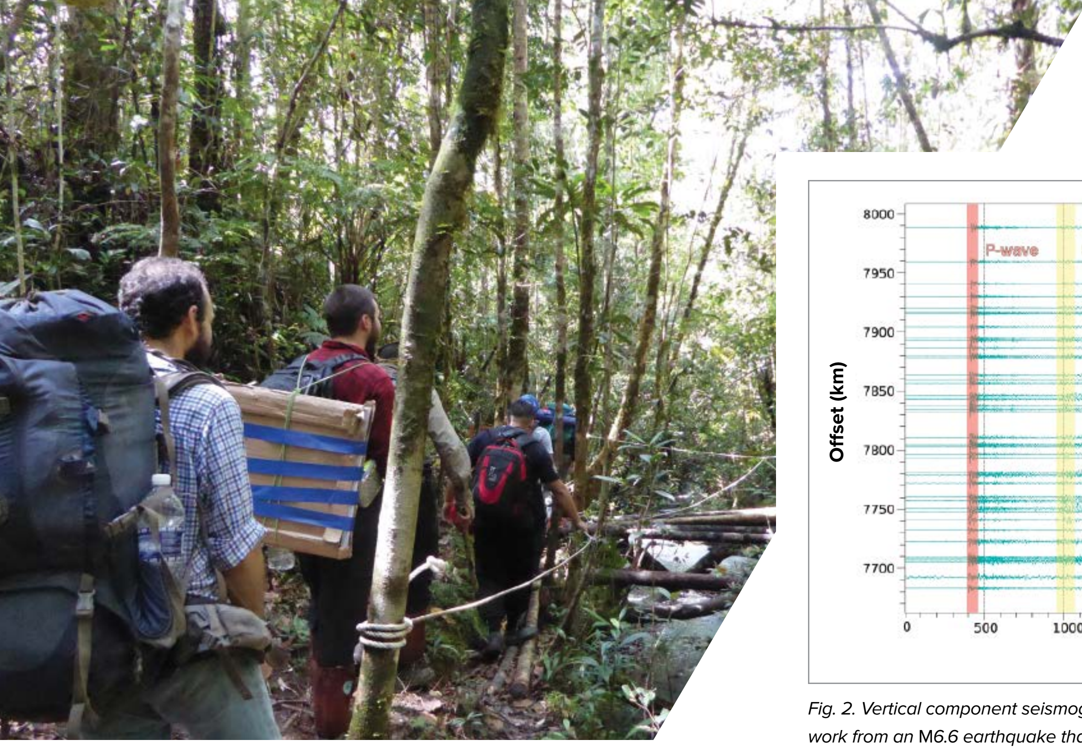


Fig. 1. Map of Sabah showing topography and bathymetry in the background. Yellow and red squares indicate CMG-6TD and CMG-3ESPD seismic sensors, respectively, deployed by the nBOSS research team. The top right inset shows the location of Malaysia (green), with the blue lines depicting the tectonic plate boundaries. The top left inset is a close-up of the black rectangle, which shows the Maliau Basin (MB). CR = Crocker Range; MK = Mount Kinabalu.



The team hiked to remote locations, including the dense jungles in the Maliau Basin, to install the seismometer network. Credit: Amy Gilligan

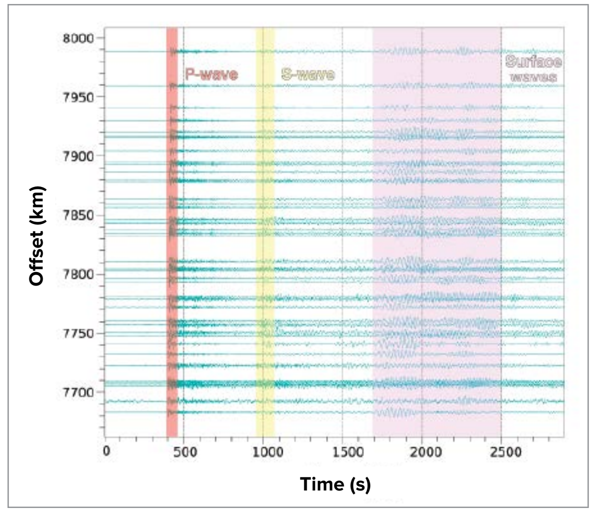


Fig. 2. Vertical component seismograms recorded by the nBOSS network from an M6.6 *earthquake that occurred about 8,000 kilometers (~5,000 miles) away from the seismic sensors in the Aleutian Islands (Alaska) on 15 August 2018. The colored stripes highlight the time periods in which body and surface waves are expected to arrive.*

surface processes to help shape the landforms we observe today. Clearly, we require detailed images of the crust and underlying mantle to understand why subduction ceased and how the landforms of Sabah may be related to deeper processes in the mantle.

This is where the North Borneo Orogeny Seismic Survey (nBOSS) project, which involves Borneo's first temporary seismic network, comes into play. The nBOSS project is the result of a collaboration between the University of Cambridge, the University of Aberdeen, the Universiti Malaysia Sabah, and the Malaysian Meteorology Department. In March 2018, we deployed a network of 46 broadband seismic stations, spaced about 45 kilometers apart, throughout Sabah (Figure 1). This dense cluster of stations complements the more widely spaced stations in Malaysia's regional seismic network.

Sabah's Complex Tectonic History

Sabah lies near the northeastern edge of present-day Sundaland, the continental core of Southeast Asia, and is separated from the Philippines by the Sulu and Celebes Seas. Like much of Borneo, it formed by accretion of continental and oceanic material onto the eastern margin of Sundaland during the Late Cretaceous to early Miocene times (~70–20 million years ago).

During the Paleogene (~60–25 million years ago), the proto–South China Sea was subducted beneath what is now the northwestern continental margin of Sabah. This subduction process came to an end approximately 20 million years ago with the collision of two continents that resulted in the formation of the Crocker Range. Subsequently, there was a separate system of northward subduction of the Celebes Sea beneath eastern Sabah, which ended 5–6 million years ago.

The lithosphere that is now northern Borneo thus bears the signature of a southeast directed subduction system, followed by a northwest directed subduction system. Consequently, Sabah is an ideal location to study the process of subduction termination, which is one of the more poorly understood stages of the global subduction cycle.

Although several models all have merit, the picture is incomplete without some understanding of how they couple with mantle processes.

Borneo's First Dense Seismic Network

The nBOSS network, the first of its kind in Borneo, is supplemented by 24 permanent broadband seismic stations that form part of the Malaysian National Seismic Network. To install the instruments in our network, we used four-wheel-drive vehicles to make use of all possible roads and fast motorboats to reach islands in the South China Sea.

We dodged leeches as we trekked into the interior of the Maliau Basin and scaled Mount Kinabalu to install an instrument high on the mountain. The first batch of data was successfully recovered in September 2018, and now the data analysis has begun.

The network will record for nearly 2 years. This time frame will allow us to record a sufficient number of distant earthquakes (Figure 2) for the application of a variety of seismic imaging techniques, including teleseismic tomography and receiver function and shear wave splitting analyses. We will extract further surface wave information from continuous ambient noise signals. The velocity and anisotropy models from this work will provide a number of critical constraints, including crustal

The new tomographic and geodynamic models will provide valuable insight into how continents evolve.

thickness, mantle flow patterns, locations of lithospheric-scale faults, and discontinuities, that will feed into subsequent geodynamic modeling.

What Happens When Subduction Stops?

Recent tectonic activity in Sabah, such as the rapid uplift and exhumation of Mount Kinabalu [*Cottam et al.,* 2013], may be related to subduction termination. However, the extent to which postsubduction processes have dictated the evolution of the surface geology in the past 5–6 million years and whether those processes continue to do so now are unknown.

Several models have been proposed for the crustal evolution of the region. One such model posits that localized uplift and detachment faulting have caused gravitational collapse—mountain ranges collapsing under their own weight—in the Crocker Range, resulting in the formation of the fold-and-thrust belt offshore northwestern Sabah [*Hall,* 2013]. Confirming that gravitational collapse is happening requires obtaining constraints on the geographic distribution and rates of uplift and linking these to mantle structure and processes.

Another model says that continental extension has caused orogen collapse and produced a core complex [e.g., *Lister and Davis,* 1989] with the associated granite intrusion manifested by Mount Kinabalu. This model would explain both offshore subsidence and onshore uplift.

A third model says that a regional compressive stress field has localized strain in a foreland fold-and-thrust belt. This model can also explain onshore mountain building and does not require ongoing subduction or underthrusting.

The lack of constraints on mantle structure and dynamics beneath Sabah means that published models tend to focus on the crust, and even then, middle to lower crustal structure and processes are often largely based on speculation. Although the aforementioned models all have merit, the picture is incomplete without some understanding of how they couple with mantle processes.

On the basis of the presence of recent (~5 million years old) basalts with ocean island character in southeastern Sabah, *Hall* [2013] proposed three models to explain the underlying cause for deformation of the lithosphere and vertical movements of the surface:

- detachment of the descending slab from the rest of the plate (slab break off)
- delamination and sinking of the dense root of the lithosphere into the mantle below
- gravitational instability due to a lithospheric drip (a sinking plume of cold, dense lithospheric material)

For instance, uplift and extension caused by slab break off could induce or enhance orogen collapse. Alternatively, if regional compression has localized strain, then there is no requirement for any significant mantle anomaly. Clearly, to properly understand the link between mantle and crustal processes, a multidisciplinary and multiscale approach is essential.

Mount Kinabalu towers over Kota Kinabalu, capital of the Malaysian state of Sabah in northern Borneo. Credit: Amy Gilligan

Linking Field Data and Models

The crust and upper mantle beneath Sabah have yet to be targeted by geophysical imaging studies. The only evidence to date comes in the form of global seismic tomography, which shows a distinct high-velocity anomaly in the upper mantle beneath northern Borneo [*Hall and Spakman,* 2015]. Although this evidence is potentially consistent with a remnant slab or mantle drip, the lack of resolution (>250 kilometers) precludes any further analysis.

Through the nBOSS project, we will use a multidisciplinary approach to address four specific aims: to understand mantle dynamics in a postsubduction setting; to determine the existence, cause, and extent of orogen collapse; to develop a model for postsubduction evolution of the continental crust-mantle system; and to unravel the cause of subduction termination in northern Borneo.

The new tomographic and geodynamic models will provide valuable insight into how continents evolve. The models we construct for the Sabah region can be compared with other recent postsubduction continental environments, including Europe's east Carpathian-Pannonian region, North America's Baja California, the Betic-Rif orogen in the western Mediterranean, and the Antarctic Peninsula.

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JOHN WESLEY POWELL and THE WEST THAT WASN'T

by Korena Di Roma Howley

One hundred fifty years ago, the explorer and scientist argued that the West needed smart development. Now the fast growing region is playing catch-up.

The American West, while steeped in mythology, is also a region that depends heavily on science for its long-term livability—and perhaps no one was quicker to realize this than John Wesley Powell. A Civil War veteran and an indefatigable explorer, Powell landed on the national stage in 1869, after an expedition he led became the first to navigate the Colorado River's path through the Grand Canyon.

In the decades that followed, Powell would argue that careful, democratic management of water resources in the West must be a crucial component of its development and that a pattern of settlement and land cultivation based on the 19th-century status quo would prove unsustainable.

He couldn't have had a more unreceptive audience. Elected officials, industry titans, and even fellow scientists wanted a nar-

No photos were taken during John Wesley Powell's pioneering 1869 expedition of the Colorado River. This photo, taken along the Green River in northern Colorado, dates from Powell's 1871 expedition, which retraced the 1869 journey. Credit: National Park Service

rative that better supported the westward march of “progress,” narrowly defined.

Fast-forward 150 years, and Powell’s 19th-century appeals are making modern headlines on the strength of their perception and foresight. Even while western states lead the nation in economic and population growth—Arizona, Colorado, Nevada, and Utah were among the top five states with the fastest growing gross domestic product between 2016 and 2017—drought conditions that have persisted for decades have left parched cities under constant threat of water emergencies.

On the Colorado River, the country’s two largest reservoirs—Lake Mead, on the border between Nevada and Arizona, and Lake Powell (so named for John Wesley), on the border between Arizona and Utah—are being drained faster than they can replenish. The effects of climate change are only adding to the pressure on limited water supplies.

In Powell’s account of his explorations, published in 1895 as *Canyons of the Colorado,* he describes the river’s waters emptying “as turbid floods into the Gulf of California.” Today only in very wet years does the river reach the ocean. Meanwhile, communities that rely on the Colorado for water, including sprawling metropolitan areas like Denver, Phoenix, and Los Angeles, are facing the possibility of having their supply cut off or severely limited in a future that’s moving alarmingly nearer.

Unforeseen Potential

It’s tempting, then, to imagine how the West might have evolved had Powell’s vision for its development been implemented, rather than shunned, a century and a half ago.

What if Congress, undeterred by the siren song of American expansion, had listened to the call of the pragmatic?

Would L.A. be a backwater?

Would Tucson even appear on the map?

Would the Colorado still rush freely to the gulf from its headwaters in the Rocky Mountains?

Speculation about what might have been is complicated by society’s shifting priorities and values, as well as by technology. Powell, for his part, envisioned much smaller communities dispersed over the western landscape.

“

One of the big things that would’ve happened if we’d listened to Powell is that we… would have responded earlier to the information about global climate change.

”

John Wesley Powell at age 35, the year he led the first expedition down the Colorado River and through the Grand Canyon. Credit: USGS

“One thing that he didn’t anticipate [was] the degree to which we would accumulate western society in big, urban complexes,” said Jack Schmidt, the Janet Quinney Lawson Chair in Colorado River Studies at Utah State University and former chief of the U.S. Geological Survey’s (USGS) Grand Canyon Monitoring and Research Center.

Powell, Schmidt said, might not have imagined that these urban complexes “would have these tentacles that extended way out into the distant landscape [or] the degree to which these big urban centers would be maintained by these really long canals…these really complicated electricity transmission systems that bring in power from distant coal-fired and nuclear and hydroelectric dam facilities.”

Although Powell’s vision of small communities was focused largely on irrigated agriculture, water management, he thought, would be developed at a more local scale. This would, among other benefits, help to hedge against the uncertainties of climate variation. When, for instance, the 1922 Colorado River Compact apportioned shares of Colorado River water to seven states, it was during a particularly wet period, leading to overestimated water allocations.

“One of the big things that would’ve happened if we’d listened to Powell is that we…would have responded earlier to the information about global climate change,” said John F. Ross, author of *The Promise of the Grand Canyon: John Wesley Powell’s Perilous Journey and His Vision for the American West.* “He was a great proponent of America’s potential; he just wanted to do it in a way that was sensible to what was on the ground.”

When the West Was Young

In 1869, as the post–Civil War United States was knitting itself back into a union, the sparsely settled expanse of states and territories that stretched between the 100th meridian and the Pacific coast was still a great unknown for many Americans. That year, Ulysses S. Grant was inaugurated as the eighteenth president of the United States, Wyoming became the first U.S. state or territory to grant women suffrage, and a spike driven at Promontory Summit in Utah connected the country’s first transcontinental railroad.

To many communities in the East and Midwest, the newly accessible West was brimming with possibility and scarcely tapped resources. John Wesley Powell, then a professor of geology at what is now Illinois State University, had identified an opportunity as he contemplated the last blank spot on the map of the continental United States: the Colorado Plateau. Today this area includes Arches, Zion, the Grand Canyon, and five other national parks, as well as nearly two dozen national monuments, historic sites, and recreation areas. In Utah alone, the states's five national parks brought in 15.2 million visitors in 2017.

But in the late 19th century it was an altogether different story. When Powell undertook the 3-month descent of the Colorado River in the name of science, the journey was considered by some to be all but suicidal. Still, the retired Union Army major—who had been wounded while fighting in the Battle of Shiloh—conquered the unpredictable 1,600-kilometer route with one arm, a small fleet of wooden rowboats, and a cobbled-together team of nine willing but inexperienced adventurers.

The expedition departed from Wyoming's Green River City on 24 May 1869, with 10 months' worth of supplies, an optimistic collection of scientific tools, and, among some of the men, hopes of finding a fortune. Four men would eventually abandon the expedition, one at the first opportunity and three others less than 2 days before the remaining team successfully emerged from the Grand Canyon. (Those three men were never seen or heard from again.)

Although Powell's scientific ambitions for the expedition were largely scuttled by the demands of survival, the widely heralded trip would help to launch his decades-long career as a geologic surveyor, shrewd political player, and government administrator. His recommendations to Congress would be instrumental in the creation of the U.S. Geological Survey, and he would later serve a dozen years as its director while also leading the Smithsonian's Bureau of Ethnology and helping to found the Cosmos Club and the National Geographic Society.

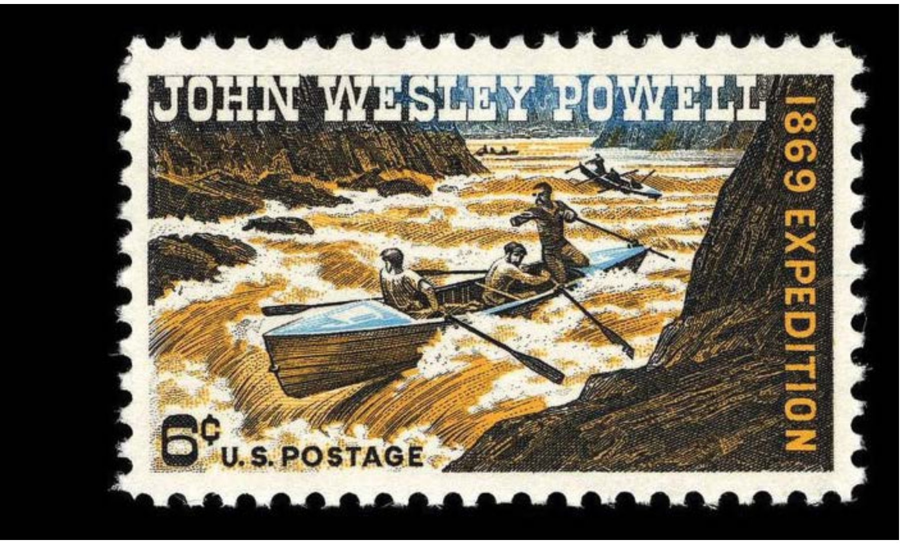
But it was Powell's unswaying advocacy for land and water management in the West that would prove to be one of his most remarkable legacies.

> *“Powell—who had been injured while fighting in the Battle of Shiloh—conquered the unpredictable 1,600-kilometer route with one arm, a small fleet of wooden rowboats, and a cobbled-together team of nine willing but inexperienced adventurers.”*

A Watershed Idea

It was the railroad that made it possible for Powell and his team to launch the expedition from the banks of the Green River. The conveniently located station at Green River City meant that Powell could easily bring his boats and supplies by train. But the technology that benefited Powell's plans in 1869 would also facilitate the idealistic expansion that he would ultimately spend the latter part of his career warning against.

The completion of the transcontinental railroad was especially timely for a nation in pursuit of Manifest Destiny, which disregarded the realities of climate and the native peoples who occupied the land in favor of spreading American industrialism and progress from coast to coast. Politicians, speculators, and homesteaders were eager to exploit the promise of the West's seemingly endless resources and would be quick to deny the hard truth that lives and livelihoods depended on one all-important ingredient: water.



Powell's expedition down the Colorado was honored by the U.S. Postal Service on the expedition's centenary in 1969. Credit: U.S. Bureau of Engraving and Printing, Smithsonian National Postal Museum

In his 1879 *Report on the Lands of the Arid Region of the United States, with a More Detailed Account of the Lands of Utah, with Maps,* Powell foresaw the consequences of applying American optimism—and opportunism—in a part of the country where annual rainfall measured below 50 centimeters. He warned that there wasn't enough water to support large-scale farming or the rapid settlement of federal lands stimulated by the Homestead Act of 1862. In addition, the costs of establishing effective irrigation systems threatened to keep control out of the hands of small farmers.

Certain conditions, Powell said, had to be met to develop the region successfully, including the identification of irrigable areas and local control of dam and irrigation projects.

It was a position Powell would refuse to abandon.

While testifying before a congressional committee in 1890, when he was head of the USGS, Powell deployed a unique visual aid: a map that divided the western states and territories into a series of drainage districts.

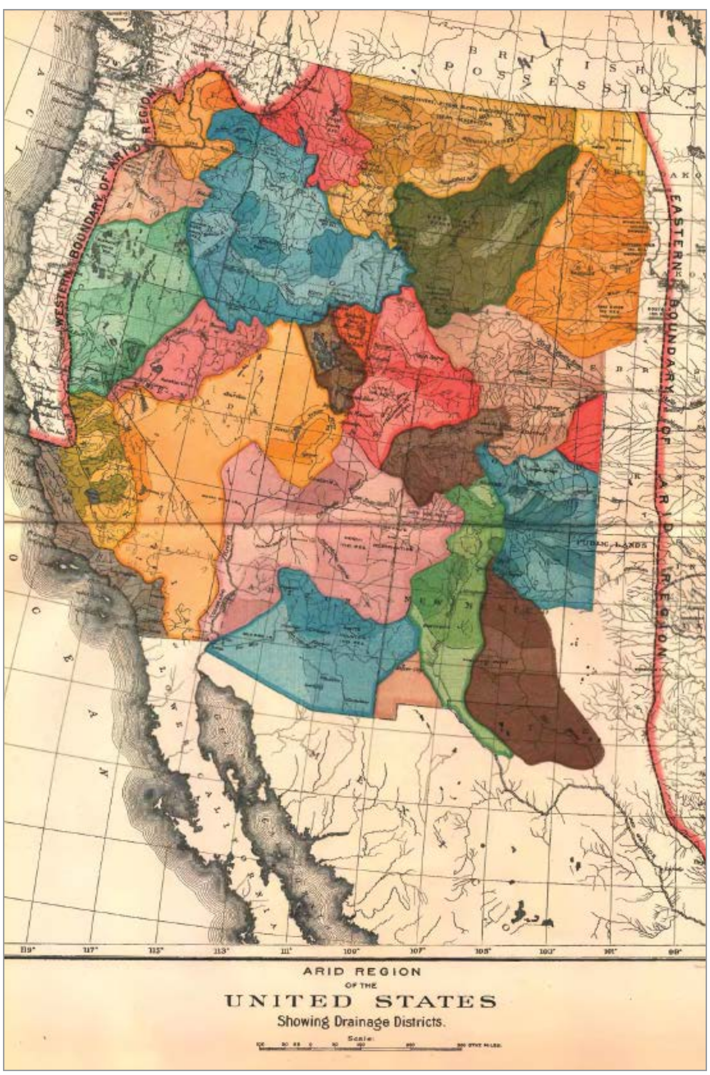
On first viewing, it's a surprising example of 19th-century cartography, made all the more striking with rich colors and irregular, organic-looking boundaries that contrast sharply with the boxy borders we're familiar with today.

But the schematic didn't hold water, so to speak, with a nation determined to grow and expand. The outlook of the nation was invested in myths that encouraged development and defied science, whereas Powell, Schmidt said, lacked the tolerance for pursuing such myths, including the widely held belief that "rain follows the plow."

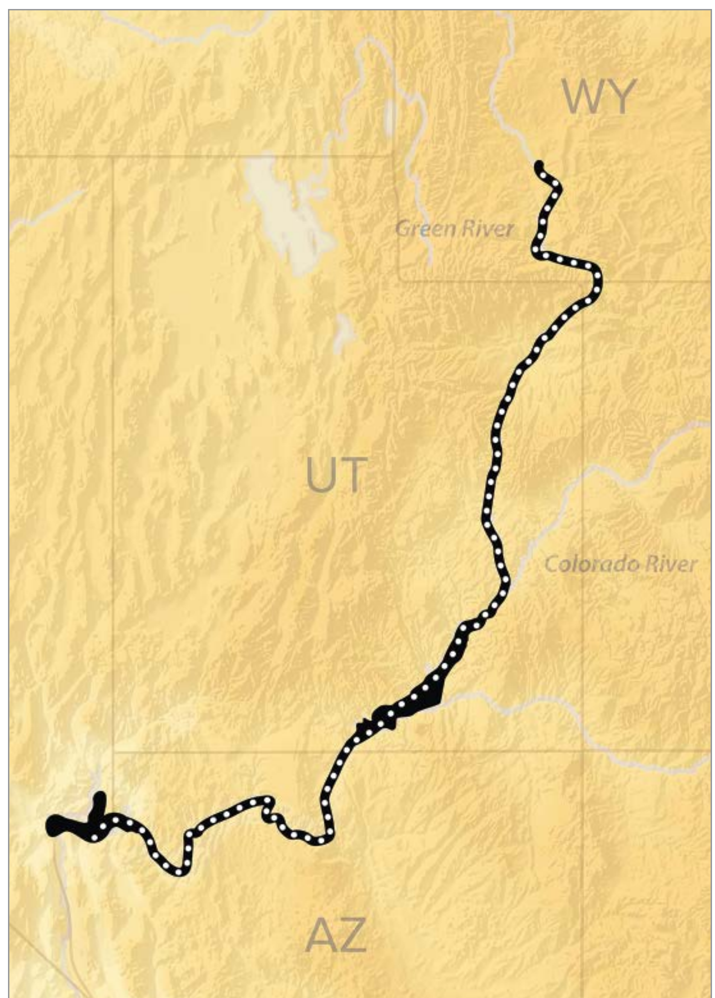
In 1902, the year Powell died, Congress passed the Reclamation Act to "reclaim" the arid region for agriculture and settlement.

"That set the stage for this really large-scale water development in the West that almost defied the functioning of the watershed from an ecological perspective," said Sandra Postel, founder and director of the Global Water Policy Project and author of *Replenish: The Virtuous Cycle of Water and Prosperity*.

> *Powell introduced the idea that arid cultures either stood or fell…not on the absolute amount of water, but on how equitably—politically and economically—the system divided that resource.*



As director of the USGS in 1890, Powell presented this map of western watersheds (drainage districts) to Congress. Credit: USGS



Powell's expedition down the Colorado River departed from Green River City, Wyo., on 24 May 1869 and ended at the far side of the Grand Canyon 99 days later. Credit: Schwabenblitz/Shutterstock.com; Cartarium/Shutterstock.com; Design: Potomac Communications Group

This boat, the Emma Dean, *carried Powell and his characteristic chair down the Colorado in 1872. Credit: National Park Service*

Today, "the river is really operated more according to needs for hydropower, flood control, irrigation, and water supply," Postel said. "You couldn't have cities like Las Vegas and Los Angeles and Phoenix and Tucson without this extra water."

In the Same Boat

Although Powell's insistence on viewing the West's water problem with scientific objectivity was deeply unpopular at the time, today it's apparent that his approach was forward-thinking. Now science is taking a leading role in helping to reclaim the region for the environment while facilitating ways for a growing population to live there sustainably.

Powell believed that "science is a process of continually improving the details of our understanding of natural processes, and he would be very proud of the role of science in informing river management and protection," said Schmidt.

According to Ross, Powell set the stage for the type of conversation we should be having about our natural resources. "He introduced the idea that arid cultures either stood or fell…not on the absolute amount of water, but on how equitably—politically and economically—the system divided that resource," he said.

And what lessons can be taken from Powell as the West moves forward?

Said Ross, "We're seeing this kind of bioregionalism now, where decisions are made not by the federal government but on a more local, or regional, basis—[which is] really the only way to work out these very knotty issues."

Postel said that successful restoration often involves collaboration, such as conservationists working with farmers to find solutions to water management issues.

"If we get smarter about using and managing water, we can do better with what we've got than we're currently doing," she said.

As the challenges and accomplishments of western settlement continue to ebb and flow, Powell's influence still lingers.

Like Postel, Schmidt believes that the key to water management in the West is in working together as a watershed community. "In a sense, that's an idea of Powell's that still exists today," he said. "It's just that the community that we call the watershed includes the entire Colorado River basin. It includes every one of the seven states, all sitting around the table together."

Author Information

Korena Di Roma Howley (korenahowley@gmail.com), Freelance Journalist

▶**Read the full story at bit.ly/Eos-Powell**

Understanding Alaska's Earthquakes

One of the longest deployments of new seafloor seismograph technology was just completed—and you can get the data now.

By G. A. Abers, A. N. Adams, Peter J. Haeussler, Emily Roland, P. J. Shore, Douglas A. Wiens, Susan Y. Schwartz, Anne F. Sheehan, D. J. Shillington, Spahr Webb, and Lindsay L. Worthington

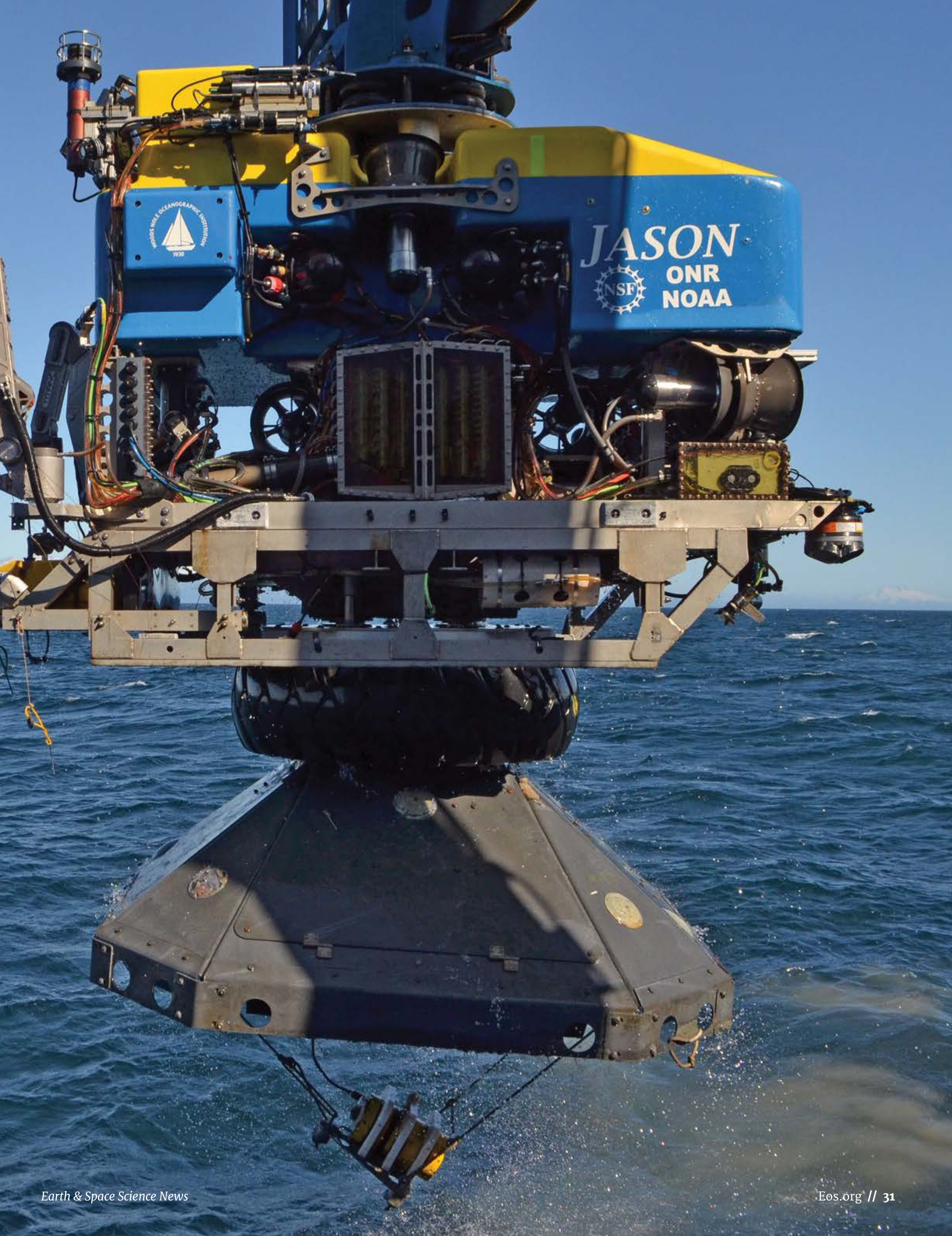
EOS CENTENNIAL COLLECTION

NORTH AMERICA'S LARGEST EARTHQUAKES and most powerful volcanic eruptions occur along the Alaska Peninsula subduction zone, a meeting of two tectonic plates that sweeps an arc across the North Pacific margin between Alaska and Russia. However, studies that would help us understand these hazards are few and far between in this remote, sparsely populated region.

A major new shoreline-crossing community seismic experiment spans the Alaska Peninsula subduction zone, with the intention of filling gaps in our knowledge of this region. Information that we collect along this margin can provide direct information about many first-order questions about subduction zone processes that influence earthquakes and volcanism.

For example, segments that have generated great earthquakes ($M > 9$) behave very differently than segments that are smoothly creeping, and various arc segments have fundamentally different volcano chemistry. If we can understand how

Recovery of a shallow-water ocean bottom seismometer, by R/V Jason, *with the volcanoes of the Alaska Peninsula in background. Photo Credit A. Adams*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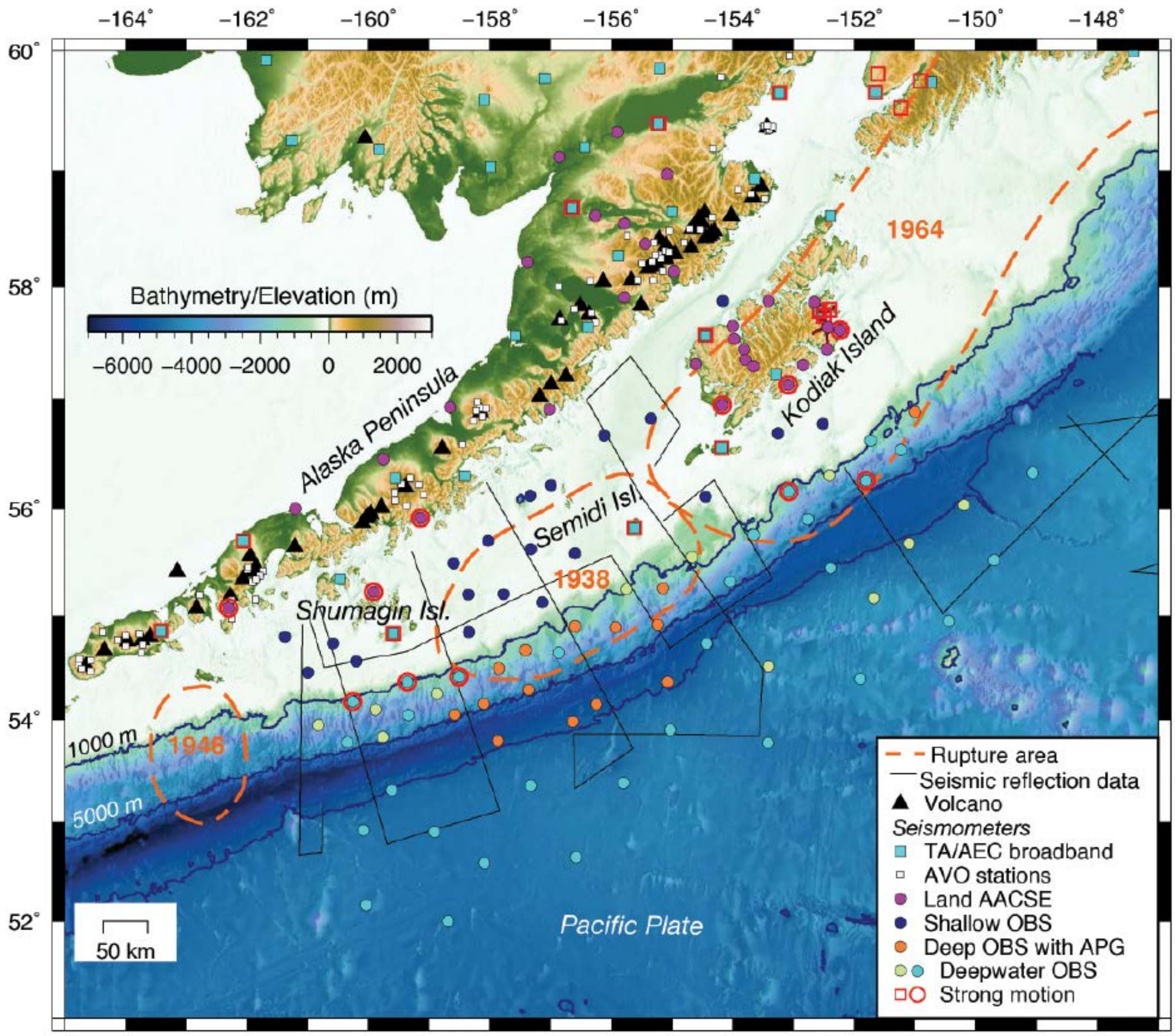

Fig. 1. Map of the AACSE deployment and the southwestern Alaska margin, showing newly deployed (circles) and existing (squares) seismometers, rupture areas of great earthquakes (orange, labeled with dates), volcanoes (triangles), and other features. Abbreviations are TA/AEC, Transportable Array/Alaska Earthquake Center; AVO, Alaska Volcano Observatory; OBS, ocean bottom seismometer; and APG, absolute pressure gauge.

geologic structures or material properties contribute to this segmentation, then we should be able to better forecast the long-term rates and effects of major geological events.

Historically, geophysical data collection has been challenging in Alaska because of difficult logistics; low population density; and, like most subduction zones, the challenge of extending comprehensive studies offshore to include the fore arc and subducting plate. The Alaska Amphibious Community Seismic Experiment (AACSE) has deployed an amphibious seismic array, designed by the scientific community, to make major advances on these problems. This array is recording earthquakes and other events in the Alaska subduction system as well as globally. All these data are made available openly as rapidly as possible, to make it as easy as possible for scientists around the world to become involved.

AN AMPHIBIOUS ARRAY

AACSE deployed an array of 75 broadband ocean bottom seismometers (OBSs) and 30 onshore broadband seismometers from May 2018 to September 2019 (Figure 1). The array covered an along-strike segment of the subduction zone spanning some 650 kilometers, including the Alaska Peninsula and Kodiak Island, and it extended about 250 kilometers seaward from the trench.

The array densified and expanded offshore the EarthScope Transportable Array, a major community experiment that is running concurrently. This is a golden age for instrumental seismology in Alaska with the full deployment of the Transportable Array, AACSE, and several other projects.

AACSE stems in part from a 2014 workshop on the future of amphibious seismology and in part from science plans for two National Science Foundation research programs, Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS) and EarthScope. In different ways, both of these decadal programs have a strong focus on understanding subduction systems, and both use North America as a natural laboratory for fundamental discovery. The AACSE project also builds on valuable lessons learned from the Cascadia Initiative, a 4-year series of linked OBS deployments farther south, across and around the Juan de

Fig. 2. Ocean bottom seismometers used in AACSE. A shallow-water instrument (left). Dan Kot prepares a deepwater OBS for deployment (right). Credits: David Heath (left); Anne Sheehan (right)

Fuca and Gorda plates, in which much of the AACSE instrumentation was developed [*Toomey et al.,* 2014].

A critical part of AACSE is its amphibious nature: tight integration of onshore and offshore observational campaigns. Virtually all subduction systems on Earth span the shoreline, from deep submarine trenches to large subaerial volcanoes (i.e., volcanoes that erupt into the air rather than in water). Consequently, subduction systems call for observational approaches that extend onshore and at sea. However, science planning and funding often place artificial barriers at the shoreline, making truly amphibious projects rare. The AACSE program has worked hard to leverage resources from NSF's terrestrial (Division of Earth Sciences) and marine (Division of Ocean Sciences) programs, and it has focused on integrated planning at every step.

A COMMUNITY EXPERIMENT

AACSE is a "community" project in several ways. First, all data from the project are made openly accessible to any interested scientist as soon as they are recovered from the field and formatted for archiving. All seismograms are available at the Incorporated Research Institutions for Seismology (IRIS) Data Management Center, which handles a wide range of seismic data and data access platforms. Other data are housed in appropriate data centers for their data types; for instance, shipboard data are at the Marine Geoscience Data System. The AACSE web page has specifics on the program and data access (bit.ly/aacse).

Second, the experimental planning, design, and participation have been kept as open as possible. A large planning meeting in 2014 evaluated a wide variety of scientific targets, followed by several web-based forums, open calls for principal investigator participation, and public comment periods once draft deployment designs were crafted.

Third, the project engages and trains the next generation of scientists by teaching them the skills required for work with amphibious data sets. Each deployment or recovery cruise included multiple early- to middle-career scientists without prior marine experience. Cruise participants ranged from graduate students to faculty to geoscience professionals to Alaskan high school science educators, all of whom gained invaluable direct experience with data collection. An undergraduate short course was held in Kodiak during fieldwork. In these ways, AACSE provides a major new data set and helps build the community that can make use of it, maximizing the potential impact of this community resource.

"Historically, geophysical data collection has been challenging in Alaska."

THE 2018 DEPLOYMENT

The heart of the AACSE project was a network of 105 broadband seismometers and numerous accelerometers, seafloor pressure gauges, and temperature sensors deployed every 20–50 kilometers along the seafloor and on land. We deployed 75 ocean bottom seismometers on two cruises on the R/V *Sikuliaq,* sailing from the home port of Seward, Alaska, with support from OBS facilities at the Lamont-Doherty Earth Observatory of Columbia University and the Woods Hole Oceanographic Institution (WHOI). Twenty of the OBSs have trawl-resistant mounts especially designed for shallow water, protected against bottom trawling, and designed to dampen wave and current noise (Figure 2). Five of these OBSs have accelerometers to record nearby strong earthquakes. All OBSs were recovered by the *Sikuliaq,* with support from WHOI's R/V *Jason*, and the R/V *Marcus G. Langseth.*

In parallel with the marine expeditions, ground teams deployed 30 broadband land stations on Kodiak Island, the Alaska Peninsula, and the Shumagin Islands, using a variety of small planes, boats, and wheeled vehicles to reach critical locations in this remote region. These instruments, provided by the IRIS Portable Array Seismic Studies of the Continental Lithosphere (PASSCAL) Instrument Center, feature broadband seismic sensors designed for postholes, and six include accelerometers. The distribution of the onshore stations was designed to complement the marine deployment, the sparse permanent networks in this region, and the EarthScope Transportable Array. All broadband sensors have 120-second response corners, and they collect data continuously at a frequency of 100 hertz.

In May 2019, AACSE deployed a dense array of approximately four hundred 5-hertz, three-component "nodal" seismometers across the road system on Kodiak, which sits

Sunset from the R/V Sikuliaq, *July 2018. Broadband ocean bottom seismometers arranged on deck are ready to be deployed in support of the Alaska Amphibious Community Seismic Experiment. Credit: Anne Sheehan*

atop the rupture zone of the great (*M*9.2) 1964 Alaska earthquake. This relatively new technology adopted from the petroleum industry allows significant oversampling of the high-frequency wavefield to enable high-resolution studies of the thrust zone structure and associated micro-earthquakes. While this dense array was deployed, the active-source system aboard the *Langseth* was deployed for 17 days of high-resolution wide-angle imaging across much of the AACSE array.

The community nature of AACSE has also inspired a series of side projects and follow-on projects, including deployments of seafloor GPS-acoustic stations, next-generation absolute pressure gauges, seafloor temperature observations linking to the water column above, and sub-seafloor electromagnetic imaging.

A 15-MONTH SNAPSHOT

The 15-month deployment of AACSE stations represents one of the longest large-scale multi-instrument amphibious seismic deployments to date. The instrument centers that engineered the OBSs designed them to accommodate a two-summer deployment duration specifically for this experiment.

Even this extended deployment time provides only a snapshot of the earthquake cycle, but this snapshot has captured much of interest. The Alaska Peninsula region generates earthquakes at very high rates and from different sources: along the plate boundary interface, within the downgoing plate, and within the overriding fore-arc crust.

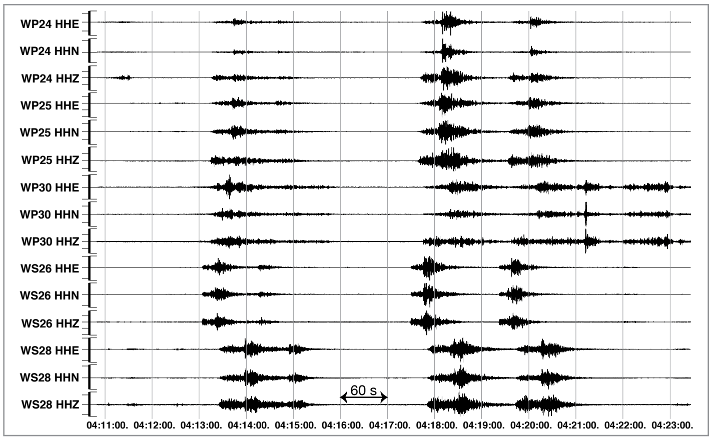

*Fig. 3. Example seismograms recorded on 24 June 2018 for three earthquakes (*M3.6, M4.5, *and* M4.3*) across five western peninsula AACSE land stations. Raw data were filtered to include only 2- to 15-hertz energy. These earthquakes occurred on the western portion of the Semidi segment.*

The 15-month deployment of AACSE stations will represent one of the longest large-scale multi-instrument amphibious seismic deployments to date.

(top) Susan Schwartz services a land-based instrument station on Alaska's Kodiak Island as a part of AACSE. Credit: Daniel Sampson. (bottom) Graduate student Amanda Price inspects a seismometer in preparation for the AACSE deployment off Kodiak. Credit: Bethany Essary

During the AACSE deployment, the Shumagin region experienced several swarms of earthquakes, including many $M > 5$ events, and other large events ($M4$–5) have happened north of Kodiak Island and within the central Semidi segment (e.g., Figure 3). At the far eastern extent of the array, an ongoing aftershock sequence of the January 2018 $M7.9$ earthquake within the Pacific plate was also recorded at close range using offshore instruments. Collectively, this experiment recorded abundant seismic activity, which should provide new insight into earthquake source properties and serve as a source for local geophysical imaging.

INTEGRATING OBSERVATIONS ON LAND AND SEA

Although broadband array seismology has greatly advanced our understanding of Earth beneath continents since the early 1990s, the capability to deploy large arrays at sea has existed only for the past few years. Yet the most seismogenic places are largely offshore or cross coastlines, and understanding the 60% of Earth beneath oceanic crust can be done only from the seafloor. AACSE is a major advance in addressing these challenges with new and emerging technologies.

Information on AACSE, including regular updates on progress and participation opportunities, is available at the project's GeoPRISMS-hosted website (bit.ly/aacse). AACSE data are archived at the IRIS Data Center under network codes XO for onshore sites and XD for OBSs.

ACKNOWLEDGMENTS

AACSE is supported by National Science Foundation award OCE-1654568, with instrumentation and data management support from IRIS and the Ocean Bottom Seismometer Instrument Center. Anne Bécel led the active-source acquisition leg. We thank the many support staff onshore and on the R/V *Sikuliaq* and R/V *Langseth* and the apply-to-sail participants who made this deployment possible.

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▶**Read the full story at bit.ly/Eos-Alaska-earthquakes**

2019 AGU Section Awardees and Named Lecturers

The 2019 section awardees and named lecturers have been selected, and AGU staff, leaders, and selection committees wholeheartedly congratulate these awardees!

Our colleagues have been selected for these prestigious honors for their sustained and unique contributions to advancing our understanding of Earth, its atmosphere and oceans, and planets and astral bodies beyond our own. The sciences encompassed by AGU are crucial for the health and well-being of our planet's inhabitants. These awardees have contributed to both that understanding and the planetary health and well-being through their scientific advancements and outstanding service to the science and to AGU.

This year's cohort of awardees reflects the diversity that is integral to the Earth and space sciences. Among the 25 sections of AGU there are 65 such awards; 21 are for early-career scientists (up to 10 years post-Ph.D.) and 6 are for midcareer (10–20 years post-Ph.D.). Twenty-seven awards provide named lectureships that offer unique opportunities to highlight the meritorious accomplishments of the awardees. AGU inaugurated the Bowie Lecture in 1989 to commemorate the fiftieth presentation of the William Bowie Medal, which is named for AGU's first president and is the highest honor given by the organization. In the list below, asterisks denote Bowie lecturers. Named lectures offered by AGU sections recognize distinguished scientists with proven leadership in their fields of science. We look forward to attending as many of these lectures as possible at Fall Meeting 2019 and encourage everyone to mark their calendars with these events.

Many, many thanks to the nominators, nomination supporters, section leaders, and, particularly, the selection committees for their important work in selecting these well-deserving colleagues. We thank you all for your continued commitment to the AGU Honors Program. We look forward to recognizing the honorees and their achievements at AGU's Fall Meeting 2019 in San Francisco, Calif.

By **Robin Bell,** President and Council Chair, AGU; and **Mary Anne Holmes** (agu_unionhonors@agu.org), Chair, Honors and Recognition Committee, AGU

Atmospheric and Space Electricity Section

Benjamin Franklin Lecture
Joseph R. Dwyer, University of New Hampshire

Atmospheric Sciences Section

Atmospheric Sciences Ascent Award
Francina Dominguez, University of Illinois at Urbana-Champaign
Jennifer G. Murphy, University of Toronto
David Noone, Oregon State University
Armin Sorooshian, University of Arizona
Rainer M. Volkamer, University of Colorado Boulder

James R. Holton Award
Nadir Jeevanjee, Princeton University

Yoram J. Kaufman Outstanding Research and Unselfish Cooperation Award
Allen H. Goldstein, University of California, Berkeley

*Jacob Bjerknes Lecture**
Cecilia M. Bitz, University of Washington

*Jule Gregory Charney Lecture**
Neil McPherson Donahue, Carnegie Mellon University

Future Horizons in Climate Science: Turco Lectureship
Alex Hall, University of California, Los Angeles

Biogeosciences Section

Thomas Hilker Early Career Award for Excellence in Biogeosciences
Kimberly A. Novick, Indiana University Bloomington

Sulzman Award for Excellence in Education and Mentoring
Rebecca T. Barnes, Colorado College

William S. and Carelyn Y. Reeburgh Lecture
Colleen Hansel, Woods Hole Oceanographic Institution

Cryosphere Sciences Section

Cryosphere Early Career Award
Natalya Gomez, McGill University

John F. Nye Lecture
Helen Amanda Fricker, Scripps Institution of Oceanography, University of California, San Diego

Earth and Planetary Surface Processes Section

G. K. Gilbert Award in Surface Processes
Kelin X. Whipple, Arizona State University

Luna B. Leopold Young Scientist Award
Joel S. Scheingross, University of Nevada, Reno

Robert P. Sharp Lecture
Joel S. Scheingross, University of Nevada, Reno

Earth and Space Science Informatics Section

Greg Leptoukh Lecture
Barbara Jane Ryan, Group on Earth Observations (Former Director)

Geodesy Section

John Wahr Early Career Award
Raphaël Grandin, Institut de Physique du Globe de Paris, Université de Paris

Ivan I. Mueller Award for Distinguished Service and Leadership
Frank Flechtner, GFZ German Research Centre for Geosciences

*William Bowie Lecture**
Véronique M. A. Dehant, Royal Observatory of Belgium

Geomagnetism, Paleomagnetism, and Electromagnetism Section

William Gilbert Award
Suzanne A. McEnroe, Norwegian University of Science and Technology

*Edward Bullard Lecture**
Gauthier Hulot, Institut de Physique du Globe de Paris, Université de Paris

Global Environmental Change Section

Bert Bolin Global Environmental Change Award and Lecture
L. Ruby Leung, Pacific Northwest National Laboratory

Global Environmental Change Early Career Award
Gretchen Keppel-Aleks, University of Michigan Ann Arbor
Abigail L. S. Swann, University of Washington
Yangyang Xu, Texas A&M University

Piers J. Sellers Global Environmental Change Mid-Career Award
Katherine V. Calvin, Pacific Northwest National Laboratory

Stephen Schneider Lecture
Andrew E. Dessler, Texas A&M University

Tyndall History of Global Environmental Change Lecture
William D. Collins, Lawrence Berkeley National Laboratory and University of California, Berkeley

Hydrology Section

Hydrologic Sciences Early Career Award
Megan Konar, University of Illinois at Urbana-Champaign
Di Long, Tsinghua University
Kaveh Madani, Yale University

Hydrologic Sciences Award
William P. Kustas, Agricultural Research Service, U.S. Department of Agriculture

*Walter Langbein Lecture**
Efi Foufoula-Georgiou, University of California, Irvine

Paul A. Witherspoon Lecture
Patrick M. Reed, Cornell University

Horton Research Grant
David Litwin, Johns Hopkins University
Magali Furlan Nehemy, University of Saskatchewan
Lorenzo Rosa, University of California, Berkeley

Mineral and Rock Physics Section

Mineral and Rock Physics Early Career Award
Sergey S. Lobanov, GFZ German Research Centre for Geosciences

Mineral and Rock Physics Graduate Research Award
Kathryn M. Kumamoto, University of Oxford
Christopher Thom, University of Pennsylvania

John C. Jamieson Student Paper Award
Suyu Fu, University of Texas at Austin
Francesca Miozzi, Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie

Natural Hazards Section

Natural Hazards Section Award for Graduate Research
Sanne Muis, Vrije Universiteit Amsterdam

Gilbert F. White Distinguished Award and Lecture
Jeroen Aerts, Vrije Universiteit Amsterdam

Near-Surface Geophysics Section

GSSI Student Grant
Zachariah Seaman, Southern Illinois University

Nonlinear Geophysics Section

Donald L. Turcotte Award
Vera Melinda Galfi, University of Hamburg

Ed Lorenz Lecture
Ian Main, University of Edinburgh

Ocean Sciences Section

Ocean Sciences Early Career Award
Nicole S. Lovenduski, University of Colorado Boulder

Ocean Sciences Award
Paula S. Bontempi, NASA

Rachel Carson Lecture
Heidi M. Sosik, Woods Hole Oceanographic Institution

Harald Sverdrup Lecture
Mary-Louise Timmermans, Yale University

Paleoceanography and Paleoclimatology Section

Willi Dansgaard Award
Valerie Trouet, University of Arizona

Harry Elderfield Outstanding Student Paper Award
Jianghui Du, Oregon State University

Nanne Weber Early Career Award
Bronwen L. Konecky, Washington University in St. Louis

Planetary Sciences Section

Ronald Greeley Early Career Award in Planetary Sciences
Xi Zhang, University of California, Santa Cruz

Fred Whipple Award and Lecture
Faith Vilas, Planetary Science Institute

*Eugene Shoemaker Lecture**
S. Alan Stern, Southwest Research Institute

Seismology Section

Keiiti Aki Early Career Award
Zachary E. Ross, California Institute of Technology

*Beno Gutenberg Lecture**
Emily E. Brodsky, University of California, Santa Cruz

Space Physics and Aeronomy Section

Basu United States Early Career Award for Research Excellence in Sun-Earth Systems Science
Evan G. Thomas, Dartmouth College

Fred L. Scarf Award
Terry Zixu Liu, University of California, Los Angeles

Space Physics and Aeronomy Richard Carrington Education and Public Outreach Award
Nat Gopalswamy, NASA Goddard Space Flight Center

Sunanda and Santimay Basu (International) Early Career Award in Sun-Earth Systems Science
Ajeet Kumar Maurya, Doon University

*Eugene Parker Lecture**
Margaret "Peggy" Ann Shea, Air Force Research Laboratory (Ret.)

*Marcel Nicolet Lecture**
Cora E. Randall, University of Colorado Boulder

Study of the Earth's Deep Interior Section

Study of the Earth's Deep Interior Section Award for Graduate Research
Neala Creasy, Yale University
Wenbo Wu, Princeton University and California Institute of Technology

Tectonophysics Section

Jason Morgan Early Career Award
Jacqueline Austermann, Columbia University

*Francis Birch Lecture**
Claudio Faccenna, Roma TRE University

Volcanology, Geochemistry, and Petrology Section

Hisashi Kuno Award
Marion Garçon, Centre National de la Recherche Scientifique–Laboratoire Magmas et Volcans Clermont-Ferrand
Daniel A. Stolper, University of California, Berkeley

Norman L. Bowen Award and Lecture
Graham Pearson, University of Alberta
Mary R. Reid, Northern Arizona University

*Reginald Daly Lecture**
Marie Edmonds, University of Cambridge

Joint Award: Geodesy, Seismology, and Tectonophysics Sections

Paul G. Silver Award for Outstanding Scientific Service
Judith Savaso Chester, Texas A&M University

Joint Prize: Nonlinear Geophysics and Space Physics and Aeronomy Sections

Space Weather and Nonlinear Waves and Processes Prize
Michael Hesse, University of Bergen

Joint Lecture: Biogeosciences and Planetary Sciences Sections

Carl Sagan Lecture
Penelope J. Boston, NASA Ames Research Center

Joint Lecture: Paleoceanography and Paleoclimatology and Ocean Sciences Sections

Cesare Emiliani Lecture
Hai Cheng, Xi'an Jiaotong University

Joint Student Grant: Atmospheric Sciences and Space Physics and Aeronomy Sections

Edmond M. Dewan Young Scientist Scholarship
Nikita Aseev, GFZ German Research Centre for Geosciences

2019 Class of AGU Fellows Announced

Each year since 1962, AGU has elected as Fellows members whose visionary leadership and scientific excellence have fundamentally advanced research in their respective fields. This year, 62 members will join the 2019 class of Fellows.

AGU Fellows are recognized for their scientific eminence in the Earth and space sciences. Their breadth of interests and the scope of their contributions are remarkable and often groundbreaking. Only 0.1% of AGU membership receives this recognition in any given year.

On behalf of AGU's Honors and Recognition Committee, our Union Fellows Committee, our section Fellows committees, AGU leaders, and staff, we are immensely proud to present the 2019 class of AGU Fellows.

We appreciate the efforts of everyone who provided support and commitment to AGU's Honors Program. Our dedicated AGU volunteers gave valuable time and energy as members of selection committees to elect this year's Fellows. We also thank all the nominators and supporters who made this possible through their dedicated efforts to nominate and recognize their colleagues.

Honor and Celebrate Eminence at Fall Meeting

At this year's Honors Tribute, to be held Wednesday, 11 December, at Fall Meeting 2019 in San Francisco, Calif., we will celebrate and honor the exceptional achievements, visionary leadership, talents, and dedication of 62 new AGU Fellows.

Please join us in congratulating our 2019 class of AGU Fellows, listed below in alphabetical order.

By **Robin Bell,** President, AGU; and **Mary Anne Holmes** (unionfellows@agu.org), Chair, Honors and Recognition Committee, AGU

Zuheir Altamimi, Institut National de l'Information Géographique et Forestière and Institut de Physique du Globe de Paris
Ronald Amundson, University of California, Berkeley
Jonathan Bamber, University of Bristol
Barbara A. Bekins, U.S. Geological Survey
Jayne Belnap, Southwest Biological Science Center, U.S. Geological Survey
Thomas S. Bianchi, University of Florida
Jean Braun, GFZ Helmholtz Centre Potsdam, and Institute of Earth and Environmental Sciences, University of Potsdam
Ximing Cai, University of Illinois at Urbana-Champaign
Ken Carslaw, University of Leeds
Benjamin F. Chao, Institute of Earth Sciences, Academia Sinica
Patrick Cordier, Université de Lille
Rosanne D'Arrigo, Lamont-Doherty Earth Observatory of Columbia University
Eric A. Davidson, Appalachian Laboratory, University of Maryland Center for Environmental Science
Gert J. de Lange, Utrecht University
Andrew Dessler, Texas A&M University
Michele K. Dougherty, Imperial College London

Joseph R. Dwyer, University of New Hampshire
James Farquhar, University of Maryland, College Park
Mei-Ching Fok, NASA Goddard Space Flight Center
Piers Forster, University of Leeds
Christian France-Lanord, CNRS Université de Lorraine
Antoinette B. Galvin, University of New Hampshire
Peter R. Gent, National Center for Atmospheric Research
Taras Gerya, ETH Zurich
Dennis Hansell, University of Miami
Ruth A. Harris , Earthquake Science Center, U.S. Geological Survey
Robert M. Hazen, Carnegie Institution for Science
Kosuke Heki, Hokkaido University
Karen Heywood, University of East Anglia
Russell Howard, United States Naval Research Laboratory
Alan G. Jones, Complete MT Solutions Inc. and Dublin Institute for Advanced Studies
Kurt O. Konhauser, University of Alberta
Sonia Kreidenweis, Colorado State University
Kitack Lee, Pohang University of Science and Technology
Zheng-Xiang Li, Curtin University
Jean Lynch-Stieglitz, Georgia Institute of Technology
Kuo-Fong Ma, National Central University and Academia Sinica
Reed Maxwell, Colorado School of Mines
John W. Meriwether, Clemson University (Emeritus) and New Jersey Institute of Technology
Son V. Nghiem, Jet Propulsion Laboratory, California Institute of Technology
Yaoling Niu, Durham University
Thomas H. Painter, Joint Institute for Regional Earth System Science and Technology, University of California, Los Angeles
Beth Parker, University of Guelph
Ann Pearson, Harvard University
Graham Pearson, University of Alberta
Lorenzo M. Polvani, Columbia University in the City of New York
Peter Reiners, University of Arizona
Yair Rosenthal, Rutgers University–New Brunswick
Osvaldo Sala, Arizona State University
Edward "Ted" Schuur, Northern Arizona University
Sybil Seitzinger, University of Victoria
Toshihiko Shimamoto, Institute of Geology, China Earthquake Administration
Adam Showman, University of Arizona
Alexander V. Sobolev, Institut des Sciences de la Terre, Université Grenoble Alpes, and Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences
Carl Steefel, Lawrence Berkeley National Laboratory
John Suppe, University of Houston
Karl E. Taylor, Lawrence Livermore National Laboratory
Meenakshi Wadhwa, Arizona State University
Michael Walter, Carnegie Institution for Science
John Wettlaufer, Yale University and Nordic Institute for Theoretical Physics
Chunmiao Zheng, Southern University of Science and Technology, Shenzhen
Tong Zhu, Peking University

2019 AGU Union Medal, Award, and Prize Recipients Announced

Each year, AGU honors individuals for their outstanding achievements, contributions, and service to the Earth and space science community. AGU medals are the highest honors bestowed by the Union. In this, AGU's Centennial year, when we commemorate the past and look to the future, we recognize individuals for their body of scientific work and sustained impact within the Earth and space science community. AGU Union awards and prizes recognize individuals who have demonstrated excellence in scientific research, education, communication, and outreach.

This distinguished group of honorees—scientists, leaders, educators, journalists, and communicators—embodies AGU's mission of promoting discovery in Earth and space science for the benefit of humanity.

On behalf of AGU's Honors and Recognition Committee, the selection committees, and AGU leaders and staff, we are pleased to present the recipients of AGU's 2019 Union medals, awards, and prizes and honor the important role they play in amplifying the voice of the Earth and space community while inspiring other scientists to help improve lives around the world.

We appreciate everyone who has shown support and commitment to AGU's Honors Program. Our dedicated volunteers gave valuable time as members of selection committees to choose this year's Union medal, award, and prize recipients. We also thank all the nominators and supporters who made this possible through their steadfast efforts to nominate and recognize their colleagues.

Celebrate at Fall Meeting

We look forward to celebrating our honorees' profound contributions at this year's Honors Ceremony and Banquet, to be held Wednesday, 11 December, at Fall Meeting 2019 in San Francisco, Calif.

Please join us in congratulating our esteemed class of 2019 Union honorees listed below.

By **Robin Bell,** President, AGU; and **Mary Anne Holmes** (agu_unionhonors@agu.org), Chair, Honors and Recognition Committee, AGU

Medals

William Bowie Medal
Barbara A. Romanowicz, University of California, Berkeley; Collège de France; and Institut de Physique du Globe de Paris

James B. Macelwane Medal
Amir AghaKouchak, University of California, Irvine
Anton Artemyev, University of California, Los Angeles
Emily V. Fischer, Colorado State University
Francis A. Macdonald, University of California, Santa Barbara
Erik van Sebille, Utrecht University

John Adam Fleming Medal
Michelle F. Thomsen, Planetary Science Institute

Walter H. Bucher Medal
Leigh Royden, Massachusetts Institute of Technology

Maurice Ewing Medal
Maureen E. Raymo, Lamont-Doherty Earth Observatory of Columbia University

Robert E. Horton Medal
S. Majid Hassanizadeh, Utrecht University

Harry H. Hess Medal
Richard J. Walker, University of Maryland, College Park

Roger Revelle Medal
Eugenia Kalnay, University of Maryland, College Park

Inge Lehmann Medal
Ulrich R. Christensen, Max Planck Institute for Solar System Research

Joanne Simpson Medal for Mid-Career Scientists
Penelope L. King, Australian National University
Ann Pearson, Harvard University
Fuqing Zhang, Pennsylvania State University

Devendra Lal Memorial Medal
Kuljeet Kaur Marhas, Physical Research Laboratory

Awards

Ambassador Award
Sunanda Basu, National Science Foundation (Ret.)
Alik Ismail-Zadeh, Karlsruhe Institute of Technology
Margaret Leinen, Scripps Institution of Oceanography
Constance Millar, Pacific Southwest Research Station, U.S. Forest Service
Lixin Wu, Ocean University of China

Edward A. Flinn III Award
James Broda, Woods Hole Oceanographic Institution

Athelstan Spilhaus Award
Brian May, Commander of the Most Excellent Order of the British Empire (CBE)

International Award
Susan Elizabeth Hough, U.S. Geological Survey

Excellence in Earth and Space Science Education Award
David J. P. Moore, University of Arizona

Africa Award for Research Excellence in Ocean Sciences
Andrew Green, University of KwaZulu-Natal

Africa Award for Research Excellence in Space Science
Andrew Akala, University of Lagos

Science for Solutions Award
Franziska C. Landes, Lamont-Doherty Earth Observatory of Columbia University

Robert C. Cowen Award for Sustained Achievement in Science Journalism
Alexandra Witze, Freelance

Walter Sullivan Award for Excellence in Science Journalism
Sarah Kaplan, *The Washington Post*

David Perlman Award for Excellence in Science Journalism
Ann Gibbons, Contributing Correspondent, *Science*

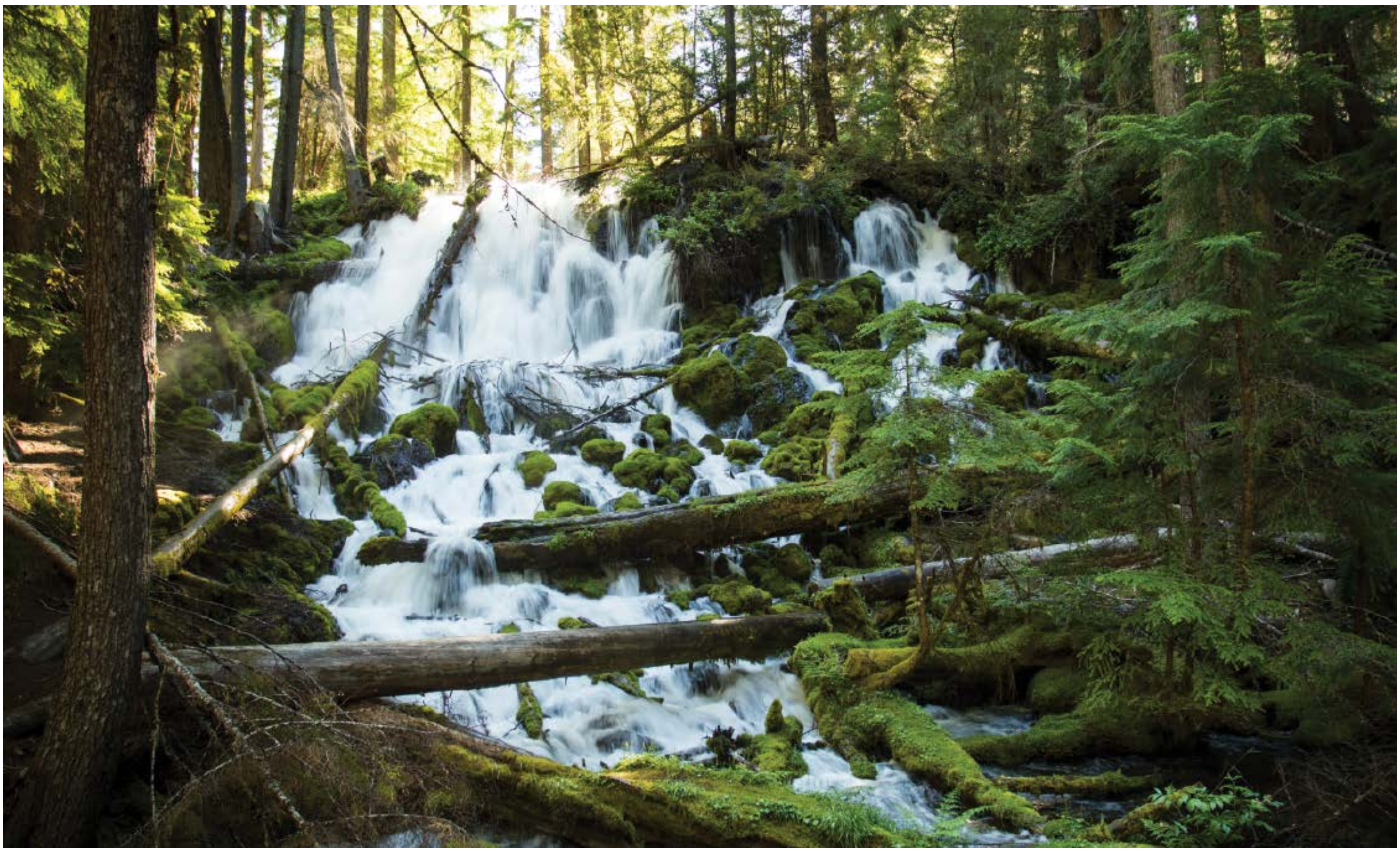
Spilhaus Ambassador Award Grant
Esteban Gabriel Jobbágy, National Scientific and Technical Research Council (CONICET) and Universidad Nacional de San Luis
Michael Edward Wysession, Washington University in St. Louis

Prizes

Asahiko Taira International Scientific Ocean Drilling Research Prize
Beth N. Orcutt, Bigelow Laboratory for Ocean Sciences

Climate Communication Prize
Marshall Shepherd, University of Georgia

Forested Streams May Warm More Than Observations Predict



Forested streams in maritime climates are getting warmer, posing hazards for cold-water fish like salmon. Credit: Bonnie Moreland, CC0 1.0 (bit.ly/ccby1-0)

As average air temperatures rise, the temperatures of forested streams that provide key habitats for salmon and other cold-water organisms typically rise as well, but the relationship isn't necessarily straightforward. New research suggests that these streams may warm even more in the future than some models have predicted.

Clarifying exactly how climatic warming affects stream temperatures is important for understanding and potentially managing negative ecosystem impacts. Previous research has suggested that empirical models relying purely on observed relationships between air and stream temperatures tend to underpredict future stream warming compared with computational models that incorporate physical processes.

To sort out the discrepancies between the different types of models, *Leach and Moore* drew on work they performed in the Malcolm Knapp Research Forest near Vancouver, B.C., Canada. They used numerous field measurements to build and calibrate a process-based model incorporating several key factors, such as tree canopy cover, snowmelt, and groundwater discharge. The model simulates daily streamflow and temperature for virtual streams that are representative of forested streams in maritime climates, such as those found in northwestern North America.

The researchers used their model to generate simulated streamflows and temperatures for a 51-year historic period as well as several future climate change scenarios, such as an increase in air temperature of 2°C. They ran the model for two elevation zones—one dominated by rain and the other with significant snowmelt contributions—and with four different values for the fraction of soil water that ends up discharging as groundwater into the stream.

The simulations revealed that stream temperatures may be up to twice as sensitive to climate change as predicted by observation-based models. The analysis suggests that empirical models do not adequately account for future effects of global warming on key processes, such as reductions in winter snow cover and reductions in plant shade. It also suggests that streams fed by groundwater may resist warming in the near term but will eventually warm as groundwater temperatures rise.

The findings highlight the importance of considering prior conditions when evaluating how sensitive cold-water streams are to climate change and, ultimately, how aquatic ecosystems will be affected. The authors call for a shift from purely empirical modeling methods to approaches that better account for key feedbacks that affect stream temperature sensitivity. (*Water Resources Research,* https://doi.org/10.1029/2018WR024236, 2019) **—Sarah Stanley, Freelance Writer**

Variations in Creep Along One of Earth's Most Active Faults

EOS CENTENNIAL COLLECTION

As part of the earthquake cycle, most active faults suddenly release strain that has gradually accumulated for extended periods of time. Some faults, however, may experience aseismic slip, or creep, which sometimes begins after a major seismic event and then steadily declines over time. Determining the relative proportion of seismic and aseismic slip occurring along an active fault is critical for accurately estimating its potential seismic hazard.

In a new study, *Aslan et al*. use recent, high-resolution interferometric synthetic aperture radar data to characterize aseismic slip occurring along Turkey's North Anatolian Fault, the 1,600-kilometer-long strike-slip feature separating the Eurasian and Arabian plates that has produced seven large (magnitude > 7) earthquakes since 1939. The most recent event, the 1999 magnitude 7.4 Izmit earthquake that occurred roughly 100 kilometers east of Istanbul, ruptured five segments and killed more than 20,000 people.

Using 307 images acquired by the Sentinel-1 and TerraSAR-X satellites, the researchers examined ground velocity changes in space and time across the central segment of the 1999 rupture for the period spanning 2011–2017. The results indicate that this segment continues to creep nearly 2 decades after the earthquake but that its maximum rate in the fault-parallel horizontal direction has tapered to an average of roughly 8 millimeters per year, about two thirds the rate measured during the previous decade.

The team also presented evidence for a transient "creep burst" that occurred along the same fault segment in November 2016. During this spike, the surface slip totaled 10 millimeters, a distance that corresponds to 1.25 years of average creep, in just 3 weeks.

Collectively, these findings indicate that postseismic slip along the North Anatolian Fault is more complex than has previously been suggested. By providing evidence that creep is not necessarily a steady process, this study offers new insight into long-term, postseismic deformation following a major earthquake along one of Earth's most active strike-slip faults. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1029/2018JB017022, 2019) **—Terri Cook, Freelance Writer**

A Better Way to Measure Cloud Composition

The effects of clouds on Earth's climate are so complex that some scientists have called them the wild card of climate science. Clouds can either cool Earth's surface by reflecting sunlight or trap heat like a blanket, leaving scientists unsure of whether clouds will accelerate or slow global warming. To understand the relationship between clouds and climate, researchers are scrambling to better measure and model clouds' ever changing qualities, such as the sizes of the tiny ice particles and water droplets that compose them.

Jiang et al. propose a new method to measure cloud properties from space more accurately, which could improve climate and weather predictions. The researchers combined two types of remote sensing technology—active and passive sensors—to create an instrument suite that can accurately capture many different properties of clouds at high resolution. Active sensors shoot beams of microwaves at clouds and use the echoed signals to study their composition, whereas passive sensors detect various wavelengths of electromagnetic radiation emitted by clouds themselves.

The new tool builds on an existing instrument called Tropospheric Water and Cloud ICE (TWICE), which detects 14 different millimeter and submillimeter wavelengths and which Jiang and colleagues have described in previous studies. The new instrument, called Earth's Next-generation ICE (ENTICE), adds two more frequencies: 94 gigahertz for active radar detection and 850 gigahertz for use in a passive radiometer. The added frequencies improve the vertical resolution of ice cloud measurements from 3–4 kilometers to 0.5 kilometer, the team reports.

The combined 94-gigahertz radar and multifrequency radiometer suite also enabled ENTICE to more accurately capture the effective diameters of ice particles within clouds while simultaneously measuring humidity and temperature. Such measurements are key to understanding the dynamic and small-scale processes that occur within clouds and could improve both climate models and weather forecasts, the team says. (*Earth and Space Science,* https://doi.org/10.1029/2019EA000580, 2019) **—Emily Underwood, Freelance Writer**

Researchers are developing new methods to better understand the composition of clouds, including wispy cirrus clouds like those pictured here, and their impact on climate and weather. Credit: PiccoloNamek, CC BY-SA 3.0 (bit.ly/ccbysa3-0)

New Perspectives on 2,000 Years of North Atlantic Climate Change

A new review paper explores recent progress in research addressing the potential role of North Atlantic Ocean circulation in historical climate shifts over the past 2 millennia. Credit: Brocken Inaglory, CC BY-SA 3.0 (bit.ly/ccbysa3-0)

Historical and natural clues suggest that Earth's climate underwent small changes over the past 2,000 years, and variations in North Atlantic Ocean circulation may have been a key driver. In a new paper, *Moffa-Sánchez et al.* compile recent advancements in analytical tools used to probe this period of ocean circulation, presenting a comprehensive overview of current knowledge.

The past 2 millennia have seen several centuries-long climate shifts, such as the Medieval Warm Period, followed by the Little Ice Age, which were particularly recorded around the North Atlantic. The North Atlantic is an important climatological region because of the strong interactions between ocean, atmosphere, and sea ice, as well as the overturning circulation between surface and deep-ocean currents. Scientists have traditionally proposed that changes in this Atlantic Meridional Overturning Circulation played a key role in the observed climate shifts, but this view remains under debate because of the lack of clear evidence.

The new review synthesizes 20 years' worth of rapid progress toward understanding the role of ocean circulation in historical climate change. The authors highlight advancements in two major fields: observational data that provide proxy clues to past oceanic and climate conditions, such as sediment cores and the remains of shelled organisms, and models that simulate the past climate.

The authors unite a number of previously published proxy data sets to paint a picture of North Atlantic Ocean circulation over the past 2,000 years. This compilation reveals details of past conditions in various regions. For example, the past 2,000 years around Greenland show progressively cooler and icier surface waters reaching the coldest conditions during the Little Ice Age. The compilation also underscores a need for more comprehensive data sets on deep North Atlantic waters for this period.

To gain further insight, the authors selected and compared three recently developed climate models that are particularly well suited for studying the North Atlantic's past climate over the past millennium. They identified key areas of uncertainty and disagreement between the models that could be addressed in future research. They also demonstrated agreement between model and proxy data estimates of sea surface temperatures for some historical periods and regions but disagreement for others.

These findings highlight important advancements toward understanding how changes in ocean circulation may have affected historical climate change while emphasizing areas for improvement. The authors note the promise of using models to fill gaps in observational data but also call for continued collection and improvement of proxy data sets. (*Paleoceanography and Paleoclimatology,* https://doi.org/10.1029/2018PA003508, 2019) **—Sarah Stanley, Freelance Writer**

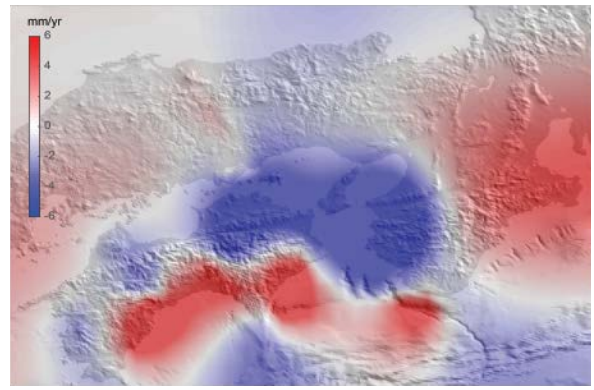
Déjà Vu: Understanding Subduction Zones' Cycle of Seismicity

EOS CENTENNIAL COLLECTION

Along the southeastern edge of Japan's Honshu Island, the Philippine Sea plate is diving beneath the Eurasian plate at the Nankai subduction zone. Seismicity there has unleashed numerous devastating, megathrust earthquakes in a cycle typically characterized by pairs of closely spaced tremors that have occurred every 146 years, on average, since 1361. The region's most recent earthquakes were the magnitude 8.1 Tonankai and the magnitude 8.4 Nankai events, which occurred in 1944 and 1946, respectively.

The seismic cycle is the process of repeatedly building stress on a fault over a long period of time that is rapidly released in a large earthquake. Previous studies have recognized that mantle flow plays a crucial role in the seismic cycle by relaxing postseismic stresses as well as straining the fault during the interseismic buildup to the next tremor. The surface deformation that accompanies this cycle can vary considerably depending on the mantle's viscosity. But inferring this parameter has proven difficult because of a lack of geodetic data sets that span the centuries-long timescales of most seismic cycles.

The only place in the world where a record exists that is long enough to potentially record a complete, postseismic phase is in southern Japan, where leveling surveys as well as tide gauge and GPS measurements collectively span the period from 1890 to the present. *Johnson and Tebo* have harnessed this unique data set to model vertical deformation in the Nankai region from 1947 to 2015.



This map shows vertical motions in southwestern Japan 7 years after the 1946 Nankai earthquake. Credit: Kaj Johnson

The results indicate that following the 1940s earthquakes, subsidence was centered about 250 kilometers inland of the Nankai trench, and its rate gradually decreased from 1947 until approximately 1995. By contrast, postseismic uplift occurred within a narrow belt stretching along Honshu's southeastern coast, but it slowed and then switched to subsidence by the mid-1960s.

According to the authors' two-dimensional modeling results, the uplift is best explained by afterslip along the coast, whereas the inland subsidence is strongly indicative of postseismic flow within the mantle wedge. The best fit to this pattern requires a viscosity on the order of 10^{19} pascal seconds, which corresponds to a mantle relaxation time of 5–15 years. As the first study to clearly capture 5 decades of postseismic mantle flow, this research offers a crucial contribution to improving our understanding of the cycle of seismicity that occurs in Earth's subduction zones. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1029/2018JB016345, 2018) **—Terri Cook, Freelance Writer**

Demystifying Sea Level Changes Along the New England Coast

The Atlantic Meridional Overturning Circulation (AMOC), a system of currents in the Atlantic Ocean that transports warm surface waters northward and cooler, deeper waters southward, is a crucial component of Earth's climate system. Because the AMOC is part of a conveyor belt of oceanic circulation that redistributes heat around the globe, variability in its strength can have significant climate consequences.

Previous modeling studies have concluded that the AMOC's strength is negatively correlated to sea level along the New England coastline, such that a weakening of the North Atlantic Current or the Gulf Stream leads to a rise in sea level at the coast. This relationship, however, has been difficult to detect in observational records.

Now *Piecuch et al.* are challenging the conventional wisdom that a direct causal connection exists between the AMOC and coastal sea level in this region. After obtaining monthly RAPID monitoring program observations of the overturning circulation at 26°N and monthly sea level records collected between 2004 and 2017 at eight New England tide gauges, they examined the physical relationships between the two records.

The authors conclude that widespread atmospheric teleconnections can simultaneously trigger changes in both the AMOC at 26°N and coastal New England sea level. Although these phenomena are temporally correlated with each other, they conclude that they are not causally linked. The researchers argue that the local atmospheric forcing mechanisms driving coastal New England sea level change are instead related to the North Atlantic Oscillation and other surface atmospheric variations.

Although this study represents a valuable contribution to improving our understanding of how coastal sea level is related to oceanic circulation, the authors caution that their results apply only to the time period studied and that the negative correlation between coastal sea level and overturning at 26°N should not be considered representative of the AMOC at other latitudes. They suggest that future studies could shed new light on the processes occurring at higher latitudes, where new AMOC monitoring arrays have recently been established. (*Geophysical Research Letters,* https://doi.org/10.1029/2019GL083073, 2019) **—Terri Cook, Freelance Writer**

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Hydrology

Assistant Professor in Hydrology & Water Sustainability

The Department of Geology and Environmental Science at the University of Pittsburgh invites applications for a tenure-track assistant professor position in Hydrology and Water Sustainability.

We are seeking a geoscientist who characterizes hydrologic change and evaluates adaptation strategies for sustainable adjustment to these changes. This colleague ideally uses combinations of field measurements and observations, modeling, and/or remote sensing to better understand water-climate-human interactions.

The successful candidate will establish an externally-funded, internationally recognized research program that complements existing Department strengths. In particular, the Department hosts the Collaboratory for Water Research, Education, and Outreach (https://www.water.pitt.edu) and the University Climate and Global Change Center (https://www.climatecenter.pitt.edu/), both platforms for cutting edge, interdisciplinary water science. Teaching duties include undergraduate and graduate courses in the candidate's area of expertise.

Review of applicants will begin on October 15, 2019 and continue until the position is filled. A PhD is required at the time of appointment, with the position scheduled to begin in Fall 2020, subject to budgetary approval. Please apply online to: https://facultysearch.as.pitt.edu/apply/index/MjY4. Applications should include: 1) cover letter; 2) CV; 3) research statement; 4) research statement; 5) diversity statement; 6) four references; and 7) copies of three relevant publications. Please direct questions to the Search Committee Chair, Dr. Daniel Bain, dbain@pitt.edu, 412-624-8766.

Information about the University of Pittsburgh can be found at https://www.hr.pitt.edu/why-work-pitt. For information on the University of Pittsburgh's generous package of benefits, visit http://www.hr.pitt.edu/benefits.

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Earth Research Scientist (career-track)

Berkeley Lab's Earth and Environmental Sciences Area has an opening for a Research Scientist in Integrated Hydrological Modeling. In this position, you will be expected to work on a wide variety of integrated hydrology problems related to water quantity and quality and to employ a range of tools from data-driven to

Massachusetts Institute of Technology

Department of Earth, Atmospheric and Planetary Sciences

Assistant Professorship in Climate-Related Sciences

The MIT Department of Earth, Atmospheric and Planetary Sciences includes a vibrant and inter-disciplinary group in climate science that we seek to expand. We are especially interested in physical oceanography, atmospheric chemistry, and atmospheric dynamics, but we encourage applications from outstanding candidates in all sub disciplines of climate science. We seek candidates who use any approach or combination of approaches, including observation, theory, modeling, and experimentation. Candidates should have the potential for innovation and leadership in research and a commitment to teaching at the undergraduate and graduate levels.

Applicants must hold a Ph.D. in earth sciences or related field by the start of employment. Our intent is to hire at the assistant professor level, but more senior appointments may also be considered. Applications from women and underrepresented minorities are strongly encouraged. A complete application must include a cover letter, curriculum vitae, one- to two-page descriptions each of research and teaching plans, and three letters of recommendation.

Please explicitly commit to our department's code of conduct (https://eapsweb.mit.edu/about/code-conduct) in submitted cover letters.

Applications are being accepted at Academic Jobs Online: https://academicjobsonline.org/ajo/jobs/14201

To receive full consideration, complete applications must be received by November 1, 2019. Complete applications will be considered starting September 15 until November 1, 2019.

Search Contact: Ms. Karen Fosher, HR Administrator, EAPS, 54-924 Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139-4307, email: kfosher@mit.edu

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mechanistic models, and a combination of them, with consideration of the appropriate climate drivers.

What You Will Do:

- Develop and use models to understand hydrological response to perturbations at multiple scales, from the global to the regional to the watershed scale.
- Combine data-driven, machine-learning and mechanistic modeling approaches to advance understanding of integrated hydrology problems affected by evolving climate forcings.
- Analyze and integrate complex datasets including high-resolution climate data and distributed hydrological measurements.
- Use weather forecasting and climate models to drive mechanistic integrated hydrological models, subsetting results where needed.
- Use a variety of computational codes available in the Department of Energy software ecosystem that simulate overland and/or subsurface flow and reactive transport.
- Develop new research areas and proposals.
- Conduct innovative research and publish in peer-reviewed and high impact journals
- Regularly present findings at major conferences and workshops
- Contribute to Lab and Community Professional Service, and lead/organize workshops/meetings.
- Collaborate with and/or lead others in groups and forge/lead collaborations across the Area, Lab and with colleagues at external institutions.

How To Apply

Apply directly online at http://50.73.55.13/counter.php?id=167292 and follow the on-line instructions to complete the application process.

Interdisciplinary

Assistant Professor of Earth and Environmental Sciences

The Department of Earth and Environmental Sciences in the College of Liberal Arts and Sciences at the University of Illinois at Chicago (UIC) invites applications for a tenure-track Assistant Professor who pursues fundamental research in climate science with an emphasis on surface processes. The applicant's research should involve more than one approach (e.g., observational, modeling, experimental) and may address topics that include, but are not limited to, the effects of climate change on biogeochemical cycling and the role of climate in landscape evolution. The successful candidate is expected to establish an innovative and productive program of scientific research that complements department strengths in ecohydrology, planetary science, and biogeochemistry, and can contribute to university strengths in areas such as public health. The candidate will

CLUSTER HIRING IN DOSE, SUSTECH

1. OVERVIEW OF SUSTECH

Shenzhen, also known as The Great Eagle City, is China's first Special Economic Zone and recognized as the driving force for the reforming and opening up of Chinese economy over the past thirty-forty years. In 2017, Shenzhen is selected by the Chinese Government to develop into one of the two of International Ocean Cities in China.

Southern University of Science and Technology SUSTech is a public research university established in 2011, funded by Shenzhen Municipality. Widely regarded as a pioneer and innovator in collectively moving China's higher education forward to match China's ever-growing role in the international arena, SUSTech aspires to be a globally-renowned university that contributes significantly to the advancement of science and technology by excelling in interdisciplinary research, nurturing creative future leaders and creating knowledge for the world. More information can be found in website: **http://www.sustech.edu.cn** .

2. OVERVIEW OF DOSE

The Department of Ocean Science and Engineering DOSE was founded in July, 2015, aiming to build a team of high quality and international faculty a "Into the deep ocean" scientific research platform and an international research program in oceanography. Our long-term vision is to station in Shenzhen, devote our research to the world three oceans!

Those three aspects Marine Geophysics/Geology (Solid), Physical Oceanography (Liquid) and Microbial Oceanography/Biogeochemistry are included in Ocean Science research area. And Offshore Engineering, Offshore Energy & Resource and Ocean Acoustic & Fiber Technology in Ocean Engineering research area.

3. OCEAN SCIENCE & FACULTY OPENINGS

Until now, nine faculties include two"Chang Jiang Scholar Program"/"National Nature Science Fund for Distinguished Young Scholars", two professors, and four assistant professors. We are seeking a senior professor in Physical Oceanography (Liquid), and about ten Assistant/Associate/Full Professors in all fields are still vacant.

All positions remain open until filled.

4. OCEAN ENGINEERING & FACULTY OPENINGS

Until now, only two faculties include one Academician of Chinese Academy of Engineering and one Member of the Norwegian Academy of Technical Sciences in Marine Civil Engineering.

We are seeking two senior professors in Offshore Engineering & Resource and Ocean Acoustic & Fiber Technology respectively, and about fifteen Assistant/Associate/Full Professors in all fields are still vacant.

All positions remain open until filled.

5. REMUNERATION & START-UP PACKAGES

I. Income and Benefits

1. Globally competitive (including US & HK) salary
2. Apartment inside campus (depending on remaining apartment quantity) or housing allowance of leasing outside;
3. Social Insurance Retirement insurance, medical insurance, unemployment insurance, industrial injury insurance, maternity insurance and housing accumulation funds. Special health insurance negotiable.
4. Shenzhen living subsides of CNY 1.6~3 million and other living subsidies according to your talent level.

II. Lab space no less than 150 square meters.

III. SUSTech start-up fund of CNY 1 million and other research funds according to your talent level

6. CONTACT INFORMATION

Candidates must have a proven and consistent track record of high-quality scientific publications and good communication skills. Chinese and English are required languages for teaching. To apply, please submit the following material electronically to **wangy9@sustc.edu.cn**: 1) Cover letter; 2) Curriculum vitae (with a complete list of publications); 3) Statement of research and teaching interests; 4) Reprints of three recent papers; and 5) Names and contact information for five references.

teach graduate and undergraduate courses, advise graduate students (MS and PhD), and mentor undergraduate students in research projects. Applicants must have a PhD in Earth Sciences or a related field, and a record of research accomplishments; postdoctoral experience is preferred.

The Earth and Environmental Sciences Department (https://eaes.uic.edu/) has extensive laboratory and computing facilities, and is expanding collaborations with other campus units including chemistry, health sciences, and biological sciences. The Department serves a growing body of majors, the majority of whom are underrepresented in STEM. UIC is a public R1 institution and one of the most ethnically and culturally diverse universities in the country. It is the largest institution of higher education in the Chicago area with over 30,000 undergraduate, graduate, and professional students. To apply, please complete the online application providing contact information and three professional references at https://jobs.uic.edu (click on the Job Board and then on the position link) and upload a cover letter, curriculum vitae, and statements of research and teaching plans. For fullest consideration, please apply by October 21, 2019. Final authorization of the position is subject to availability of funding. The University of Illinois at Chicago is an affirmative action, equal opportunity employer, dedicated to the goal of building a culturally diverse and pluralistic faculty and staff committed to teaching and working in a multicultural environment. We strongly encourage applications from women, minorities, individuals with disabilities and covered veterans. The University of Illinois may conduct background checks on all job candidates upon acceptance of a contingent offer. Background checks will be performed in compliance with the Fair Credit Reporting Act.

Deputy Division Director for the Division of Astronomical Sciences (AST)

Serves as Deputy Division Director for the Division of Astronomical Sciences (AST) in the Directorate for Mathematical and Physical Sciences. The Division contributes to NSF's mission by supporting research in all areas of astronomy and astrophysics and related multidisciplinary studies. Modes of support include single-investigator and collaborative awards, construction, operations, and maintenance of national observatories, as well as funding for acquisition and development of astronomical instrumentation, technology development and future ground-based facilities, and education projects that leverage the Division's research investments to build research and workforce capacity and to increase scientific literacy. Through the national observatories, including international partnerships, the Division provides support for a system of multi-aperture, research-class telescopes as well as frontier facilities that enable transformational capabilities in both radio and optical/infrared astronomy. Within the Division, the Deputy Division Director works with the Division Director in providing leadership and management to the Division's programs and assists the Division Director in carrying out Division-wide responsibilities such as the preparation of budget submissions for Congress, oversight and management of the Division budgets, and the recruitment of scientific staff. The incumbent also supervises and provides leadership and guidance to administrative and support personnel within the Division. Externally, the Deputy Division Director represents the Division in a variety of NSF-wide and interagency activities related to research and education, and in interactions with the community. The Deputy Division Director assumes the Division Director's role in the absence of the Division Director.

Apply via email at execsrch@nsf.gov

Assistant Lecturer/Assistant Teaching Professor

The Department of Geology and Environmental Earth Science at Miami University invites applications for a full-time Assistant Lecturer or Assistant Teaching Professor position on the Oxford campus, beginning August 2020. The Assistant Lecturer/Assistant Teaching Professor will teach undergraduate courses, including foundation courses in physical and environmental geology, as well as intermediate level courses; advise undergraduate students; and provide professional service to the department and university. Required: M.S. in geoscience (for appointment as Assistant Lecturer) or Ph.D. in geoscience (for appointment as Assistant Teaching Professor) by time of appointment, and documented teaching experience; applicant must be a U.S. citizen, a lawful permanent resident, admitted for residence as an applicant under the 1986 immigration amnesty law, refugee or asylee. Desired: interest in contributing to supervision of undergraduate student research and field-based experiences. Submit letter of application, curriculum vitae, and evidence of teaching effectiveness to http://jobs.miamioh.edu/cw/en-us/job/495551. Letters of reference will be requested upon receipt of application. Inquiries can be directed to Cathy Edwards at edwardca@miamioh.edu. Review of applications will begin on October 2, 2019 and continue until position is filled.

Miami University, an Equal Opportunity/Affirmative Action employer, encourages applications from minorities, women, protected veterans and individuals with disabilities. Miami University prohibits harassment, discrimination and retaliation on the basis of sex/gender (including sexual harassment, sexual violence, sexual misconduct, domestic violence, dating violence, or stalking), race, color, religion, national origin (ancestry), disability, age (40 years or older), sexual orientation, gender identity, pregnancy, status as a parent or foster parent, military status, or veteran status in its recruitment, selection, and employment practices. Requests for all reasonable accommodations for disabilities related to employment should be directed to ADAFacultyStaff@miamioh.edu or 513-529-3560.

As part of the University's commitment to maintaining a healthy and safe living, learning, and working environment, we encourage you to read Miami University's Annual Security & Fire Safety Report at http://www.miamioh.edu/campus-safety/annual-report/index.html, which contains information about campus safety, crime statistics, and our drug and alcohol abuse and prevention program designed to prevent the unlawful possession, use, and distribution of drugs and alcohol on campus and at university events and activities. This report also contains information on programs and policies designed to prevent and address sexual violence, domestic violence, dating violence, and stalking. Each year, email notification of this website is made to all faculty, staff, and enrolled students. Written notification is also provided to prospective students and employees. Hard copies of the Annual Security & Fire Safety Report may be obtained from the Miami University Police Department at (513) 529-2225. Criminal background check required. All campuses are smoke- and tobacco-free.

Research Positions to investigate new approaches to modeling planetary boundary layers and convection in Earth system models

The Atmospheric and Oceanic Sciences program at Princeton University, in cooperation with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks postdoctoral or more senior researchers for new projects on modeling planetary boundary layers and convection in Earth system models at GFDL, particularly for (1) implementing and analyzing an eddy diffusivity/mass flux (EDMF) parameterization for boundary layers and convection and (2) improved modeling of momentum flux in planetary boundary layers. The first project is a collaboration with the Jet Propulsion Laboratory. The researcher will work in collaboration with GFDL, UCLA, The University of Connecticut, and the National Center for Atmospheric Research, aiming at a unified approach to moist turbulent processes for boundary layers and deep convection. The second project is a collaboration with the Pennsylvania State University. The researcher will work in collaboration with GFDL, Penn State, and the National Center for Atmospheric Research, aiming at including momentum flux in higher-order closure for boundary-layer turbulence. The positions support newly funded, multi-agency, interdisciplinary Climate Process Teams. The teams will provide opportunities to blend modeling, theory, and observational perspectives. The Climate Process Teams are tackling some of the most challenging problems in climate science and atmospheric prediction using one of the world's leading modeling systems.

Successful applicants will work with Leo Donner and Ming Zhao at GFDL and multi-institutional team members.

Scientists with backgrounds in general circulation modeling, parameterization development, and modeling of atmospheric processes are especially encouraged to apply. Candidates must have a PhD in atmospheric science or a related field. Complete applications, including a CV, a statement describing research interests and how they would contribute to the project, and contact information for 3 references should be submitted by September 15, 2019 for full consideration. Applicants should apply online to http://www.princeton.edu/acad-positions/position/13141. For more information about the research projects and application process, please contact Leo Donner (leo.j.donner@noaa.gov) or Ming Zhao (ming.zhao@noaa.gov). This position is subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Director, Electron Microbeam Laboratory, University of Wisconsin-Madison

The Department of Geoscience at the University of Wisconsin-Madison invites applications at the Assistant, Associate, or Senior Scientist level to fill the Director's position in the Eugene Cameron Electron Microprobe Laboratory (http://www.geology.wisc.edu/~johnf/sx51.html). This is a full-time, institutionally-supported position with competitive salary. The lab houses SX51 and SX5FE electron microprobes, a Hitachi S3400 VP scanning electron microscope, and a lab manager to assist with SEM maintenance and operations. The lab serves as a hub for interdisciplinary scientific inquiry, providing hands-on training of students from disciplines across campus. Additional departmental resources include two electronics engineers and a staffed thin-section lab. Applicants should hold a Ph.D. in Earth Sciences, Chemistry, Physics, Material Science, or related fields at time of appointment. Demonstrated ability and experience in the use of electron beam instruments for high-quality, quantitative analyses is required. Two or more years of daily hands-on management of an electron microprobe lab is preferred, as is demonstrated ability to pursue fundable research using electron microbeam instrumentation. Applicants should submit the following: (1) cover letter that includes your research statement, (2) curriculum vitae, and (3) the names and contact information for three referees. Please apply by October 15, 2019 to guarantee full consideration, although applications will continue to be accepted until the position is filled. For more information and to apply, go to: https://jobs.hr.wisc.edu/en-us/job/502003/epma-lab-director

Ocean Sciences

Postdoctoral Research Scientist in Lagrangian Sea-Ice Modelling

The Atmospheric and Oceanic Sciences Program and the Andlinger Center for Energy and the Environment at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral or more senior researcher to develop a Lagrangian model of sea-ice dynamics for use in regional and global ocean circulation models.

This work will involve exploring innovative approaches to modeling sea ice, with a focus on representing sea ice floes, and collections of floes, as Lagrangian elements. The project aims to construct an operational Lagrangian sea-ice model, which can be tested against existing grid-based numerical models of sea-ice. The Lagrangian sea-ice model will be used to study the large-scale properties of sea ice, which are emergent from individual floe interactions.

The ideal candidate has a strong background in one or more areas among sea-ice dynamics, material science, geophysical fluid dynamics, soft-matter science, and numerical methods. Experience with scientific software development, Lagrangian methods, discrete-element methods or smoothed particle hydrodynamics solvers will be advantageous in this research.

Candidates must have a Ph.D. in either applied mathematics, physics, cryosphere, or a related field. Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding.

Complete applications, including a CV, publication list, a statement of research interests, and contact information of 3 references should be submitted by September 15, 2019 for full consideration. Applicants should apply online https://www.princeton.edu/acad-positions/position/12908. For more information about the research project and application process, please contact Alistair Adcroft (aadcroft@princeton.edu) and Olga Sergienko (osergien@princeton.edu).

This position is subject to the University's background check policy.

Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Planetary Sciences

Professor of Earth and Planetary Sciences

The Department of Earth and Planetary Sciences at Washington University in St. Louis invites applications for a tenure-track or tenured faculty position at the assistant, associate, or full professor rank, commensurate with experience, in the field of planetary science. The candidate is expected to perform research in the broad area of planetary surfaces and processes, have or seek active involvement in planetary science missions, and eventually assume leadership of the NASA Planetary Data System Geosciences Node at Washington University. The ideal candidate will employ quantitative tools and will integrate computational approaches with remotely sensed observations.

The successful candidate is expected to develop a vigorous, externally funded research program, maintain a strong publication record, advise students, provide outstanding teaching of undergraduate and graduate courses, and participate actively in departmental governance and university service. We seek candidates who will strengthen existing research programs in planetary science and remote sensing, as well as foster collaboration with scholars across the Washington University community.

Candidates must have a Ph.D. in planetary science or a related field at the time of appointment. In addition, candidates at the associate or full professor rank must have an advanced record of research, publication, and teaching warranting tenure. Complete applications include cover letter, curriculum vitae, statements of teaching and research interests, and names and contact information of at least four references, submitted via Interfolio: https://apply.interfolio.com/66099. Applications must be received by October 31, 2019 to ensure consideration.

Washington University in St. Louis is committed to the principles and practices of equal employment opportunity and especially encourages applications by those underrepresented in their academic fields. It is the University's policy to recruit, hire, train, and promote persons in all job titles without regard to race, color, age, religion, sex, sexual orientation, gender identity or expression, national origin, protected veteran status, disability, or genetic information.

Seismology

Postdoctoral or more Senior Researcher, Department of Geosciences at Princeton University

The Theoretical & Computational Seismology group in the Department of Geosciences at Princeton University, led by Professor Jeroen Tromp, has an opening for a postdoctoral or more senior researcher. Essential qualifications include a Ph.D. in Geosciences or related field and excellent computational skills. The research will focus on seismic full waveform inversion of controlled-source data to determine shallow heterogeneities and voids. The position is available for one year, with a possibility for renewal contingent upon satisfactory performance and funding.

Applicants should include a cover letter, a curriculum vitae including a publication list, and contact information for three references and must apply via the Princeton University Academic Hiring website https://www.princeton.edu/acad-positions/position/13161. This position is subject to the University's background check policy. Princeton University is an equal opportunity employer/affirmative action employer and all qualified applicants will receive consideration for employment without regard to age, race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Greetings from near Shreveport, Louisiana!

This is one of the very first field shots from the Investigation of Seismicity in Louisiana (ISLA) project backdropped against a colorful rainbow. The ISLA project aims to monitor seismicity and study the subsurface in northwestern Louisiana over the next 2 years. We first took delivery in Baton Rouge of a whopping 1,300 pounds of seismic equipment loaned to us by the Portable Array Seismic Studies of the Continental Lithosphere (PASSCAL) Instrument Center and then started our installation of 10 broadband seismic stations on 29–30 June near the Texas–Louisiana border, about a 5-hour drive north of Baton Rouge. The photo was taken at dusk and shows us digging a hole for one of our sensors.

The deployment teams were made up mainly of a diverse group of students from Louisiana State University, Tulane University, and University of Louisiana at Lafayette. We put six stations in the ground in a record 24 hours! Our network was up and running just in time to capture recordings of seismic waves from the distant 4 July *M*6.4 and 6 July *M*7.1 earthquakes in central California.

Stay tuned for more seismic updates from the field!

—**Justin Kain, Rasheed Ajala,** and **Madison Menou,** Louisiana State University; **Betina Brockamp** and **Samantha Hilburn,** Tulane University; **Brennan Brunsvik,** University of Louisiana at Lafayette; **Mario Ruiz,** Universidad de La Plata, Argentina; **Alissa Scire,** IRIS PASSCAL Instrument Center; **Patricia Persaud,** Louisiana State University; **Cynthia Ebinger,** Tulane University; and **Gabriele Morra,** University of Louisiana at Lafayette

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