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SCIENCE NEWS BY AGU

Reimagining the Geosciences

How? Adaptable models can light our way

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Shaping the Future of Science

Every community around the world has weathered extreme changes this year. The geosciences are no different. As the AGU community gathers for its first all-online Fall Meeting (#AGU20) this December, we offer you this special double issue of *Eos* as an introduction and, we hope, inspiration. *Eos* science advisers Lisa White (Diversity and Inclusion) and Eric Riggs (Education) worked with us to design an issue that embraced the #AGU20 theme: Shaping the Future of Science.

"This issue highlights novel diversity, equity, and inclusion practices, direct recommendations from underrepresented scholars, and creative strategies—many rooted in activism—that have the potential to shift long-held, historically exclusive traditions in Earth science," said White, director of education at the University of California Museum of Paleontology in Berkeley.

Our slate of expert Opinions are primers for implementing this kind of progress. You'll find incisive recommendations for adapting fieldwork to draw in—and keep safe—Black, Indigenous, and People of Color (page 30) and LGBTQ+ scholars (page 22); stories from scientists juggling parenthood and careers and a global pandemic (page 27); and how to develop resourceful STEM learning ecosystems in your own community (page 24).

In our feature articles, we look at institutions that are already accelerating ahead. Who better to show us how to mentor students from a distance than a seafaring organization? Learn from STEMSEAS' experience on page 32. Then read about a community college–university partnership that is drawing students to the geosciences—and retaining them—on page 51. It's not a model that can be airlifted onto every institution, but it offers important lessons on intentional design that many educators are focused on right now.

"I have seen the geoscience community look inward to see how systemic racism and gendered behavior may be embedded in our current practices as educators," said Riggs, a professor of geoscience education at Texas A&M University. "Department leaders need to meet with students at all levels, as well as with faculty, to find out where people are thriving, and where they are not. Without sincere information gathering and introspection, we risk changing everything too fast or, worse, changing the things that are working."

We also report on what the practice of science should look like in a world where respect and empathy for one another are paramount. Julie Maldonado and colleagues reframe the issue of managed retreat so that communities can retain agency when they are forced to relocate due to climate change (page 38). We also look at where geoscientists aren't. More than 2 million people are incarcerated in the United States in facilities that are often deliberately placed in polluted areas or are ill-equipped to deal with climate change. On page 56, read about this environmental justice movement and how geoscientists can be a part of it.

"This special issue offers a road map of where we might go from here," said White. The scientists and institutional models featured in this issue are remarkable examples for those who support AGU's vision of a thriving, sustainable, and equitable future supported by scientific discovery, innovation, and action. We should remember, said Riggs, "that efforts to help lower barriers and enhance the access and success for communities facing the greatest challenges will improve the environment for all communities."

Illustrator Carlos Basabe was thinking about the future—in particular, his daughters' future—when he designed our wonderful cover. We hope his artwork and the reporting in this special issue offer you motivation for the unique role you'll play in creating the best possible future. As White reminds us, "The responsibility to advance diversity, equity, and inclusion in the geosciences truly lies in all of us."

Read the rest of our special issue on Shaping the Future of Science at eos.org/special-topics#future.

Heather Goss, Editor in Chief

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On the Cover

"Working on this cover forced me to be mindful of the rays of light peeking through the darkness. Seeing the energy of young people, using every civic tool at their disposal to fight for their future, has given me hope that our kids will have the strength to rise to the challenges of the world they inherit from us," said **Carlos Basabe,** who created the cover of this special issue of *Eos.* Basabe, born and raised in Cuba, is an editorial and portrait illustrator currently living in Maryland. See his work at foursixsix.com.

Features

Columns

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Have We Got Dust All Wrong?

This 3-meter astronomical dome with Sun-tracking capabilities hosts the solar polarimeter (SolPol) instrument of the Panhellenic Geophysical Observatory of Antikythera (PANGEA). Credit: Stav Dimitropoulos

The "Godzilla" Saharan dust plume that clouded over parts of the United States in June generated a lot of talk and a lot of magnificent sunsets. Dust is an intriguing type of matter, vital for the formation of clouds and precipitation. We also know that if enough dust gathers in the atmosphere, it can block solar radiation. But what if some of these dust-related assumptions were slightly dusty—or completely wrong?

Members of the Remote Sensing of Aerosols, Clouds and Trace Gases (ReACT) team are trying to find out. The team, a group of atmospheric and climate scientists operating under the umbrella of the National Observatory of Athens (NOA), said the main reason for this "dust misconstruction" may be that we have failed to grasp the correct dust particle orientation in the first place.

"Dust particles might be vertically aligned," said Vassilis Amiridis, a climate scientist and team leader of ReACT, as well as director of research at NOA. Amiridis is resuming what a research project in La Palma, Canary Islands, proposed in 2007. In that instance, researchers from the University of Hertfordshire in the United Kingdom and Macquarie University in Australia used optical polarimetry observations during a Saharan dust episode and found evidence of vertically aligned dust particles in the atmosphere.

Amiridis recently received a European Research Council consolidator grant to spearhead the development of the Panhellenic Geophysical Observatory of Antikythera (PANGEA). As part of the project, Antikythera, a tiny island situated between the Peloponnese and Crete, will be outfitted with avant-garde equipment to start unraveling the great dust particle alignment mystery.

"Probably everything we've so far hypothesized about the impact of dust on the atmosphere might be misplaced."

"Our first measurements point to a vertical alignment of dust particles," said Alexandra Tsekeri, an environmental engineer and member of the ReACT team. Tsekeri, along with scientists from Raymetrics (a Greek company specializing in systems used in atmospheric, meteorological, and air pollution applications) and Ludwig Maximilian University of Munich, has designed and constructed lidar systems to monitor particle orientation in the atmosphere.

"We will have definitive results in about a year from now, when our systems will be put to test in Cape Verde in an experiment that would have taken place this summer had COVID not shut down everything," said Tsekeri. Meanwhile, she and the rest of the team are putting the final touches on their lidar systems, which they call WALL-E and EVE after the robotic couple in the 2008 movie *WALL·E*.

The Devil in the Details

But what's all the fuss about the orientation of dust particles?

"Probably everything we've so far hypothesized about the impact of dust on the atmosphere might be misplaced," said Amiridis.

For a start, dust may be accelerating the greenhouse effect instead of cooling the planet. A vertical particle orientation may create a type of "Venetian blind" effect, allowing more radiation to sneak through the atmosphere—as much as 10%–20% more radiation in dust episodes like Godzilla, said Amiridis.

In addition, whether dust particles are randomly or vertically aligned might be of paramount importance for satellite observations: "Remote sensing retrievals are affected by the assumption of particle shape and orientation," said Amiridis. Some of the satellite observations we get over a given area during dust storms may not be entirely accurate.

"A vertical dust orientation is certainly a possibility," said Stephen Holler, a physicist at Fordham University who is not a part of the ReACT project. He said there are many uncertainties in terms of the effect of aerosols on climate.

Holler explained that most of his colleagues do calculations on the basis of orientational averaging: "Because we don't

PANGEA scientists stand with EVE, one of their lidar instruments in Antikythera, Greece. Credit: NOA and Raymetrics

know the orientation of particles in space, we'll just average over all orientations." Most also think particles in the atmosphere behave much in the same way particles in liquids behave. "Much as particles in liquids tumble around and move all over the place, we expect particles in the atmosphere to tumble all over the place likewise."

"We have had a clear big picture on climate change for years, but as they say, the devil is in the details."

Holler is optimistic that the Greek scientists will help the scientific community better understand aerosol dynamics and its influence on radiative forcing. "The work of the ReACT team will reduce some of the uncertainties that are associated with the effects of airborne particles," Holler said. "We have had a clear big picture on climate change for years, but as they say, the devil is in the details."

By **Stav Dimitropoulos,** Science Writer

Kabuki Actor's Manuscript Yields Clues About 1855 Quake in Japan

In 1855, a powerful earthquake struck the Japanese city of Edo (today's Tokyo), killing thousands. The region sits atop multiple tectonic plates that have caused innumerable quakes over the centuries, and because the greater metropolitan area is now home to more than 30 million people, it's critical to mitigate the threat. Japanese scientists have been examining historical records to better understand past quakes and have found that the autobiography of a Kabuki actor can shed light on the 1855 temblor.

A Time of Turmoil

The 1855 Ansei Edo quake, named for the Ansei imperial era of 1854–1860, came at a time of upheaval in Japan, both literally and figuratively. There were three great Ansei earthquakes: the Tokai and Nankai quakes, both in 1854 and both magnitude 8.4, and the Edo quake the following year, magnitude 7.0. Meanwhile, Japanese society was facing its greatest challenge in centuries. Having been under the hegemony of the Tokugawa shogunate, which implemented a policy of national seclusion for over 230 years, Japan was finally forced to open its doors to ships and trade by American gunboat diplomacy in 1854.

When Edo was hit on 11 November 1855, as many as 10,000 people lost their lives, and over 50,000 structures were destroyed by the temblor and in subsequent fires. Some of the devastation can be seen in woodblock prints of the day that depict a giant underground catfish (*Namazu*) that was believed to have caused earthquakes when it thrashed about.

The Forgotten Manuscript

Fast-forward to 2020, and researchers at the University of Tokyo have found another way to use art to scientifically evaluate the 1855 calamity. Scientists analyzed a manuscript written by Kabuki actor Nakamura Nakazo III to infer the depth of the earthquake. In a poster presented at a joint conference of the Japan Geoscience Union and AGU (JpGU-AGU Joint Meeting 2020) in July, they noted that later editions of the manuscript had already been the basis for varying estimates of the quake's hypocenter from relatively shallow in the crust to deep in the Philippine Sea plate (bit.ly/earthquake-poster). However, when the team analyzed Nakamura's original handwritten manuscript of the autobiographical work *Temae Miso* (Self-Praise), recently acquired by Tokyo's National Diet Library, it found a significant difference compared with later editions (bit.ly/quake-hypocenter).

"A strong rumble occurred," Nakamura wrote. "The women and children were surprised and screamed. I said, 'Calm down, it's a big earthquake.' Omitu Bando said to me, 'You should stand up rather than sit.' I stood up. Then the strong shaking started, and I could not walk normally." Instead of the first sentence, one later edition read, "a

As many as 10,000 people lost their lives in the 1855 Edo earthquake, depicted here in the Edo Oojishin no zu picture scroll. Credit: Historiographical Institute, University of Tokyo

Courtesans from Edo's Yoshiwara pleasure district attack a mythical giant catfish, which was believed to have caused earthquakes, in this 1855 woodblock print. Credit: Earthquake Research Institute Library of the University of Tokyo

strong upward movement came from the ground," and where the writer describes standing, the later edition reads, "I stood up and walked. Then the strong shaking started...."

Researchers concluded that because the shaking began when Nakamura stood up instead of after he began walking, there was a relatively short period between the arrival of different seismic waves from the quake—in this case, the rumble and the shaking. Longitudinal, or *P*, waves are fastest and correspond to the rumble described by Nakamura. Transverse, or *S*, waves travel at about half the speed and correspond to the shaking. Just as the distance to a thunderstorm can be estimated by the lag between a lightning flash and the sound of thunder, the *S*–*P* interval can suggest the distance to an earthquake's epicenter.

The team concluded that the 1855 quake had an *S*–*P* time of 5–10 seconds and, because of the thick sedimentary layers of the Kanto region surrounding Tokyo, a relatively shallow depth of about 20 kilometers, which would place the rupture in the subducting Philippine Sea plate. Many researchers have estimated the depth at over 30 kilometers.

Such details are critical because the Japanese government believes there's a 70% chance of another 1855-type quake in the next 30 years with as many as 23,000 casualties, according to poster coauthor Kenji Satake, director of the University of Tokyo's Earthquake Research Institute. "Since the typical recurrence interval of large earthquakes is several decades to centuries," Satake added, "we have to use other methods and data to study such large earthquakes in the past and the potential for the future."

"Seismologists have debated [the quake's depth] for more than a century.

"Ground shaking and earthquake damage are larger for shorter hypocentral distances," said coauthor Ryoichi Nakamura, another member of the institute. "Because the 1855 earthquake occurred right beneath Tokyo, the depth strongly affects ground shaking and damage."

Interdisciplinary Teamwork

William Ellsworth, a professor of geophysics at Stanford University who was not involved in the research, believes the poster conclusions agree with other findings.

"Seismologists have debated [the quake's depth] for more than a century," said Ellsworth. "The plates colliding beneath Tokyo provide a wide range of possibilities, both deep and shallow. The recent paper by Nakamura et al.…makes clever use of reports of the shaking to argue for a relatively shallow depth. Their work supports the conclusion of William Bakun, who used other historical accounts of the earthquake shaking to determine its magnitude, location, and depth."

The poster is part of a greater interdisciplinary effort at the University of Tokyo. Seismologists teamed up with historians from the Historiographical Institute in an effort called the Collaborative Research Organization for Historical Materials on Earthquakes and Volcanoes. Inaugurated years after the catastrophic magnitude 9 Great East Japan Earthquake of 2011, its aim is to improve seismic understanding by compiling a long-term database of events based on historical materials. That means analyzing obscure records like Nakamura's manuscript, written in a highly cursive hand that only experts can decipher.

"Different kinds of materials provide different kinds of information on earthquakes," said poster coauthor Reiko Sugimori, an associate professor in the Historiographical Institute and the only team member who was able to read the Kabuki actor's manuscript. "Earthquake casualties or damage in each village were summarized as reports, which are useful to estimate the distribution of seismic intensity, from which earthquake location and size can be estimated. On the other hand, daily records or personal diaries, written by the same person in the same location, can provide homogeneous daily records of seismicity, including foreshocks or aftershocks. Pictures are also useful because they provide visual records of earthquake damage."

Researchers plan to continue adding details from historical materials to their historical seismic event database, and their work highlights the importance of long-term seismic knowledge. *Seismological Research Letters* also published a focus section coauthored by Satake on historical seismology in September (bit.ly/focus-section).

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

Scientists Support Local Activities to Rescue the Mesoamerican Reef

Cayos Cochinos, Honduras, is part of the Mesoamerican Reef, which was recently given a poor score in ecosystem health. Credit: Ian Drysdale

Earlier this year, Healthy Reefs for Healthy People published its sixth report card on the status of the Mesoamerican Reef system (bit.ly/healthy-reefs). After an analysis of 286 sites in Belize, Guatemala, Honduras, and Mexico, the report concluded that the health of the system is poor, with an index of 2.5 out of 5. This conclusion was based on the status of the reef's coral and fleshy macroalgal cover, as well as the biomass of herbivorous fish and commercial fisheries in the region.

"There is poor fishing regulation in all four countries," said Ian Drysdale, coordinator of Healthy Reefs for Healthy People in Honduras. "The decline in coral health that we experience is due to fishing, both industrial and artisanal."

On top of overfishing, the Mesoamerican Reef suffers from coral bleaching events, in which corals expel the algae that provide most of their food and characteristic color. Stony coral tissue loss disease (SCTLD), also known as white syndrome, also plagues the reef. White syndrome is a condition that weakens the coral tissues, causing their death.

In the region of the Mesoamerican Reef near the Yucatan Peninsula, SCTLD has caused the death of up to 98% of some coral species. "When we approach the loss of 90% to 98% of the individuals of a particular species, we could well speak of the definitive disappearance of this species," said Nallely Hernandez, regional deputy director of the National Commission of Natural Protected Areas (CONANP) and cocreator of the "White Syndrome Action Plan in the Caribbean Reefs of Mexico."

In 2019, the National Autonomous University of Mexico and Florida State University partnered with CONANP to carry out an experiment to understand the behavior of SCTLD. Although coral bleaching spreads systematically because of warming waters, white syndrome spreads without a specific pattern. "At first, [the disease] behaved radially, on the edges of the colony. But later, we realized that it could appear in isolated points, without warning, or, in some cases, everywhere in the colony," Hernandez said.

Besides documenting this erratic behavior, the results of the experiment have been inconclusive. Scientists suspect that the cause of SCTLD may be a virus or bacteria, which is enhanced by poor water quality. "Some banks, south of [the Mexican state of] Quintana Roo, still did not show signs of disease, perhaps because of their remoteness from the coast. This reinforces the hypothesis of the relationship of wastewater and pollution from the coast to the sea with the disease," Hernandez added.

In the region of the Mesoamerican Reef, stony coral tissue loss disease has caused the death of up to 98% of some coral species.

Water Treatment and Community Involvement

Local and federal government agencies are taking action to protect the Mesoamerican Reef. In 2018, Mexico added 10 species of parrotfish to its national registry of protected species. In February, Guatemala did the same and also included the butterflyfish, angelfish, and surgeonfish. These herbivorous fish consume macroalgae, which compete with corals for the reefs. Protecting the fish encourages corals to thrive.

Hernandez supports community-oriented approaches and reduced consumption. "The solutions rest in the way we all behave in our everyday routines," he said. "We need to make adjustments throughout the system, in order to understand the positive impact that we can generate with changes in our consumption habits."

Drysdale, however, said that overfishing limits the efficacy of both federal protections and individual consumption habits. "We are not just fishing efficiently, but we are also destroying critical habitats, such as mangroves and seagrasses," he said.

"Unfortunately, the fishing industry has a lot of political and economic power, and its interference makes it difficult for us to work to protect our marine ecosystems," Drysdale said.

By **Jorge Rodriguez,** Science Writer

Decrease in Lightning Recorded over the Continental United States

Lightning research is a burgeoning field that spans not only meteorology and atmospheric science but also public policy and personal safety. As in all scientific fields, however, mysteries sometimes arise: In May and June of this year, a network of lightning detectors recorded distinctly lower than average lightning counts across the continental United States. The cause of this downturn isn't well understood, but a ridge of high pressure in the atmosphere might have played a role, researchers suggest. It's also possible that the decline is linked to decreased levels of pollution associated with the ongoing COVID-19 pandemic, other scientists propose.

A Midyear Checkup

Meteorologist Chris Vagasky and his colleagues mined data from the National Lightning Detection Network (NLDN), which uses roughly 120 sensors to monitor lightning over the continental United States. (Vagasky's employer, Vaisala, runs the NLDN.) The researchers compiled data from January through July 2020 to take a midyear look at lightning statistics.

"We've passed the peak of lightning signals in the United States, so we wanted to see where we were at this year compared to previous years," said Vagasky.

The scientists found significantly lower than average lightning counts in May and June. During those months, the NLDN recorded just over 51 million instances of in-cloud and cloud-to-ground lightning. That's a 32% decrease compared with the roughly 76 million lightning events recorded on average for May and June from 2015 to 2019. That difference is far more than the expected interannual variability, which is on the order of 5%–10%, said Vagasky. "We were kind of surprised."

These results appeared in a blog post that Vagasky published last month (bit.ly/Vagasky-lightning). "It's an intriguing finding," said Joel Thornton, an atmospheric scientist at the University of Washington who was not involved in the research. But it's still not well understood why this downturn occurred and whether it's a rare phenomenon, he said. "What we're lacking right now is some context."

Lightning flashes over El Paso, Texas. Credit: iStock.com/mdesigner125

A Ridge of High Pressure

Vagasky and his colleagues have some ideas. Using data from the National Centers for Environmental Prediction, they measured a ridge of high pressure over the Southern Plains, eastern Colorado, and the Gulf Coast region in May and June.

"We saw that there was an anomalously strong area of high pressure over the main region where you'd get severe weather," said Vagasky. This high pressure would have prevented air from rising, a necessary ingredient for a thunderstorm. (Upward movement allows air to cool and condense into clouds, which is where supercooled water, ice crystals, and graupel collide and transfer electrons. That sets up the charge separation necessary for lightning.)

So far, other lightning networks haven't reported similar results. Robert Holzworth, an atmospheric and space physicist at the University of Washington and the director of the World Wide Lightning Location Network (WWLLN), analyzed unpublished WWLLN data and found a statistically insignificant decrease in lightning counts worldwide in 2020 compared with the year prior (see bit.ly/world-wide-lightning).

"The overall decrease in 2020 compared to 2019 is just 0.4%, or an order of magnitude smaller than the expected daily variation," he said. However, it'd be worth analyzing WWLLN data just over the continental United States to make a direct comparison with Vagasky's findings, Holzworth acknowledged.

A Potential Virus Link

The idea that a localized region might have experienced a decrease in lightning in the spring of 2020 isn't completely out of the blue, said Holzworth. Researchers have speculated that the COVID-19 pandemic might have inadvertently triggered a downturn in lightning, he said. That's because with the economy on hold, there's less air pollution and therefore likely fewer aerosols. The presence of aerosols has been linked to enhanced lightning activity, at least over the ocean.

Vagasky and his colleagues are continuing to collect data, and they've seen that the lightning counts for July and August have been closer to average. They hope to have more answers by the end of the year. "We'll prepare our annual lightning report in December," said Vagasky. "We'll be able to compare to a much broader data set in the coming months."

By **Katherine Kornei** (@KatherineKornei), Science Writer

Eos thanks Robert Holzworth, who generously provided the analysis of unpublished WWLLN data.

▶ Read our May 2020 special issue on lightning: bit.ly/Eos-lightning

Leaded Soil Endangers Residents of New York City Neighborhoods

Long Island City, above, has seen a population growth of more than 20% over the past decade, and soil samples from local parks range from 26 to 6,300 milligrams of lead per kilogram of soil. Credit: iStock.com/Auseklis

City parks can be a haven for homebound residents looking to escape the quarantine blues this year, but these play areas offer another kind of hazard. A new study describes dangerously high levels of lead in the soil of several parks in New York City. Researchers found that lead levels are highest in areas undergoing rapid growth and redevelopment.

"We have over 36,000 people moving into these areas—and lead contamination in the soil," said study coauthor Brian Pavilonis, a professor at the Graduate School of Public Health and Health Policy at the City University of New York (CUNY). "That's a lot of people who could all be exposed."

Pavilonis and his colleagues at CUNY and Brooklyn College analyzed hundreds of samples from 34 parks in six different geographic areas throughout the city. Many of the results far exceeded the Environmental Protection Agency's soil cleanup value of 400 milligrams of lead per kilogram of soil.

In Long Island City, for example, abandoned factories and parking lots have given way to glittering apartment towers with waterfront views and short commutes to Manhattan. The population has grown by more than 20% in the past 10 years. Soil samples from parks in the area ranged from 26 to 6,300 milligrams of lead per kilogram of soil. "We confirmed our initial hypothesis, that [lead] levels in these areas would be very, very high," Pavilonis said, "but I was surprised to see samples in the thousands of milligrams, especially in a park."

The study was published in the *International Journal of Hygiene and Environmental Health* (bit.ly/NY-lead).

"Condemned to Being Lead Poisoned"

Lead in soil comes mostly from legacy uses in paint, industry, or transportation. Between 1926 and 1985, motorists burned 7 million tons of tetraethyl lead in gasoline. Although leaded gasoline has been nearly phased out, the lead persists today, having stuck to vertical surfaces such as buildings and trees and then been washed into the soil. During dry summer months, wind and construction activity resuspend lead-containing soil in the air as dust. Lead levels in the blood of children living nearby rise during these months and fall again each winter.

"People think if there is lead in the soil, the kid has to go to the park and ingest it somehow, but you don't even have to use that park or outdoor space—that lead gets into the air and then it's inhaled," Pavilonis said.

"Lead paint has certainly been a horrendous problem," said Howard Mielke of Tulane University, who was not involved in the new study. "But the immediate lead in the atmosphere has been the source that has really just condemned us to being lead poisoned."

The median lead concentration in soil, according to a 2013 U.S. Geological Survey report describing 4,841 soil samples from nonurban locations in the United States, was

This map shows the approximate locations of the six geographic areas examined by the study, along with the median lead level observed (red numbers indicate a concentration above the EPA's soil cleanup value of 400 milligrams of lead per kilogram of soil), recent population growth, and the proportion of new construction. Credit: Matthew Stonecash, adapted from Copernicus Sentinel-2, ESA; CC BY-SA 3.0 IGO (bit.ly/ccbysaigo3-0) only 18 milligrams of lead per kilogram of soil. This figure led some experts to suggest that the EPA cleanup value (400) is far too high. Among them is Mielke, who said that in areas where children have low levels of lead in their blood, lead levels in the soil are below 40 milligrams of lead per kilogram of soil.

According to the Centers for Disease Control and Prevention (CDC), there is no safe level of lead in the bloodstream. The disastrous effects of lead on brain development in children are the most alarming and well known, but the CDC's toxicological profile for lead describes health effects on every organ system.

Research by Mielke and others suggests that combating these effects may be as simple as covering contaminated soil with clean soil and grass. Toward this aim, New York City's Office of Environmental Remediation established the PUREsoil NYC program in 2018. Using soil excavated from deep underground at construction sites, the program distributes free, clean soil to community organizations for use in gardens and other open spaces.

Meanwhile, Pavilonis plans to continue exploring how soils differ from neighborhood to neighborhood. Researchers are now collecting samples from all of the parks in Brooklyn for use in an ecological study of the relationship between lead in the soil and blood lead levels of children living in the area. "We're much more concerned with the effects on children," Pavilonis said. "The problem with lead is, once it impacts the developing brain, that's permanent."

According to the Centers for Disease Control and Prevention (CDC), there is no safe level of lead in the bloodstream.

By **Matthew Stonecash** (@mattstonecash), Science Writer

This piece was produced with support from the National Association of Science Writers' David Perlman Virtual Mentoring Program.

Severe Cyclones May Have Played a Role in the Maya Collapse

Sediments recovered from the Great Blue Hole (seen here), off the coast of Belize, hint at extremely severe storms during the late Classic period in Maya history. Credit: iStock.com/Mlenny

Why the once great Maya civilization withered away is still a matter of debate among historians, archaeologists, and geoscientists. The leading theory is that the Maya suffered a series of severe droughts around 800–1100. New evidence suggests there may have been another reason: severe tropical storms.

Researchers studying climate records in the Caribbean found that storm activity was weak and predictable up to about 900. At that point, storms became more intense and unpredictable. The stress of dealing with the highly variable and intense storms, in addition to battling drought, may have pushed the Maya over the edge, according to research published in *Scientific Reports* (bit.ly/Maya-storms).

Reconstructing Past Climate

Atlantic hurricane activity, which includes the Caribbean, and how it varies over the long term are often attributed to the behavior of ocean and atmospheric systems like the Atlantic Multidecadal Oscillation (AMO) and the El Niño–Southern Oscillation (ENSO). "But without long-term observations of storm behavior, it's hard to speak to these relationships conclusively," said Richard Sullivan, who studies paleoclimatology at Texas A&M University at Galveston and was not part of the new study.

Historical or instrumental records of hurricanes and tropical storms go back only a little more than a century. To peer further back in time, scientists often decipher telltale signatures left in sand and mud deposited by ancient storms.

One source for finding undisturbed sediments is blue holes, marine sinkholes into which sediments are continually deposited. Generally, the sediments in deposition layers are smooth. But when a large storm passes by, it rakes up and deposits coarse particles. Because of the structure of a blue hole, material can be deposited but cannot get out, allowing the feature to act as a near-perfect record of ancient storms.

Sediment cores from blue holes like those near Great Abaco Island and Thatch Point (both in the Bahamas) have already provided records of hurricanes in the Caribbean going back about 1,500 years.

Now Dominik Schmitt of Goethe University in Frankfurt, Germany, and colleagues have reconstructed past storms in the region going back 2,000 years. The researchers recovered and studied an 8.5-meter-long sediment core from the Great Blue Hole on Lighthouse Reef off the coast of Belize.

Upon analyzing the results, Schmitt's team found evidence of the AMO going back to 300. According to Schmitt, this provides statistical proof that the AMO, along with

ENSO, modulates hurricane activity in the southwestern Caribbean.

When the Weather Changed

The sediments also revealed something else. "The tropical cyclone activity of the southwestern Caribbean generally shifted from a less active to a more active state," said Schmitt. The shift, around 900 CE, occurred right around the time when the Maya civilization was in decline.

The Classic Maya civilization, which once occupied most of the Yucatán Peninsula, began to wane starting in the late 800s. During the next century, great Maya cities like Copán (in what is now Honduras) and Tikal (in what is now Guatemala) were abandoned.

Climate change is thought to have been a primary driver of this collapse. The leading theory suggests that a series of severe and prolonged droughts plagued the Yucatán Peninsula, which may have reduced the availability of fresh water and decreased agricultural productivity.

In addition to drought, the Maya may have had to contend with increased and more unpredictable Caribbean cyclones. The Great Blue Hole sediment core showed five exceptionally thick layers—15–30 centimeters—deposited between 700 and 1150. These layers suggest extremely intense cyclones; for comparison, the deposition layer left by Hurricane Hattie, a Category 5 hurricane that passed over the same area in 1961, was just 4 centimeters thick.

Deposits line the 8.5-meter-long sediment core recovered by researchers from the Great Blue Hole off Belize. Credit: Dominik Schmitt

Two of the ancient cyclones struck during drought periods, and the others struck just before and after severe droughts. It's likely these cyclone landfalls destroyed Maya infrastructure, caused coastal flooding and crop failures, and added to the environmental stress of the intensive drought phases.

The increased storm activity around 900 is similar to what Sullivan found in his study of sediment cores from a sinkhole south of Tulum, Mexico, near the Maya site of Muyil (bit.ly/Yucatan-hurricanes). Still, he is cautious in interpreting the results, saying they do not necessarily mean that an increase in storm frequency definitely contributed to the Classic Maya collapse.

However, "it's not hard to imagine that a culture contending with severe drought and already in decline would have been stressed further by persistent, devastating storms," Sullivan added. "It is certainly possible that increasing hurricane frequency factored in to the collapse of the Mayan empire, but the extent of that contribution is something we may never know conclusively."

By **Lakshmi Supriya** (rlsupriya@gmail.com), Science Writer

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Using Dirt to Clean Up Construction

Concrete ranks as the most popular construction material in the world. But its key ingredient, cement, is responsible for 8% of global carbon dioxide emissions each year. Scientists want to replace concrete with a more environmentally friendly material, and one candidate is soil. In one of the most recent iterations of these efforts, the Banerjee Research Group at Texas A&M University has created a tool kit for using local soil to make construction materials.

Concrete production, especially of its binding agent, cement, releases massive amounts of carbon dioxide (CO_2). "If [cement production] were a country, it would be the third-largest emitter in the world," said Gaurav Sant, a professor of civil and environmental engineering and materials science and engineering at the University of California, Los Angeles.

"We need to go carbon neutral by 2050 and carbon negative thereafter," Sant said. To do that, the construction industry needs to drastically change or replace concrete. "We're talking about disrupting and transforming our entire basis of society as a whole in the next 30 years."

The modern form of concrete, a mixture of sand and gravel bonded by cement and water, has been used for only the past 150 or so years. The development of modern concrete reinforced with steel has allowed builders to erect massive structures, giving us city skylines dominated by skyscrapers. With the growth of additive manufacturing, a process in which layers of concrete are 3D printed one on top of the other in a predetermined design, more complex building parts can be created more efficiently.

"A lot of emerging economies are going through a massive construction boom, and if we do this all in concrete, the consequences for the environment are going to be catastrophic," said Sarbajit Banerjee, a chemistry professor at Texas A&M University, at the 2020 meeting of the American Chemical Society in August.

Building with Backyard Soil

Banerjee and Aayushi Bajpayee, a Ph.D. candidate in Banerjee's group, wanted to develop a sustainable material that could work with existing building codes and concrete-based construction methods. For their source material, the team settled on soil.

That idea came from both nature and history. In nature, termites make impressive use of soil, building intricate and durable mounds. "That was one of our motivations, and the second one was ancient times," said Bajpayee. "In ancient Rome and India, there are a lot of places [where people used] soil."

The difference between ancient earthen structures and a soil-based concrete alternative is that in ancient times, the main instinct for such construction was survival, said Bajpayee. "Now our main instinct is sustainability."

Banerjee and Bajpayee used clay soil from a colleague's backyard in College Station, Texas. They combined the clay, a water-repelling additive derived from beets, and sodium silicate to bind everything together. A 3D printer then extruded this material according to the desired design, forming a model a few inches tall.

They hope that their method can serve as a chemical tool kit to be used at any construction site, particularly in remote or hostile environments.

They hope that their method, presented at the meeting and published in *Frontiers in Materials*, can serve as a chemical tool kit to be used at any construction site, particularly in remote or hostile environments (bit.ly/frontiers). Once a construction team analyzes the local soil, it can tweak the ingredients in the tool kit, mix the material, and start printing.

By cutting out the energy-intensive production steps, using local resources, and eliminating transport concerns, Banerjee predicts that their material will have a much lower emissions profile than concrete, but they're still running simulations to nail down the figures. "I think the numbers are going to be significant," he said.

But soil-based replacements have limited applications. Although they could prove valuable for building housing in remote areas, on the basis of the current work, Sant doesn't think these materials are viable for larger structures.

Scientists and engineers are developing soil-based concrete replacements like this prototype structure. Credit: Aayushi Bajpayee

Expanding Possibilities

Gnanli Landrou, cofounder of Oxara, a sustainable construction material start-up, said his group uses a process similar to Banerjee's to make a soil-based building material. "The goal is not to replace concrete but to efficiently use concrete where needed," he wrote in an email. He and his group want to use their product, Cleancrete, for housing or nonstructural pieces of larger buildings. "Overall, we want to enable access to sustainable and affordable building materials and homes."

More robust replacements for concrete are in the works. Sant, for example, has developed CO_2Concrete, a cementless concrete in which CO_2 from industrial waste gas reacts with calcium hydroxide to bind everything together. "You get structural cementation with limestone in a seashell," said Sant, which is exactly how CO_2Concrete forms. It's similar in cost and function to concrete, he said, but with half the carbon footprint.

"Concrete is still the gorilla in the room because it's been the norm for many years," said Banerjee. "There are costs involved that are not cheap, rising CO_2 emissions that are tremendously large. We can do better than that."

By **Jackie Rocheleau** (@JackieRocheleau), Science Writer

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Groundwater Crisis in Zimbabwe

Kudzai Mungazi (far right), a traditional leader of a small village in Manicaland Province, Zimbabwe, closely monitors a water-rationing exercise at a local borehole during a severe drought in 2016. Credit: Andrew Mambondiyani

In parched Zimbabwe, farmers—along with water experts and policy makers—are apprehensive because groundwater is being depleted rapidly by drawn-out droughts.

Many hand-pumped boreholes and wells have dried up this year, forcing thousands of people in rural areas to crowd for drinking water at the few sources where water is still available. Annual rainfall in Zimbabwe is no longer sufficient to replenish the aquifers that nourish these boreholes.

Anna Brazier, an independent climate change researcher and consultant based in Zimbabwe, said that although drought years are part of the normal climate cycle in this part of Africa—often associated with the well-known El Niño–Southern Oscillation—global warming is causing droughts to become more frequent, more intense, and less predictable. "Models predict an average rainfall decline across Zimbabwe of between 5% and 18% by the end of the century. The range is large because different models give different results," Brazier said.

Richard Taylor, a professor of hydrogeology at University College London, in a report identified groundwater as an important and climate-resilient source of freshwater (bit.ly/groundwater-report). Depletion of groundwater is especially relevant for tropical countries like Zimbabwe.

"As the world warms, amplification of rainfall extremes and its consequences will be most pronounced in the tropics where, by 2050, over half of the world's population is projected to live. Yet it is here where substantial increases in freshwater withdrawals are required to achieve United Nations Sustainable Development Goals (SDGs) of enhancing food security through irrigation," Taylor wrote in the report.

Amid the current prolonged drought in Zimbabwe, which started in 2018, fears abound that the boreholes that still have water will dry up before the start of the next rainy season in November or December.

"Water shortages are getting worse with each passing day," said Danai Mutoro, a farmer in Chitora, a small farming village about 50 kilometers south of Zimbabwe's eastern border city of Mutare. "We were expecting better rainfall during the 2019–2020 summer season; instead, the season was even worse than before."

Lovemore Muradzikwa, a farmer in Mafuke, a farming community on the outskirts of Mutare, said water shortages in his area have now reached critical levels.

"We are now strictly rationing the little water still available. Each household is getting only 20 liters of water per day for cooking and other household uses regardless of the size of a family," Muradzikwa said.

Across Zimbabwe, more than 38% of the population depends on groundwater for household, agricultural, and industrial use.

Use Water Resources Sustainably

Washington Zhakata, director of climate change management in Zimbabwe's Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement, explained that underground water is recharged by normal seasonal rains, and Zimbabwe is getting less seasonal rainfall. The country has suffered severe recurrent droughts since 1992.

"In long periods of droughts, there is a higher risk of depletion of aquifers, especially in cases of small and shallow aquifers. People in water-scarce areas will increasingly depend on groundwater because of its buffer capacity," said Zhakata. "And when it rains these days, it's so intense [as] not to allow gradual seepage of the water to lower depths. Water is then lost as runoff into the streams and straight to the nearby ocean."

Seasonal rainfall has also not been consistent across the country, Zhakata said. The provinces of Manicaland, Masvingo, Matabeleland North, and Matabeleland South have been hardest hit by shortages of intraseasonal rainfall. "Some other areas experiencing this problem [of groundwater shortages] are those areas close to urban areas where consumption of water is very high and a lot of boreholes have been sunk," he added.

Intensification of human activity (including agriculture and industry) and land use changes (including industrial agriculture and urbanization) increase the demand for groundwater.

"Strategic use of groundwater for food security in a changing climate is becoming more and more important. It is important for farmers to utilize water resources sustainably to allow water seepage to greater depths," Zhakata said.

By **Andrew Mambondiyani** (@mambondiyani), Science Writer

Typhoons Getting Stronger, Making Landfall More Often

Typhoons and hurricanes are two drivers of intensifying natural disasters, which in 2019 caused some $150 billion in damages around the world, according to the insurer Munich Re. Typhoon Hagibis, 2019's costliest event, cost $17 billion in Japan alone.

The growing threat from typhoons as the planet heats up, a topic of critical importance to East Asia, was discussed at a joint conference of the Japan Geoscience Union and AGU (JpGU-AGU Joint Meeting 2020).

More Storms Landing in China

In a long-term study that was the basis for a poster submitted to the conference, scientists found that severe typhoons making landfall have increased abruptly in China since 2004 (bit.ly/severe-typhoons). The researchers analyzed tropical cyclone data from the China Meteorological Administration's Shanghai Typhoon Institute for the July–September period from 1973 to 2017. They showed that about 9.7% of landfall typhoons in southern China underwent a rapid intensification in the 24 hours before coming ashore during the 2004–2017 period, more than double the 1.6% and 3.1% intensification over the previous periods. Citing previous research exploring the relationship between more intense typhoons and global warming (bit.ly/climate-typhoons), the scientists noted that overall, warmer oceans are driving such storms, whereas warmer land surfaces in southern China are helping attract them.

"The warming ocean, especially the warming northern South China Sea, benefits typhoon enhancement before landfall."

"The intensifying typhoons are controlled by several factors," said study coauthor Zhixiang Xiao of the Guangxi Institute of Meteorological Sciences. "However, our results show that the warming ocean, especially the warming northern South China Sea, benefits typhoon enhancement before landfall."

Because of the complexity of the various interacting systems at play, Xiao said that it's very difficult to make predictions that could result in better policy making to mitigate storm impact and suggested that computer simulations using deep learning techniques could be more effective than traditional prediction methods.

Rising Super Typhoons

Researchers in Taiwan, meanwhile, looked at how super typhoons, which have average maximum wind speeds of over 209 kilometers per hour, or 113 knots, are increasing in the northwestern Pacific. In a study submitted to the conference as a poster, the researchers used satellite infrared imagery and wind vector plots for each typhoon and considered environmental factors that can strengthen such storms (bit.ly/poster-typhoon).

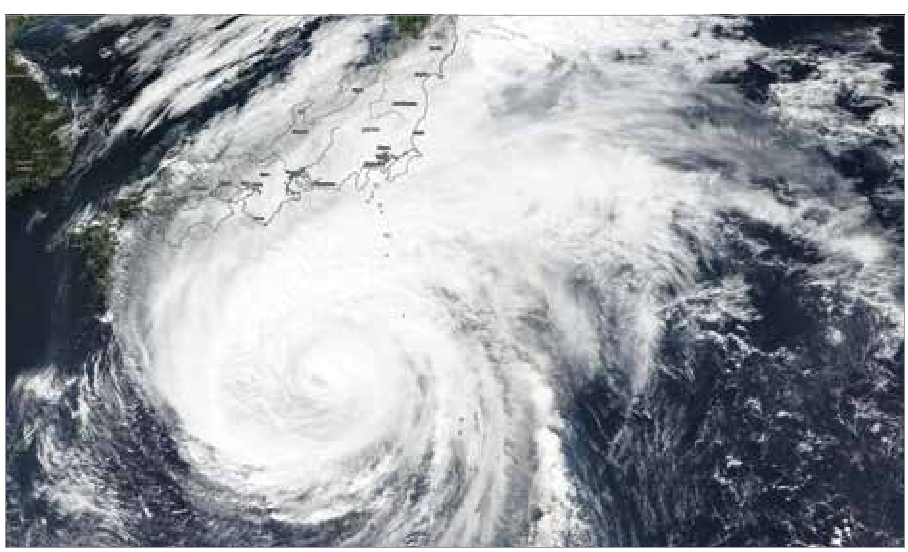
They found that southwest airflows and northwest cold air masses play crucial roles in strengthening super typhoons in summer and winter, respectively; southwest air flows boost most winter super typhoons as well, making them more intense than their summer counterparts. The scientists noted that the period 2013–2016 had the highest average number of super typhoons per year, at seven, with nine in 2015, second only to 11 in both 1965 and 1997.

"The increasing strength of typhoons in the Northwest Pacific Basin in recent years is in response to global warming," study coauthors Yuei-An Liou, a professor at the Center for Space and Remote Sensing Research at Taiwan's National Central University, and Ravi Shankar Pandey, a Ph.D. student, said in an email. "This issue needs proper attention to mitigate the risk involving them in the region."

Autumn Threat

Scientists in South Korea also called for further research to cushion typhoon blows, particularly for storms that come relatively late in the season. In a conference poster based on 65 years' worth of data, researchers at Inje University in South Korea reported finding that the frequency and intensity of typhoons affecting the Korean Peninsula in September and October, known as autumn typhoons, have been increasing (bit.ly/korea-typhoon). A study of typhoons from 1954 to 2019 using statistical analysis and numerical modeling showed that five of the eight October typhoons to affect the peninsula since 1954 occurred from 2011 to 2019; three of Korea's seven typhoons in 2019 occurred in September and caused significant damage.

Typhoons' maximum instantaneous wind speeds, a driver of wind damage, were also



Typhoon Hagibis, above, tore through Japan in 2019, causing nearly 100 deaths and more than $15 billion in damage. Credit: NASA Worldview, Earth Observing System Data and Information System (EOSDIS) up. The researchers attribute this increase to rising sea surface temperatures (SSTs) in the northwestern Pacific, noting that regional SSTs are increasing faster than the global average and that SSTs remain high around Korea in September and October. But≈they also said a hypothetical storm approaching the peninsula in October will not weaken, which was the case in the past, because while the land begins to cool, the sea remains warmer longer.

"This will develop into a powerful typhoon due to the greater temperature difference around the Korean Peninsula, which lies on the border between the cold continent and the hot sea," said study coauthor Woo-Sik Jung of Inje University's Department of Atmospheric Environment Information Engineering. "In other words, the larger the temperature difference, the stronger the wind, the more powerful the autumn typhoon around the Korean Peninsula can be compared to the summer typhoon."

"The increasing strength of typhoons in the Northwest Pacific Basin in recent years is in response to global warming."

One scientist based in Japan who was not involved in these studies said there are conflicting findings from research about whether the number of typhoons is increasing or decreasing amid climate change.

"However, most studies have shown that the typhoon intensities in terms of wind and rainfall would increase under global warming," said Sridhara Nayak of the Disaster Prevention Research Institute at Kyoto University, who participated as a convener of a session on extreme weather events at JpGU-AGU Joint Meeting 2020. "So the super or severe typhoons are expected to occur in the future warming climate, which would bring much stronger winds compared to present typhoons and heavy rains to the landfall region and would be a more severe threat to human life and property."

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

Chicago Wetlands Shrank by 40% During the 20th Century

As Chicago's industries and population boomed in the late 1800s, city officials decided to reverse the course of the Chicago River so that it flowed away from Lake Michigan. The river's reversal in 1900 carried industrial pollution away from population centers and increased shipping opportunities from the Great Lakes to the Mississippi River. It also began draining the extensive network of wetlands that had covered most of the Chicago area after the last ice age. Industrial and residential developments further altered the wetlands' reach.

All told, Cook County, Illinois, which encompasses Chicago, has lost 40% of its wetland area from the time of the reversal to today, according to research published in *Urban Ecosystems* (bit.ly/urban-eco). Wetlands such as rivers, streams, marshes, swamps, and lakes remove pollutants, manage groundwater, cycle nutrients, and support biodiversity comparable to tropical forests and coral reefs.

"Wetlands are not only the kidneys of the region, absorbing and cleaning a whole lot of water, but they are vital habitats for many birds and insects," said Iza Redlinski, a conservation ecologist at Chicago's Field Museum of Natural History who was not involved with the research. "Monitoring wetlands and other habitats is important to knowing how we're progressing and what actions can be undertaken to preserve them on both the large and small scale."

Draining Swamps to Make Lakes Instead

The researchers analyzed historic and modern maps of Cook County. They counted the numbers and types of distinct wetland features and measured the individual and total area covered by wetlands.

They found that from the historic period (1890–1910) to the modern period (1997–2017), the total area of Cook County wetlands shrank from 73 to 44 square kilometers (−40%). The number of wetland locations increased roughly tenfold over that time, but the average size of each location is about 10 times smaller today than it was in 1900. This shrinkage was led by the conversion of sprawling marshes to small lakes and retention ponds, said lead author Joey Pasterski, a graduate student in Earth and environmental sciences at the University of Illinois at Chicago (UIC). Overall, the region lost 85% of its swamp and marsh area during the 20th century, the team found.

"The thing that struck me the most was how clear the connection was between what was wetland and what now is lake," Pasterski said. When walking or biking around the city, he added, it's easy to notice a small isolated lake here and there, but the research revealed how widespread the phenomenon is across Cook County. "When you look at the map, it's unmistakable."

"This whole area was wetlands" that have since been transformed by human development, Pasterski said. "Now every time it rains and the park outside my house floods, I reflect on the idea that, yeah, it should flood. It should always be flooded."

"We've changed the hydrology of the entire area, and that's going to be true of any city," especially in the wetland-rich Midwest, said coauthor and UIC paleontologist

The Lake Calumet area of Cook County was the center of extensive wetlands until the late 1800s. Calumet lost significant wetland area between the early 20th century (blue) and the present day (pink and red) as it was developed into a hub for the shipping, rail, and steel industries. The original footprint of the Calumet wetlands now encompasses both an Important Bird Area of Illinois for three bird species and also a Superfund site. Credit: Wesley Tucker

Roy Plotnick. "The connectivity of the landscape has changed significantly as a result of [metropolitan expansion], and that's something that needs to be thought about going forward as we think about conservation and restoration of the land."

"Intact wetlands are of critical importance for native wildlife in general," said Field Museum conservation ecologist Mark Johnston, who was not involved with the project. "When protected in urban areas, they can also serve as connective corridors, which are super important in fragmented landscapes, particularly with the increased pressures of climate change."

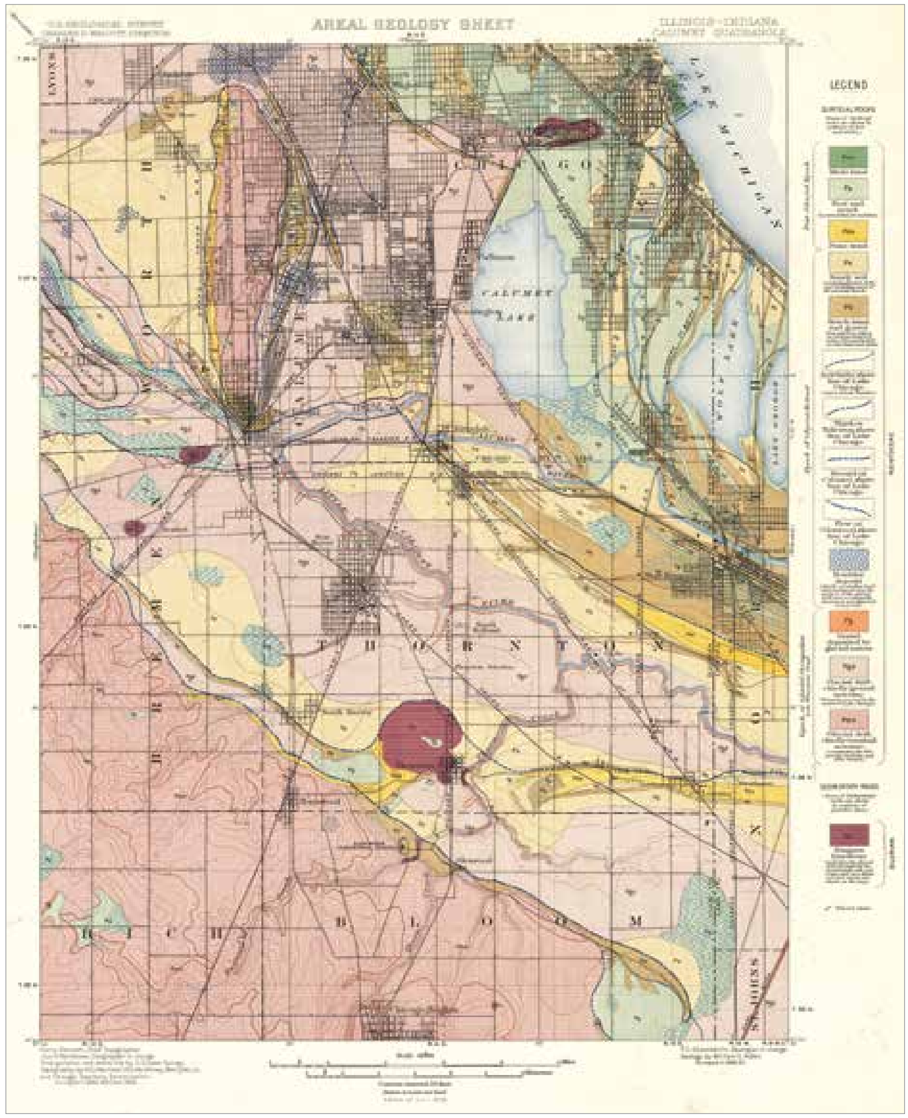
Native Biodiversity Lost

Both the loss of total wetland area and the transition from swamps to lakes affected Cook County's wetland-reliant species. The team gathered information on historic and modern species of mollusks, fishes, birds, reptiles, amphibians, and mammals by scouring publicly available resources like museum collections, online databases and catalogs, and even apps used by wildlife spotting communities.

The researchers found that wetland-reliant reptiles, amphibians, and mammals experienced little to no biodiversity loss during the 20th century. Mollusk species, however, changed significantly: Of the 107 native mollusk species present 100 years ago, 53 remain today, and 26 nonnative mollusk species were introduced into wetland habitats intentionally or accidentally. And although the numbers of fish and bird species have increased over time, the increased biodiversity is largely due to nonnative species replacing native ones. Some of the nonnative species, like silver carp, have been deemed invasive and injurious to local ecosystems.

This research will aid conservationists, Redlinski said, and can also help developers plan projects that will have minimal impact on the remaining wetland ecology. "Knowing what species have disappeared or which ones are on the decline can allow managers either to prepare sites for reintroductions, if that is possible, or to adjust the site in such a way to allow for that organism's life cycle to be completed," for example, keeping the land wet long enough for native frogs to complete all the stages of their development.

This research was conducted by graduate students enrolled in a course on species extinction taught by Plotnick, developed out of a class project, and relied solely on freely available public resources. The graduate researchers have moved on to other projects since the course ended last spring, but Pasterski hoped similar projects would spring up in other metropolitan areas.



The Calumet Quadrangle boasted extensive wetland areas in 1902 as Chicago faced rapid industrial expansion. Credit: USGS/W. C. Alden

"The fact that we were able to do this as a class project using just resources from the city that were free...to me reflects the ability for this study to be repeated in other areas as well using similar resources," he said. "Anywhere you have a museum collection over a 100-year time span or more you can do a similar study in the classroom in the span of a year."

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

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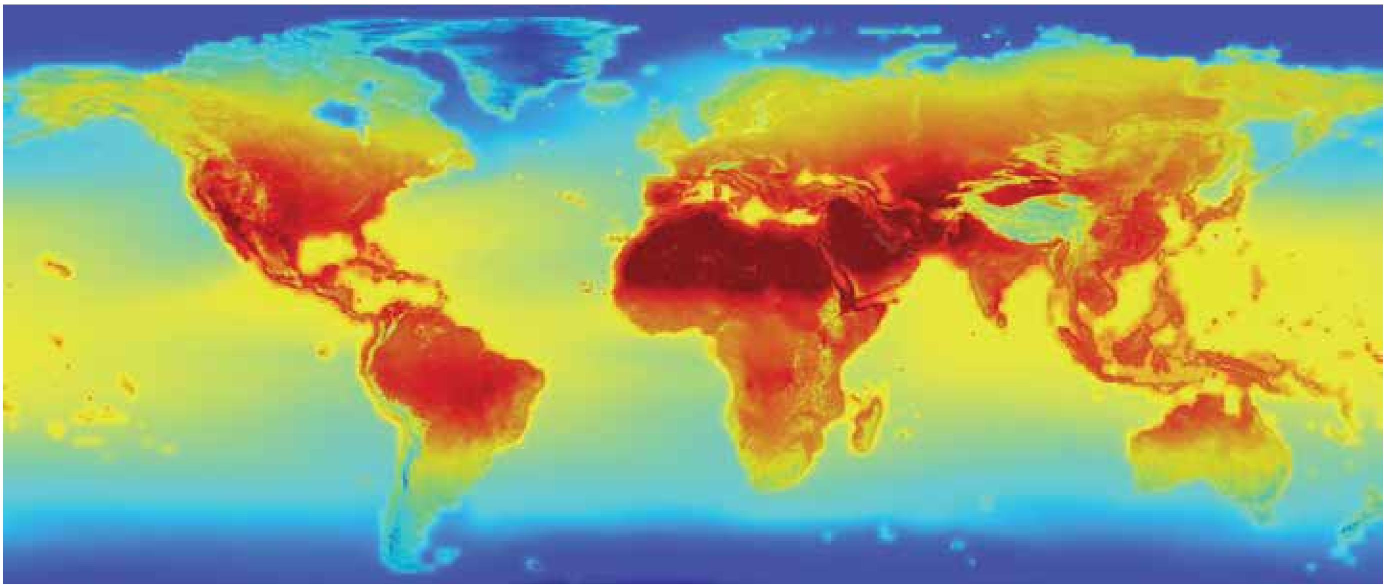
Will COVID's Cleaner Skies Muddy Climate Models?



A climate simulation showing possible temperature forecasts by 2100. Simulations like these will remain accurate despite a sudden drop in carbon dioxide emissions associated with the COVID-19 pandemic. Short-term models, however, might be affected. Credit: NASA

The year 2020 is an anomaly for many reasons, but the COVID-19 pandemic that has slowed normal day-to-day activities to nearly a halt stands out.

Earth's atmosphere has noticed.

In May, a team of international researchers published a paper showing that carbon dioxide emissions had dropped nearly 8% in March and April (bit.ly/COVID-CO2). And even as the world began to relax stay-at-home measures and emissions rose once more, the team suggested that the cumulative emissions for this year would remain 4%–7% lower than usual.

In terms of slowing the effects of climate change itself, this year won't make much of a difference, scientists say. The effects of climate change, like higher sea surface temperatures, more intense rainfall, and retreating glaciers, have more to do with the amount of carbon dioxide that has accumulated in the atmosphere over decades, and one anomalous year won't affect that.

But will this anomalous year affect the sophisticated models that scientists use to study potential future outcomes of our current levels of greenhouse gas emissions?

How We Model Climate

Scientists feed climate models an enormous amount of data from the very top of the stratosphere to the deepest reaches of the ocean. These data include air temperatures, wind speed and direction, cloud properties, concentrations of aerosols and greenhouse gases (like carbon dioxide and methane), sea ice cover, glacier extent, sea surface temperatures and salinity, current, nutrient cycling, and more.

But what happens to the models if one year is thrown off by an event that causes an unprecedented drop in a major variable like carbon emissions?

A team at the University Corporation for Atmospheric Research (UCAR) in Boulder, Colo., is trying to answer that question. Although the drop in emissions has been relatively small, it is still significant, Jean-François Lamarque, director of the Climate and Global Dynamics (CGD) Laboratory at UCAR, said. Over the next year or so, "how will it translate into a climate signal that we can observe? That's a real question [the answer to which] we just don't know."

Diverging Timelines

Basically, the team wants to know how different climate projections will be as a result of the pandemic. It's like seeing a timeline suddenly split, said Gokhan Danabasoglu, a senior scientist in the CGD Laboratory. There exists a set of emissions "as usual," but now a new timeline has emerged: emissions during a pandemic.

For long-term models, like those forecasting the outcomes over the next century of anthropogenic emissions of greenhouse gases and aerosols, the reduction this year probably won't make a difference, said Qiang Fu, a professor of atmospheric science at the University of Washington in Seattle who is not involved in the UCAR project.

If the difference in carbon emissions between this year and last year—due to the pandemic—is statistically significant, Lamarque said, then that might affect how scientists forecast shorter-term phenomena, like a hurricane season.

But the UCAR team doesn't have the answer yet. The team has only just begun asking the questions and designing experiments.

One thing is for certain. "Maybe this very unfortunate event is giving us the opportunity to gain an understanding of how the [climate] system responds" to sudden changes in carbon dioxide emissions, Lamarque said.

By **JoAnna Wendel** (@JoAnnaScience), Science Writer

Wildfires Trigger Long-Term Permafrost Thawing

Wildfires kick-start permafrost thawing, observations of eastern Siberia reveal. Credit: Kazuki Yanagiya

Permafrost underlies much of the far north, but this amalgam of ice and frozen soil is far from stable—it's thawing as temperatures rise worldwide. That's bad news, because permafrost is a significant repository of carbon that can be readily converted into carbon dioxide, a major greenhouse gas. Now researchers have used satellite remote sensing to monitor one signature of permafrost thawing—ground subsidence—after a wildfire in eastern Siberia. The team found that parts of Earth's surface subsided more than others despite the relative homogeneity of the fire. This variation is likely due to differences in the thickness of the insulating active layer directly above the permafrost, the scientists suggested.

Kazuki Yanagiya and Masato Furuya, both geophysicists at Hokkaido University in Japan, focused on a 3,600-hectare swath of permafrost in eastern Siberia, Russia. The region, composed of low shrubs dotted with 3- to 5-meter-tall larch trees, burned in July 2014 in a wildfire of unknown cause.

Siberia has been plagued by many blazes recently, said Roger Michaelides, a geophysicist at the Colorado School of Mines in Golden not involved in the research, and there's no sign of the fires abating. "With climate change, wildfire frequency and severity are expected to increase."

The team traced how the ground subsided in the burned region to centimeter-level precision.

Maps of Sinking Ground

The researchers used a remote sensing technique called interferometric synthetic aperture radar to generate maps of ground subsidence following the fire. Subsidence is a common outcome of thawing permafrost and can wreak havoc on built structures.

Wildfire triggered the measured subsidence but only in an indirect way, said Furuya. "The fire itself doesn't melt permafrost directly." Rather, a blaze eradicates vegetation, which reflects and absorbs sunlight. When that insulating layer is lost, the ground heats up more readily, causing permafrost to thaw.

Using microwave data collected by two satellites—Sentinel-1 and the Japanese Advanced Land Observing Satellite-2—the team traced how the ground subsided in the burned region between October 2015 and June 2019 to centimeter-level precision. This time-resolved look at how permafrost thawing proceeds after a fire is novel, said Yanagiya. "The detailed time series of deformation is very new."

A Bulkier Layer to the Rescue

Subsidence proceeded the fastest in 2015 and 2016, Yanagiya and Furuya found. That's probably because of a negative feedback loop, the authors propose: Initial permafrost thawing bulked up the active layer—the layer above permafrost that freezes and thaws seasonally—which in turn provided additional thermal insulation against further thawing.

The researchers also found that east facing slopes tended to experience the most subsidence. That's consistent with previous research and makes sense because these areas receive less intense sunlight, Yanagiya and Furuya suggested. Their active layers are therefore thinner to begin with and accordingly provide less insulation, the scientists proposed.

A New Megaslump?

In total, the fire-scarred region lost roughly 3.5 million cubic meters of permafrost, the scientists calculated. For comparison, that's about an order of magnitude less than the thawed volume of the nearby Batagaika megaslump, an enormous craterlike depression formed by thawing permafrost. In September 2019, Yanagiya and Furuya did fieldwork in Siberia and flew a drone over the Batagaika megaslump. "It's huge," said Furuya.

It's possible that the burned area they studied might one day come to look like Batagaika, the researchers hypothesized. "We are kind of expecting it," said Furuya.

These results were published in the *Journal of Geophysical Research: Earth Surface* (bit .ly/wildfire-permafrost).

By **Katherine Kornei** (@KatherineKornei), Science Writer

Restored Tropical Forests Recover Faster Than Those Left Alone

Researchers found that actively restored tropical forests, like Malaysia's Danum Valley Conservation Area, above, recovered 50% faster than those left to regenerate naturally. Credit: Gido, CC BY 2.0 (bit.ly/ccby2-0)

Actively restored forests recover aboveground biomass faster than areas left to regenerate naturally after being logged. According to a new study on tropical forests in Sabah, Malaysia, areas that have undergone active restoration recovered 50% faster, increasing from 2.9 to 4.4 metric tons of aboveground carbon per hectare per year (bit.ly/Malaysia-forests). The findings suggest that the reduction in carbon associated with a single logging event would be recovered to the same level as unlogged forest after 40 years with active restoration, as opposed to about 60 years if the forest is left to regenerate naturally.

In addition to demonstrating the value in protecting previously logged forests, the study engages with the efficacy of carbon pricing, said coauthor Mark Cutler, professor of geography and environmental science at the University of Dundee in Scotland.

Cutler explained that "the costs associated with the most intensive forms of active restoration, if to be recovered through the voluntary carbon market, require a higher carbon price than has been seen in recent times."

"However," he added, "varying the type and intensity of restoration treatments according to the residual amount of carbon in the forest stand has the potential to reduce net costs and bridge the gap to financial sustainability, thus enabling much larger areas of forest to be restored."

"The paper raises an important issue regarding the effectiveness of carbon pricing if it is to serve as a financial incentive for restoring logged forests," said Robin Chazdon, a professor emerita at the University of Connecticut and a research professor at the University of the Sunshine Coast in Queensland, Australia. Chazdon was not involved in the study. "Several other papers have also noted that high potential for carbon storage during forest restoration is not being matched by an adequate price on the voluntary carbon market."

Researchers estimated the current cost to offset 1 metric ton of carbon dioxide equivalent (CO_2e) in voluntary carbon offsetting schemes to be around \$2–\$10. Carbon prices required to fulfill the 2016 Paris Agreement (\$40–\$80 per metric ton CO_2e) would provide an economic justification for tropical forest restoration, according to the paper.

Restoring the "Most Productive Forests on Earth"

Tropical forests contain 55% of global stores of aboveground forest carbon, but stocks are declining because of forest loss and degradation.

Pierre Taillardat, a postdoctoral researcher on coastal and terrestrial wetlands at the University of Québec, Canada, explained that "tropical forest management can be an effective way to mitigate climate change considering that they are the most productive forests on Earth."

Study authors noted that protection of existing forests, even those that have been degraded or previously exploited, is paramount for retaining aboveground carbon density, as well as for maintaining biodiversity and other critical ecosystem services.

Researchers used a restoration approach called "assisted natural regeneration" at Malaysia's Ulu Segama Forest Reserve and Danum Valley Conservation Area. In this case, assisted natural regeneration involved planting tree seedlings and cutting climbing plants that compete with young trees for access to light and nutrients. The open areas created for the tree seedlings were maintained free of competing plants by cutting them back for several years after the seedlings were planted. This process gave the seedlings a head start in the race to form a new forest canopy. These restoration treatments were applied annually to different places in the study areas.

Chazdon noted that this study is an excellent application of assisted natural regeneration measures to hasten the recovery of heavily logged forests, but it considers only one dimension of forest recovery: aboveground carbon density. This dimension can be assessed through making routine measurements of tree diameter and height on the ground as well as through remote sensing and airborne approaches.

"Further experiments are needed to guide cost-effective practices," she explained. "Collecting seed and growing seedlings in nurseries and planting them out is much more expensive than merely cutting climbers."

Moreover, Chazdon said, it is "important to note that these results cannot be generalized outside of the Sabah, Malaysia, context, as the scale and intensity of logging in forests there are much greater than in other tropical regions based on selective logging with less timber removed."

By **Mohammed El-Said** (@MOHAMMED2SAID), Science Writer

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Surveying the Challenges of Fieldwork for LGBTQ+ Geoscientists

Fieldwork is often framed as central to geoscience research. What fieldwork comprises varies across geoscience disciplines and can encompass everything from wilderness treks, oceanographic cruises, and class field trips to museum and laboratory visits, trips to research centers, and attending conferences around the world. What varies just as widely, unfortunately, is how safe field research and work-related travel are to the geoscientists who must perform it.

There is increasing awareness of the hazards of sexual harassment and assault in the field-based sciences and a growing understanding that fieldwork is not always accessible for geoscientists with varying physical abilities or young families. However, there has not been a deliberate focus on challenges faced by the lesbian, gay, bisexual, transgender, and queer (LGBTQ+) community in the geosciences with respect to fieldwork.

This is not to say that interventions for other discrete groups cannot help members of the LGBTQ+ community. People are complex, and their identities intersect many realms—there are, of course, LGBTQ+ geoscientists with disabilities and those with young children. However, it is often assumed that interventions intended to help one minoritized group will help all such groups—an "a rising tide lifts all boats" approach. For instance, in the seminal study on harassment in the field [*Clancy et al.*, 2014], the authors noted that "our results cannot adequately speak to the experiences of people of color or [LGBTQ+] individuals because they are under-represented in our fields and therefore our dataset, but the experiences reported by our respondents are likely reflective of a broader climate for members of various minority groups."

There has not been a deliberate focus on challenges faced by the LGBTQ+ community in the geosciences with respect to fieldwork.

But without data, this widely held assumption cannot be assessed. One of the biggest barriers to supporting the LGBTQ+ geoscientist community is that to date, there have not been many systematic attempts to describe and understand this community. Individual geologists have shared their stories in places like 500 Queer Scientists or in the media, which is a crucial way of increasing visibility, but storytelling does not help assess the needs and challenges of the community as a whole.

This lack of information is not limited to the geosciences. Every 2 years the National Science Foundation publishes reports on the state of "women, minorities and persons with disabilities" in science and engineering but has not yet collected information on LGBTQ+ scientists. There have been some efforts to collect data about LGBTQ+ scientists in physics and chemistry, as well as across all science, technology, engineering, and mathematics (STEM) fields. One 2016 study surveyed 1,603 LGBTQA STEM professionals, including 108 geoscientists, although the data were published only in aggregate [*Yoder and Mattheis,* 2016].

First, Quantify the Community

To better understand the needs and struggles of LGBTQ+ geoscientists, we launched a survey in fall 2019 that grew out of one author's (M.R.D.) attempt earlier that year to connect with his own community. As part of a presentation to an on-campus branch of the organization Out in STEM, he tweeted an informal survey trying to understand the concerns of other LGBTQ+ paleontologists. The results revealed that many of these scientists felt unseen, unheard, and unsupported in their field. The responses to the informal survey prompted us to conduct an official survey of geoscientists, modeling ours on that of *Yoder and Mattheis* [2016]. Once we were granted permission from the human subjects board at our university, we conducted the survey online, as studies have shown that this is the best way to collect information related to identity [*McInroy,* 2016].

On the basis of 261 responses, we found that the geosciences contain a diverse LGBTQ+ community. Most participants identified as cisgender women (47%) or as transgender (an umbrella term that includes transgender man, transgender woman, nonbinary, genderqueer/genderfluid, agender, and other identifiers for people whose gender does not strictly match the gender they were assigned at birth; 31%), with 22% identifying as cisgender men. Diverse sexualities are also represented, dominated by bisexual/pansexual/queer identities (52%), followed by gay/lesbian identities (34%), and then asexual/demisexual/romantic-spectrum identities (14%).

These results also revealed that the composition of the LGBTQ+ community in the geosciences is different from that found in STEM in aggregate, as well as in physics in the United States and the United Kingdom. By comparison, there are fewer gay men and a higher proportion of women and nonbinary/genderqueer and bisexual people in the geosciences. The racial demographics of LGBTQ+ participants in our survey were similar to those of the geosciences as a whole, as 83% of the respondents were white, 8% were Asian, and 7% were Hispanic/Latinx, while the remaining 3% were Black, Native American, or Pacific Islander.

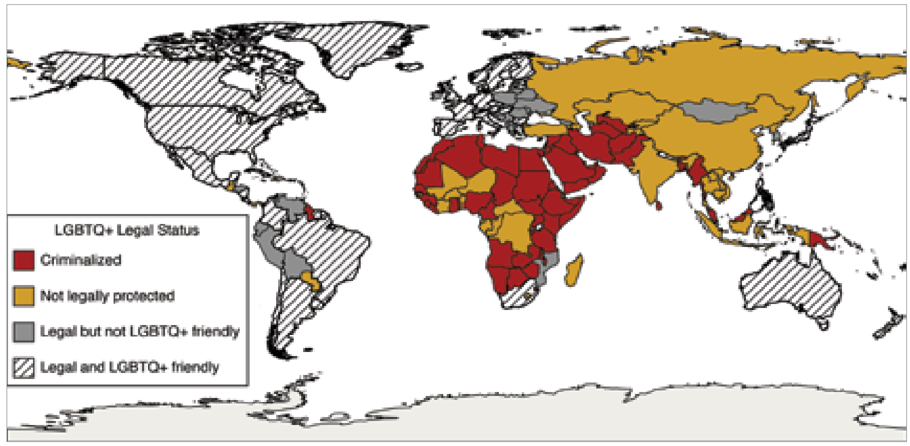

Fig. 1. This map shows areas in the world where lesbian, gay, bisexual, transgender, queer, plus (LGBTQ+) status is criminalized or not legally protected, as well as countries in which residents do not believe the country is a hospitable place for LGBTQ+ people. (Individuals in Antarctica are each covered by the laws of their own country.) Credit: Alison N. Olcott

Then Quantify the Problem

Although the survey asked about many experiences in the geosciences track, we were particularly struck by the data we collected on fieldwork and remote research. When asked about experiences with fieldwork or remote research, almost 55% of respondents indicated that they had been in an area where they did not feel safe because of their identity, expression, or presentation. Furthermore, about a third of the respondents indicated that they have refused to do fieldwork because of concerns for personal safety related to their identity. The need for these concerns becomes clear when looking at a world map highlighting where LGBTQ+ identities are not protected or are even criminalized (Figure 1). Even in places where these identities are not categorized as unlawful, the dominant culture may not be LGBTQ+ friendly.

These findings are striking, both in their scale and in how widespread they are. For instance, *Clancy et al.* [2017] conducted a methodologically similar study of astronomers and planetary scientists identifying those likely to feel unsafe in their workplaces because of gender (women, 35%; men, 1%) and race (women of color, 28%; men of color, 1.5%; white men and women, <1%). Our data show that a majority of individuals in *all* demographic groups identified by Clancy et al. who also identify as LGBTQ+ have felt unsafe with fieldwork or remote research experiences, and 34% refuse to do fieldwork over fears related to their identity. In fact, 62% of cisgender white men reported feeling unsafe in the field due to their LGBTQ+ identity; the only group that reported feeling more unsafe was cisgender women of color (75%). Cisgender women of all races and transgender people of color reported the highest rates of refusing to do fieldwork because of safety issues (50% and 46%, respectively).

Support Is Lacking for Graduate Students

Another troubling finding of our survey is that LGBTQ+ graduate students (29%) are significantly less likely than professors (57%) to have opted out of fieldwork in a specific locality because of safety fears. This is not surprising given the power imbalances present in graduate programs; a graduate student's research is often done in consultation with faculty advisers as part of a larger research agenda, which means that relative to faculty, students typically have far less control over their field site selection.

This power imbalance speaks to the need for graduate programs to develop adequate support and mentorship for LGBTQ+ graduate students, a need that is echoed in the survey responses. Most respondents (87%) reported that increased LGBTQ+ mentorship would have been helpful during their time as a student. Responses indicated that faculty support for the LGBTQ+ community was low both inside and outside the classroom, with 85% and 69% of respondents, respectively, reporting rarely or never experiencing such support. These two metrics are correlated: A student who experiences in-class support is likely also to have experienced out-of-class support.

It's clear that existing interventions to make the geosciences more inclusive are not sufficient for LGBTQ+ geoscientists.

Compounding the lack of available support, the overwhelming majority (85%) of respondents felt that other LGBTQ+ people in geology were not visible during their time as a student, presenting a challenge to them to even seek out and solicit mentorship. An even greater majority (91%) expressed that greater visibility and representation of LGBTQ+ people in geology would have been helpful during their time as a student, both in the field and at their home institution.

Using Data to Support LGBTQ+ Geoscientists

Given that almost all respondents wished for visible representation and that individuals in all demographic groups have felt unsafe doing fieldwork or remote research, it's clear that existing interventions to make the geosciences more inclusive are not sufficient for LGBTQ+ geoscientists. These findings are key for developing solutions for challenges faced by the LGBTQ+ geoscientist community.

Advisers, employers, and institutions need to be aware of safety issues associated with fieldwork and to educate themselves about

Opposite: iStock.com/helovi

potential dangers to LGBTQ+ geoscientists at field sites. However, the need for support and mentorship goes beyond the field [*Mulcahy et al.*, 2016]. In the classroom, support for LGBTQ+ students starts with professors confronting homophobia, using inclusive language, and using students' preferred pronouns. Out of the classroom, faculty and staff can engage in supportive academic advising, visible allyship, and diversity training. Such gestures may seem small but are, in fact, tremendously meaningful. LGBTQ+ students report that a crucial part of their overall success is having a mentor to whom they are comfortable disclosing their identity.

Over the past few years, the geosciences community has been trying to broaden participation by making fieldwork and conferences more accessible and welcoming. Our survey makes clear that we need to reach out further to explicitly support the LGBTQ+ community. An important place to start is with education and awareness that allow our LGBTQ+ colleagues to be safe and feel supported in the field.

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By **Alison N. Olcott** (olcott@ku.edu) and **Matthew R. Downen,** University of Kansas, Lawrence

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

STEM Learning Ecosystems Engage Communities in the Geosciences

Students participate in an outdoor geoscience class. Credit: Donna Charlevoix (UNAVCO), CC BY-NC-SA 3.0 (bit.ly/ccbyncsa3-0)

Geoscience expertise is required to solve societal problems like seismic hazards, coastal erosion, and ensuring adequate clean water supplies. These problems, which are often local in scale and impact, are most likely to be solved when the sources of geoscience expertise consulted are also local (and thus highly invested in finding solutions) and when they work collaboratively with the community. An example of science-community collaboration was demonstrated in September 2013, when Denver, Colo.–area geoscientists responded quickly to community concerns about nearby flash flooding. The scientists assessed flood effects on the landscape, soils, and water and air quality and communicated critical information to the public.

Geoscientists tend to be concentrated in regions rich in natural resources and geologic hazards. However, areas outside these regions are still faced with numerous environmental and natural resource–related challenges, which will likely persist without local geoscience expertise and community awareness. As communities work to become more resilient and sustainable, they need access to place-based education that's unique to the local people, cultures, landscapes, and ecology [*Apple et al.*, 2014].

One way to achieve sustainable local solutions is to invest in community geoscience education that integrates science, technology, engineering, and mathematics (STEM). Collaborations that adopt this approach, known as Geo-STEM learning ecosystems, involve partnerships among diverse organizations throughout a community—from K–12 schools and higher education institutions to museums, local businesses, and government organizations—that join together to address a local issue and to engage more young people in the geosciences. Any community can create Geo-STEM learning ecosystems to cultivate community literacy and motivate sustainable and transformative solutions. More such programs are certainly needed. Maybe your community can build the next one.

A History of STEM Learning Ecosystems

In a seminal 2014 report, Kathleen Traphagen and Saskia Traill defined STEM learning ecosystems (Figure 1) and emphasized that developing these systemic collaborations requires buy-in from a variety of community organizations [*Traphagen and Traill*, 2014]. That same year, the National Academies held a convocation on building learning ecosystems at which participants explored challenges and developed recommendations. In December 2018, the National Science and Technology Council's Committee on STEM Education issued a 5-year strategic plan that charged government agencies with fostering STEM learning ecosystems to unite communities around STEM education.

Several examples of STEM learning ecosystems have demonstrated success by engaging and educating people of all ages about new innovations and garnering sustained community support. The most recognized of these are the Burroughs Wellcome's STEM Learning Ecosystems Communities of Practice (STEMCoP), which consist of 89 ongoing and sustainable projects around the world that teach young people STEM-related ways of thinking, content, and skills. STEMCoP encourages K–12 students' interest in STEM fields, especially within the health sciences, computer technology, and robotics. Few of the STEMCoP efforts involve students in place-based investigations of local ecosystems, however, and none emphasizes the geosciences.

Geo-STEM Takes Off

More recently, three programs that foster geoscience-focused STEM learning ecosystems have emerged. As of the time of this writing, AGU's Thriving Earth Exchange has facilitated 153 place-based collaborations globally, with approximately 20 new projects beginning soon. In these collaborations, scientists, community leaders, and sponsors work together—typically without the same explicit focus on students that STEMCoP has—to solve local challenges related to climate change, water quality and availability, natural hazards, natural resources, ecological systems, and healthy communities. To date, 10 of the existing and many of the new collaborations have specific educational components that either created materials for local schools or engaged K–12 students in geoscience-related investigations and problem solving.

Another program, Educational Partnerships for Innovation in Communities–Network (EPIC-N), connects undergraduate and graduate students with local community leaders to investigate and develop sustainable solutions and to improve community well-being through urban planning. Projects address traffic and mass transit, homelessness, waste management, and gentrification. Students engage in service learning and conduct research through place-based projects that elevate geoscience concepts related to water quality, erosion, and land use. Of the 29 EPIC-N programs to date, only two addressed community education explicitly, and these have concluded.

EarthConnections and the Supporting Emerging Aquatic Scientists (SEAS) Islands Alliance are two STEM learning ecosystems that have been supported by the National Science Foundation's (NSF) INCLUDES (Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science) program. EarthConnections, a 2016 INCLUDES pilot project, created 11 alliances that supported the development of pathways by which precollege students can access geoscience learning opportunities. Each alliance engaged multiple parts of a community and helped participants explore career tracks by addressing local geoscience-related challenges. EarthConnections is currently seeking support to sustain ongoing activities.

The SEAS Islands Alliance establishes community networks focused on coastal geosciences in U.S. and affiliated island jurisdictions, including in the U.S. Virgin Islands, where the SEAS Your Tomorrow program "fosters curiosity, instills stewardship, and forges and strengthens educational pathways for Virgin Island youth to explore and secure careers in marine science" through culturally relevant, place-based learning opportunities, according to the program's website. Funding from various NSF programs—INCLUDES, EPSCoR (Established Program to Stimulate Competitive Research), and HBCU-UP (Historically Black Colleges and Universities–Undergraduate Program)—enables professional societies, formal and informal education entities, local governmental and nongovernmental organizations, and universities and colleges on the islands and in the mainland United States to collaborate to achieve social change around geoscience problems.

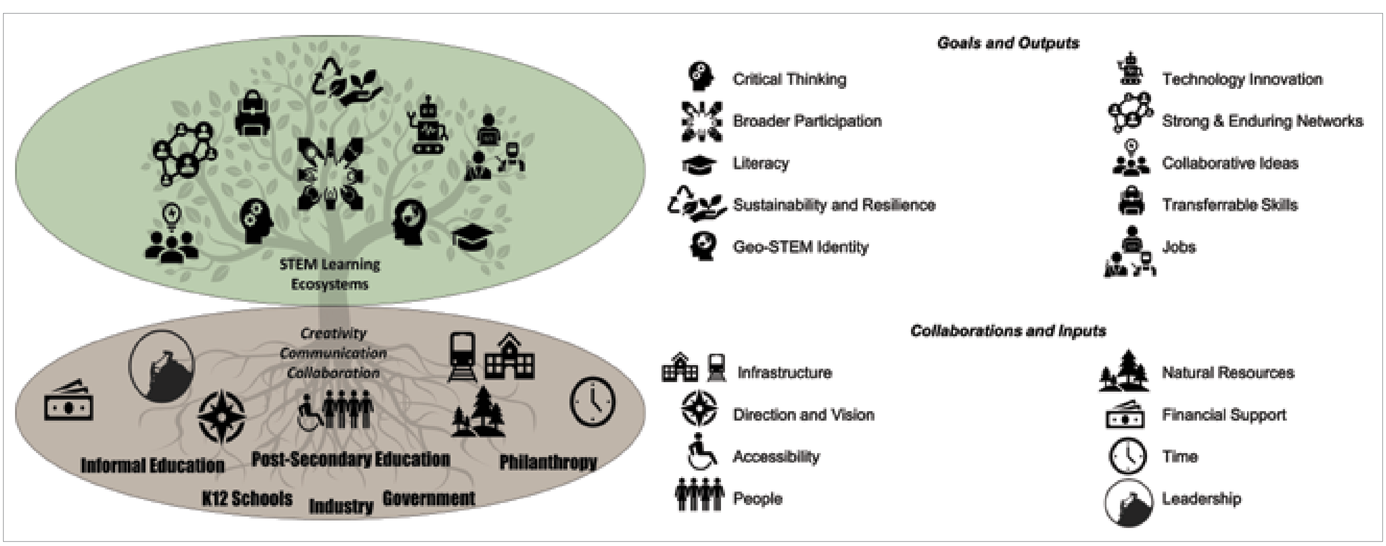

Fig. 1. This conceptual model of science, technology, engineering, and mathematics (STEM) learning ecosystems shows how community organizations develop systemic collaborations that engage learners from all walks of life, facilitate enduring and effective STEM learning opportunities, elevate community literacy and innovation, improve networks, and activate sustainable and transformative solutions for the broader community.

Of the projects noted above, 112 function as STEM learning ecosystems; 73% of these encourage and facilitate STEM learning in urban communities, with 69% engaging youth from urban communities that have been traditionally underrepresented. The concentration of learning ecosystems in urban communities is to be expected, as the ecosystems are often associated with urban colleges, universities, and organizations like museums that provide out-of-school learning opportunities. Of the urban STEM learning ecosystems that engage precollege learners, however, only eight programs currently address any geoscience concepts.

Thirty-four percent of the 112 STEM learning ecosystems address the needs of rural communities, with a handful of these ecosystems having a specific objective to address the needs of Indigenous learners. Within this 34%, only Thriving Earth Exchange, EarthConnections, and SEAS learning ecosystems have addressed geoscience content areas specifically. Learners in rural and remote communities would benefit from stronger connections to Geo-STEM learning ecosystems because these communities are heavily affected by issues of water quality and availability, soil health and erosion, climate change, natural resource extraction, and food security.

Opportunities for New Geo-STEM Learning Ecosystems

Creating Geo-STEM learning ecosystems that address the needs of different communities presents both challenges and opportunities. There is no one right way to set up a Geo-STEM learning ecosystem because each one is unique to its location, engaged partners, and target audience. Sustainable programs will require strong and flexible organizations, sound infrastructure, dedicated personnel, and long-term funding. Should individuals or organizations wish to cultivate a Geo-STEM learning ecosystem, here are some suggested steps.

First, find a credible and engaged lead organization, such as a museum or outreach center, that is committed to collaborating with schools, educational organizations, academic institutions, industry, utilities, local governments, and other nontraditional partners. These diverse partnering organizations should reflect community demographics and demonstrate respect for each other's expertise.

Next, identify and reach out to potential partners. (Don't worry if the list is long to start; that just means you have a lot of options.) Once you have narrowed the list of collaborators, work with them to identify goals that maximize learning opportunities for the target audience—such as engaging learners to understand local seismicity, coastal erosion, or pollution—and to create accessible, robust, and connected learning experiences for the audience. Examples of such learning experiences include multistage bridge programs that help middle and high school students see themselves as geoscientists, encourage undergraduates to participate in research, and facilitate postgraduate professional opportunities.

Then you'll need to secure funding to meet your goals—it is likely you will need start-up funding and sustained long-term funding. In addition to the INCLUDES program, another potential route to secure start-up funding is through NSF's Improving Undergraduate STEM Education GEOPAths (Pathways into the Earth, Ocean, Polar and Atmospheric & Geospace Sciences) program. The goal of GEOPAths is to increase the number of students pursuing undergraduate and postgraduate geoscience degrees by promoting the design and testing of novel approaches that engage students in authentic, career-relevant experiences. Multiple GEOPAths funding tracks support geoscience learning for broad audiences in informal settings (e.g., museums, nature centers) and for undergraduates and graduate students in academic settings.

Giving students intriguing and relevant local geoscience problems to solve is an effective way to cultivate their interest and create a sense of belonging.

Each Geo-STEM learning ecosystem will have its own unique goals, but the overarching goal should be to engage more young people in the geosciences and promote geoscience literacy for generations to come. Unlike more general STEM learning ecosystems in which students build robots or do cool science experiments, these Geo-STEM ecosystems focus young people on solving local geoscience issues related to water quality, pollution, soil erosion, natural resource management, and hazard mitigation—all issues that pose significant ongoing challenges for many communities and can engage young people with their local natural landscapes and with their neighbors.

For geoscientists, these programs are both self-serving and altruistic. To diversify the geoscience community and expand our scientific capabilities, we can attract young people who might not otherwise have seriously considered geoscience careers. Giving students intriguing and relevant local geoscience problems to solve is an effective way to cultivate their interest and create a sense of belonging. Ultimately, however, these programs educate and serve local communities by addressing local problems.

Creating New Pathways to Geoscience

Geo-STEM learning ecosystems offer researchers, professionals, and educators opportunities to broaden geoscience participation by activating local formal and informal education networks, supporting K–12 Earth system science learning, and building a strongly skilled local workforce. Geoscientists in all domains can work together to help frame community needs, to collaborate with educational providers to reach K–12 audiences directly, and to host professional learning opportunities for teachers.

The greatest opportunities lie in developing these ecosystems to include K–12 education in urban, rural, and Indigenous communities. Successful existing STEM learning ecosystems suggest that Geo-STEM learning ecosystems are worth serious investment and have considerable potential to capture students' imaginations and motivate them to develop the skills needed to identify and solve a host of geoscience-related problems affecting communities around the world.

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

Perspectives on Parenting While Researching (During a Pandemic)

An attendee at AGU's Fall Meeting 2015 spends time with his son at an interactive exhibit during the conference. Credit: Karna Kurata

The Centennial gathering of AGU last year was significant in the milestone it represented for the organization and members and because it was the first Fall Meeting at which the challenges of parenthood within academia were formally raised. At a moderated session, four invited panelists shared stories of obstacles they had confronted and how their experiences shaped their career paths and their families.

Relative to other professional societies, AGU has been an early advocate and adopter of family-friendly accommodations at its meetings, including offering subsidized childcare. The parental-professional trapeze act does not start on the Monday morning of Fall Meeting, however, nor does it end after the Friday evening poster session. For decades, what academics could talk about in the workplace did not include the substantial personal challenges associated with balancing a demanding career in academia and research with parenthood. Thankfully, that's changing, and conversations about managing parenthood and academic research careers have never been so vigorous.

The COVID-19 pandemic has made these conversations only more urgent. The necessary fusion of our professional and personal lives—which has been catastrophic for some and highly challenging for nearly all—has clarified how inescapable these issues are. We do not know when or how these conditions will end, and we cannot yet know the lasting impacts this extraordinary time will have on our lives.

Below, the panelists from the Fall Meeting discussion reflect on how our present era emphasizes the need for open and honest conversations within AGU and the academic community. Through open discussion, we join in the cathartic exercise of sharing experiences and learning from our respective journeys, and by combining such dialogue with purposeful action and empathy, we can effect meaningful structural and cultural change.

We've Had This Conversation Before

***Tanya Furman**, Professor of geosciences, Pennsylvania State University, University Park; and president-elect, Education section, AGU*

***Children:** age 25*

***Current situation:** Working full-time at home indefinitely*

This is a particularly interesting time for dialogue about structural and cultural influences on the timing of child-rearing among scientific professionals in the United States. The novel coronavirus has brought the challenging realities of balancing work and personal life to the fore in households and workplaces where such issues were not even topics of conversation a few months earlier.

But the challenges of parenting and working simultaneously have always existed. When I asked my female colleagues for their thoughts on the topic prior to the Fall Meeting panel discussion, they uniformly rolled their eyes and sadly shook their heads. We know. The reality is that if we want our children to be advocates for learning and to be empathic, curious, and joyful, it takes time and effort from us—a lot of time and a lot of effort that would otherwise be spent on career.

Roughly 20 years ago, a pregnant colleague was reassured by her department head that he could secure her the requested extra year for her tenure clock from their university: "I'll say you got a slow start on your research. We won't even need to mention the baby!"

Fortunately, most academic institutional policies have evolved since the times when an academic's family was generally dismissed as, at best, a weekend activity and, at worst, an impediment to career growth. For example, family leave and tenure process extensions are becoming standard benefits, and these policies are percolating down into training and early-career positions. However, cultural change—in academia as in society—usually occurs slowly, and undercurrents of disbelief, resentment, and unrealistic expectations remain pervasive.

It is time to bust the myth that maternity leave (or other family caregiving) is a secret opportunity to conduct research free of the demands of teaching and to recognize it for what it is: selfless emotional work that benefits personal, family, and societal well-being. Likewise, it is important to recognize that working full-time at home while caring full-time for small children is just not possible. Something has to give. And there's the rub: Someone—indeed, many someones—must raise the next generation. That is our job and our joy as parents, but we still don't talk about it openly. The AGU session was an attempt to start this conversation; sustaining it is our collective responsibility.

The Balancing—and Rebalancing—Act

***Amy Clement**, Professor of atmospheric science at Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Fla.*

***Children:** ages 16 and 12*

***Current situation:** Worked full-time at home from March through July; began teaching in person in August; spouse working full-time at home; children are largely self-sufficient*

When I first read Anne-Marie Slaughter's 2012 *Atlantic* article "Why women still can't have it all," my boys were 5 and 9 years old and more or less independent (i.e., the probability of spontaneous home combustion was decreasing). As they grew and matured, I felt more energy to put back into work. But Slaughter's article reminded me that the career-parenting arc is not a linear progression toward freedom (*Hallelujah!*), in which time spent on family during the burning-down-the-house years is miraculously returned when toddlers become teenagers, and becomes available for new professional challenges and opportunities.

I have since realized that the more complex needs of a teenager require my husband's and my attention in new ways, and things like sitting down together around the dinner table are even more critical now. Career opportunities that would take me out of the house on weeknights or on extensive travel just have to wait—these are choices every parent must make at times.

COVID-19 has changed the conversation. As I write this, I am quarantining at home with my family, watching the parenting arc playing out within my living room. Early in the COVID-19 era, I was struck with a feeling familiar from my early days of parenting: exhaustion and inadequacy on all fronts (teaching, research, and family). As we have settled into our new routine, in which we are each tucked away in four corners of the house and rejoin each other at the end of the day for bike rides or jogs or walks, my husband and I are faced with the challenge of dealing with problems for which none of us has answers.

There is more than one correct way to raise a child; and I believe that the roles of parents in shaping children for success can be overstated. With that in mind, I think we can all put less pressure on ourselves to find a perfect equilibrium between our personal and professional lives. Just like a career, parenthood is a marathon, and the balance you achieve at one time will necessarily have to be rebalanced in the future as both domains of your life evolve.

My experience having children during my academic training involved bringing my infant to conferences across the country, pumping between classes and seminars, and squeezing work into the margins.

A Need for Knowledge

***Ni Sun-Suslow**, Postdoctoral fellow in clinical neuropsychology, Department of Psychiatry, University of California, San Diego*

***Children:** ages 4, 2, and pregnant with third*

***Current situation:** Working full-time at home (90% clinical research, 10% seeing patients virtually); spouse also working full-time at home; attempting to balance childcare and virtual school with husband and nanny*

When I was a graduate student, I googled: "When is the best time to have children in academia?" The search results were full of opinion articles and advice columns. Although it was reassuring to see I was not alone in pondering the topic, there were few empirical data sets, especially within the science, technology, engineering, and mathematics (STEM) fields, to shed light on the subject. I was left wondering, At what age do most academics have children? Do people even want to have children? How many people leave or stay in academia after having children?

After seeking advice from a number of women faculty-parents, I learned that women who had children early in their training often did not regret their decision, and some of those who had children later felt they could have had them earlier. This was all anecdotal, but because being a mom was a high life priority for me, David and I got pregnant in my third year of graduate school. I worked on my degree through two pregnancies and was very pregnant during both my qualifying exam and my dissertation defense. My experience having children during my academic training was similar, I imagine, to having children anytime during an academic career. It involved bringing my infant to conferences across the country, pumping between classes and seminars, and squeezing work into the margins: during naps and after bedtime.

Prior to COVID-19, David and I worked full-time outside our home and paid for full-time preschool. Six months into the COVID-19 era, we are still trying to find a rhythm amid so many uncertainties. Early in the pandemic, we took childcare shifts—and were lucky if we each were able to work half-time. We could write emails and address administrative tasks, but focused writing was nearly impossible. As we quickly found this unsustainable, we sought help from grandparents for a few months, which allowed us to increase our productivity to 75%, though it came at the expense of substantial physical strain on our aging parents. In July, our desperation for childcare outweighed our "infection guilt" over opening our home to someone else, and we were fortunate to be able to hire a nanny.

Now that the school year has begun, we are faced with a host of new challenges—attempting virtual transitional kindergarten with a 4-year-old and assessing the risks and benefits of possible in-person instruction, for example—all the while attempting the impossible task of being 100% productive with our own careers.

In November 2019, David and I received support from AGU to release a survey assessing AGU members' perspectives on parenthood during academic training. About 1.4% of AGU's membership (726 individuals) participated in our study, with respondents equally distributed between those in training and those who had completed training. About half (48%) reported having at least one child, revealing that this topic is important to many AGU members, with or without children, throughout their career trajectories. These data will help academic and research institutions make informed and evidence-based policy decisions and will also help transition conversations about parenting and research out of the margins and into open forums.

Motherhood and my career are both at the top of my priority list; at times, each must give ground to make space for the other. Although this can seem impossible at times, I am grateful I pursued both simultaneously and that I started early. Now that I am finishing my training, I am finding that the flexibility I enjoyed during my training years, which was so helpful when I was a new parent, has been gradually dissipating as I accumulate more critical professional responsibilities. But my experience has shown me that it is possible both to raise well-adjusted children during academic training and to train successfully. Of course, this was my own experience, which reemphasizes the need to collect empirical data.

Stress on a System Reveals Tension

***Henry Potter,** Assistant professor of oceanography, Texas A&M University, College Station*
***Children:** ages 3 and 1*
***Current situation:** Working full-time at home; spouse also working full-time at home; no childcare*

With two young children and being one of two full-time working parents at home during the pandemic, I find about 25 hours per week for my job as an assistant professor. I squeeze in a few hours of work after my children's bedtime or sacrifice a few hours of sleep to stay afloat, yet papers and proposals remain unwritten. In the latter half of the semester this past spring, when classes were in session remotely, I barely had enough time to finish my daily duties in teaching, grading, emails, and meetings—much of which does not advantage my tenure review.

Over the summer, I didn't teach, but my productivity remained disappointing. I still sacrifice my evenings and weekends, splitting the workweek with my spouse, and being frequently interrupted means papers and proposals stay on the to-do pile. I am fortunate that my university allowed me to pause my tenure clock this year, but I still feel I am lagging my nonparent peers. Routinely stuffing work into the margins just to keep up is the norm of parenting as an academic, an already difficult scenario that has been significantly exacerbated by the pandemic.

The COVID-19 era has uncovered the stark contrasts between the realities of nonparents and parents in academic research environments (and elsewhere). When a parent misses work to care for a dependent, career-building activities are inevitably sacrificed for insistent daily responsibilities. This situation engenders perceptions of a lack of productivity that have a detrimental impact on long-term career growth and success by affecting competitiveness for advancement, job opportunities, and funding.

Early evidence suggests that COVID-related disruptions, especially to pre-K–12 school programs, will have substantial impacts on the career trajectories of academics with children as compared with colleagues who are not parents. These impacts are already being felt disproportionately by women [*Staniscuaski et al.*, 2020], and time will reveal the lasting effects of the COVID era on the demographics of academia for years, or possibly decades, to come.

Although academics willingly accept added responsibilities when becoming parents, the strain is no less significant when individuals silently navigate these challenges. Perhaps the shared challenges and experiences of the pandemic can motivate academics to unmute this topic. We are in a narrow window of time in which the difficult balance between careers and caregiving, and unavoidable professional hiccups and productivity declines, are on the minds of many people and are affecting every professional sector. And yet we know that tensions between parenthood and professional domains will not be inoculated by a SARS-CoV-2 vaccine. For now, though, I'd like to have the time and mental energy to work on submitting my NASA proposal for the fast approaching deadline, and like everyone else, I hope to just "get through this."

Early evidence suggests that COVID-related disruptions will have substantial impacts on the career trajectories of zacademics with children as compared with colleagues who are not parents.

Looking Forward

With the tumult and anxiety of 2020, conversations of how to manage parenthood simultaneously with academic or research careers are moving closer to the professional and cultural zeitgeist. Yes, this conversation is not new, but the disruptions wrought by the pandemic have thrown the parenting and research balance into a new—and harsher—light. Although some have found a semblance of equilibrium, the persistent strain caused by the impossible duality of being a full-time worker and a full-time child caregiver is taking a heavy toll on others. Donning rose-colored glasses in an attempt to obscure our discomfort with this COVID era is not helpful or adaptable. For now, it is completely acceptable to hold on to hope *and* to acknowledge that this era of COVID-19 is fundamentally, and negatively, affecting many of us, including parent-academics; and it may continue for a long time. The full ramifications on our lives and the academic community are yet unknown. Enduring the present and mitigating long-term impacts of this pandemic will require empathy and our communal effort to maintain open and *meaningful* dialogue, even after the "new normal" returns to the "old normal."

Acknowledgments

We thank AGU for its support of the Fall Meeting 2019 session and for encouraging this dialogue. D.O.-S. and N.S.-S. specifically thank AGU for its support of the Parenthood in Academic Research Environments during Training (PARENT) survey project. We are all deeply thankful and appreciative of our families' love and support throughout our respective careers and, most important, for their patience.

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

Ten Steps to Protect BIPOC Scholars in the Field

Mammoth Hot Springs at Yellowstone National Park. Credit: Hendratta Ali

The geosciences are not diverse. Discussions attempting to address this lack of diversity often center around voyeuristic accounts of traumatic experiences, which, although accurate, have clearly not caused the needed institutional change for diversity to take root. Rather than relive our trauma, we, as Black geoscientists, want to equip the community with actionable steps to create accepting and supportive spaces for BIPOC (Black, Indigenous, and People of Color) students. Specifically, we'll address one area in which geoscience institutions have failed underrepresented students: fieldwork safety.

Fieldwork has long been core to the identity of the geoscience community. That impression reigns despite the fact that most geoscience work happens away from the field, in laboratories and offices. Yet fieldwork still underpins geoscience curricula at undergraduate and graduate levels; it is frequently viewed not only as a necessary rite of passage but also as a prerequisite for employment. Geoscientists who lack field experience may be at a competitive disadvantage when applying for jobs or promotions.

For BIPOC students, fieldwork continues to be a barrier. Studies on this topic have shown that some BIPOC students are born and raised in urban areas and may come from families that lack the financial ability to take extended outdoor trips. Therefore, by the time they join their white peers to study geoscience in undergraduate programs, BIPOC students lack equivalent exposure to the types of environments in which fieldwork takes place. These factors make it hard for BIPOC scholars new to the geosciences to fully participate in and enjoy field camp or other field-based research and educational outings.

Once they do begin to participate in fieldwork, BIPOC students often face racism and prejudice in these outdoor spaces. Fieldwork usually happens in remote, nonurban, racially homogeneous places—places that can be dangerous to minoritized students, who may face hostility, distrust, and disrespect.

The Need for a Culture Shift

Negative field experiences are common for BIPOC scholars. One might argue that it is not the job of institutions to protect students from the world, but this mindset can result in the inadvertent exclusion of BIPOC students who feel they must remove themselves from potentially dangerous situations.

An attitude that BIPOC students' problems are not the research team's problems also discourages the types of planning that can foster a safe environment for *everyone* when practicing fieldwork. A proactive strategy would consider protection from racial discrimination and racialized violence with at least the same diligence carried out to protect students from ticks, falls, or snakebites. Many institutions already have good on-campus policies but often do not extend or enforce those policies during activities taking place off campus.

Risk assessment is an integral part of geoscience fieldwork. It is imperative that these assessments include race-related risks associated with field trips. The racism and other forms of discrimination experienced by BIPOC students in the field are exacerbated because these spaces are outside of the campus environment, sometimes in a community of people who may or may not have had prior interactions with minoritized students. The only experience that white people in these communities may sometimes have had with BIPOC students is through the media, where, often, a negative story of the BIPOC community is presented.

For inclusion to take root in the geosciences, institutions must actively listen and take substantive steps to protect BIPOC scholars from harm in the field. On our campuses, white faculty and staff can use their privilege to minimize the chances of racist and other discriminatory actions toward the BIPOC students on their teams. Here are our recommendations:

We, as Black geoscientists, want to equip the community with actionable steps to create accepting and supportive spaces for BIPOC students.

1. Institutions that run field programs should have a *mandatory racial risk assessment* requirement as part of pretravel protocols. This assessment requires faculty to consider the experiences of their BIPOC students.

2. To perform those assessments appropriately, faculty should take *antidiscrimination training* to help them identify and learn ways to address potential discriminatory attitudes (nonverbal, verbal, and physical threats) that BIPOC students experience in

field locations. For example, faculty can create and have plans in place to de-escalate racial tension and protect students from violence.

3. Before traveling, faculty should lead collaborative discussions to identify discriminatory or race-related incidents with team members that could occur in the field and then *encourage bystander interventions.*

4. Before field trips, team leaders should *reach out* to local authorities, businesses, and community leaders, especially in white communities, to provide early notice of the diverse nature of their teams.

5. Institutions should *identify and share cultural norms,* expectations, jargon, policies, and rules practiced in field communities that may be unfamiliar to the fieldwork team.

6. Institutions should provide *allyship training* to educate and empower non-BIPOC members of the team. BIPOC students could be paired with white field allies. These partnerships would help build trust within field parties, as well as help interactions with local communities.

7. Team leaders should interrogate and *identify blind spots* in team members from the majority racial group. Self-awareness of one's own privilege can be a good impetus to becoming a strong ally.

8. Team leaders should be present in the field to *introduce all of their team members* to the host community and other stakeholders.

9. Team leaders should *document hostile encounters* that team members face during field visits regardless of severity. This accounting is particularly important to address microaggressions faced by BIPOC individuals. Microaggressions, which routinely go unacknowledged or are minimized, wear down morale over time and have adverse impacts on mental health. For students, this impact can lead to their eventual exit from the geosciences.

10. Team leaders should *address incidents of discrimination when they happen.* Team members should practice and use the 5D strategy for bystander interventions: direct, distract, delegate, delay, document (see bit.ly/5D-strategy). The team should have a plan to exit dangerous scenes or to relocate the field party to a place of safety if other strategies fail.

A Field for All

When students and scholars feel that their experiences and concerns are considered valid, they are more likely to speak with faculty or team leaders as issues arise. This discourse, in turn, fosters a sense of belonging. Without this sense of belonging, BIPOC students and scholars internalize negative experiences and risk further traumas that drive them from the geosciences and STEM (science, technology, engineering, and mathematics) fields in general.

There has been a growing recognition of the unacceptable state of inequity, lack of diversity, and challenges with the inclusion of people from minoritized groups in the geosciences. This article centers the experiences of BIPOC students in outdoor field spaces, but we must acknowledge that the lack of equity in field access is a much bigger issue in the geosciences. Access to fieldwork and field trips has traditionally been designed for able-bodied, cisgender individuals within the geosciences who have, in Western communities, historically been white men. And globally, able-bodied cisgender men are still the primary group for whom field access is planned. We need the geoscience community to create outdoor experiences that are welcoming to everyone, including people with disabilities, LGBTQ+ people, and women.

This article centers the experiences of BIPOC students in outdoor field spaces, but we must acknowledge that the lack of equity in field access is a much bigger issue in the geosciences.

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▶ Read the article at bit.ly/Eos-BIPOC-scholars

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MENTORSHIP AT A DISTANCE

Three geoscience programs offer case studies on how to form meaningful connections during a time of social distancing.

By Richard J. Sima

With the COVID pandemic limiting academic opportunities at sea and in the field, mentors and mentees are getting onboard with virtual strategies. Credit: Ocean Networks Canada; IconFlat/Depositphotos.com (laptop graphic)

The summer of 2020 was supposed to be one of exploration, discovery, and mentorship for students in the geosciences.

But then the pandemic happened.

Laboratories shuttered their doors; research vessels stayed docked.

Many of the mentorship programs to which students applied are now navigating the still-uncharted waters of the “new normal” and working to provide quality, albeit remote, mentorship.

STEMSEAS—short for Science, Technology, Engineering and Math Student Experiences Aboard Ships—is one such program.

Run out of the Lamont-Doherty Earth Observatory at Columbia University, the National Science Foundation–funded initiative has been a gateway for more than 125 students to experience ocean science up close every summer since 2016. In a normal year, STEMSEAS gives undergraduates the opportunity to spend 6–10 days aboard a U.S. Academic Research Fleet research vessel with experienced faculty mentors as the ship makes transits between expeditions.

“Going to sea is really quite life changing the first time one goes, I think regardless of your stage in life,” said Jon Lewis, a professor of geoscience at Indiana University of Pennsylvania and co-principal investigator of STEMSEAS. “It is very powerful.”

> “IT TOOK US ACTUALLY UNTIL A COUPLE OF WEEKS AGO TO FINALLY ADMIT DEFEAT, THAT WE WEREN’T GOING TO BE ABLE TO DO THIS.”

Of course, 2020 has not been a normal year.

“It took us actually until a couple of weeks ago to finally admit defeat, that we weren’t going to be able to do this,” said Sharon Cooper, a senior staff associate at Lamont and STEMSEAS co-principal investigator, in July. “We want to go to sea! We’re kicking and screaming.”

Ashley Smith, a biology major from Rensselaer Polytechnic Institute, pipettes dye for gel electrophoresis during the 2019 BIOS REU program. Credit: BIOS

“These are unique times, and we really should just step up and try to keep maintaining engagement and get people excited,” said Lewis, who, with Cooper, originally sketched out the concept of STEMSEAS over coffee. “The irony is, the entire project is based on something that is truly a sui generis experience. It’s really [such] a one-of-a-kind, transformative experience that you virtually can’t do it virtually.”

Though the onboard experience cannot be replicated, Lewis and Cooper are building out the mentorship aspect of STEMSEAS and working to connect their students to resources, opportunities, and mentors virtually.

Other programs are in a similar boat.

The Nautilus Live science and engineering internship program of the Ocean Exploration Trust also did not go to sea. Program leaders decided to defer all would-be participants for the ship-based program to next year and instead provide opportunities to participate virtually from shore.

“It’s such a hard decision because we know how important and how timely these experiences can be in the career track of students,” said Megan Cook, manager of Education Partnerships and Programs at the Ocean Exploration Trust. “That’s the thing really in our hearts and minds.”

Many of the GEO Research Experiences for Undergraduates (REU) programs, usually hosted by laboratories at different research institutes throughout the United States, were either canceled or moved to virtual research internships and professional development workshops in 2020. This pivot, forced by social distancing concerns, affected student engagement in geoscience education and career preparation. Regardless, it was apparent that “the students were very hungry for something,” said Valerie Sloan, director of the GEO REU network and an internship specialist at the National Center for Atmospheric Research.

These three programs—STEMSEAS, Nautilus, and GEO REU—may serve as case studies for creating remote mentoring networks that can still develop meaningful connections and professional development for students in a time of social distancing.

Serendipity and Intentional Mentoring

As an undergraduate student at Iowa State University, Chanel Vidal took part in the 2018 STEMSEAS cruise on the R/V *Endeavor* as it sailed from Rhode Island to Barbados.

With Vidal hailing from landlocked Iowa, the program was life changing in more ways than one. “It was the best experience I had in college. The idea of being able to just go to sea for a week and only see ocean was mind-blowing,” she said. “It’s not something that I ever thought that I would be able to do.”

Interacting with professors, graduate students, and other mentees while working on her research project shifted Vidal’s academic trajectory by showing her how interdisciplinary ocean sciences research worked and that it was something she herself could do.

“[STEMSEAS] definitely formed what I want to study for the rest of my life,” Vidal said. “I had interest in it [before], but they helped me prove to myself that it’s realistic and I can do it and it’s possible.”

The relationships she formed are still strong and influential years later; she still keeps in touch with her cohort and mentors. “The teamwork and the relationships and just the beauty of it all were so memorable and have resonated with me even though I’ve

Research Experiences for Undergraduates (REU) programs, such as this one at the Incorporated Research Institutions for Seismology (IRIS), provide opportunities for students to physically experience what it's like to conduct research. Credit: Michael Hubenthal of IRIS

been in landlocked Iowa for 2 more years," said Vidal. "I still think about it every day."

One of her project mentors, Joseph Montoya, a professor of biological sciences at the Georgia Institute of Technology, recently helped with Vidal's application to the Nautilus internship program.

Montoya is an example of a chance mentor brought on board by the program: He was on the ship in preparation for a follow-on expedition and not originally part of STEMSEAS. Today he has become one the program's biggest contributors.

That happenstance is the beauty of the program, said Cooper. "We like to work with anybody else who might be on the transit."

These kinds of serendipitous connections may be one of the more challenging aspects to emulate in a remote program.

"The difference between mentoring and just supervision is that you're helping [students] to talk about their professional goals," said GEO REU's Sloan.

The goal of the GEO REU program is to give students experience doing geosciences research for 6–10 weeks during the summer so they understand how science works and whether it appeals to them, said Sloan. "And the things that distinguish REU programs from, let's just say, being a student assistant in a lab would be that in an REU program, you have intentional mentoring" and professional development, both of which are particularly important for students from historically underrepresented backgrounds.

This means, in part, nurturing an environment for informal mentoring stemming from spontaneous interactions in the cafeteria to introductions to faculty or invitations to lab meetings.

In a typical year, approximately 65 GEO REU sites would provide 800 students with hands-on research experiences and mentorship. Moving programs online this year made introducing students to people more difficult by far, Sloan said.

To help bridge the gap this past summer, Sloan developed the 2020 National Science Foundation Ocean Sciences REU, a virtual professional development workshop series, to bring together 45 undergraduates hosted by different REU programs around the United States in weekly Zoom meetings with faculty facilitators on a variety of topics ranging from career exploration to research ethics to resumé building.

Before the workshops began, Sloan held more intimate sessions with four students at a time to get to know them. "It was small enough that I felt like I was connecting with them, and I hope they felt that as well," she said.

Pivoting and Finding the Silver Linings

There are physical limits to the number of people who can fit on a ship or in a research lab. But mentorship and programming this year are not subject to such physical constraints, which may be an opportunity: Though the virtual programs may have less depth of impact, they could have considerably more reach.

As part of an REU program, Chanel Vidal (left) helps build a flex cam aboard the R/V Endeavor. *Credit: Chanel Vidal*

Rebecca Ju, an environmental studies major from Yale University, participates in the 2018 Bermuda Institute of Ocean Sciences (BIOS) REU program. Credit: BIOS

"A major challenge was the frameshift for us to recognize that if you can't go to sea, you shouldn't just assume we can't do anything," said Lewis of STEMSEAS. "And I think once we got over that, [we] said what we really need to do is meet the moment and pivot and figure out a way to connect."

Normally, STEMSEAS receives several hundred applicants each year, and only 40 students can sail. This year, those applicants who would not have had an opportunity to participate could stay engaged, Lewis said. "So that's kind of a plus. We're going to reach more people in a very different way than we would have normally, so it's a little bit of a silver lining."

"WE'RE GOING TO REACH MORE PEOPLE IN A VERY DIFFERENT WAY THAN WE WOULD HAVE NORMALLY, SO IT'S A LITTLE BIT OF A SILVER LINING."

In charting out its new remote programming, STEMSEAS called upon its built-in network of 30-odd instructors and even more alumni who were eager to pitch in by connecting with a student or giving a lecture or webinar, things that could have happened almost as easily on a ship as on a computer. The STEMSEAS Facebook alumni page has fostered continued interaction and conversations, and alumni have made conscious efforts to connect their students with upcoming opportunities and internships.

STEMSEAS online programming also tried to bring some of the ship experiences to their students by connecting them to the ship operators, who may have more time now that there is not much sailing, Cooper said.

"We can arrange for them to talk to the students in a way that probably wouldn't have been available," she said. "You know, when you haven't sailed on a ship yet, you think of the ship captain as some very intimidating, grizzled old guy, right? But most of the ship captains we've sailed with have been super hip and fun and crazy people with interesting stories. If we can have a captain talk to the students, I think that's really cool."

Similarly, the Nautilus internship program is taking advantage of the resources it has already built to offer students opportunities to stay engaged. The program was designed to train undergraduate and graduate students working aboard the E/V *Nautilus,* which explores the deep sea with remote-controlled vehicles. For 2–5 weeks, interns would get hands-on experience working as seafloor mappers, data loggers, pilots of remotely operated vehicles, or video engineers.

"We try to target students who we really think will benefit from the opportunity of getting to sea," said Nicole Raineault, the chief scientist and vice president of exploration and science operations at Ocean Exploration Trust.

The entire internship program cohort has been deferred this year because of limitations on how many can safely crew the ship. As an alternative, the students are encouraged to participate in the Scientists Ashore Program, another Nautilus initiative that allows scientists to participate in expeditions via live video and data feeds with text dialogues with shipboard scientists.

"For 10 years, we've pioneered telepresence and pushed that technology forward, and now we're kind of being asked to put our money where our mouth is and flex that telepresence at a new level,” Cook said. “We’ve always said you can come to the seafloor using technology—now let’s actually take you to the seafloor.”

During its delayed expedition season from October to December, Nautilus also plans to host career panels and student background talks about their experiences in ocean science, drawing from some of the program’s almost 140 intern alumni. “We really look to position everyone as role models,” Cook said.

These events, available on the Nautilus Live website, will be open to students as well as the general public.

“This is such a wild year,” Cook said. “And I think it’s forcing us all to be really willing to be on our toes. And I think that’s a good lesson for students.”

> “THIS IS SUCH A WILD YEAR. I THINK IT’S FORCING US ALL TO BE REALLY WILLING TO BE ON OUR TOES. AND I THINK THAT’S A GOOD LESSON FOR STUDENTS.”

Lessons Learned for an Uncertain Future

This past summer may not be the last time these virtual programs are needed.

“Incidentally, two students that I know of got COVID,” Sloan said. “They are recovering okay. If they had been on campus, it would have been complicated for everyone involved—the cohort, the lab staff, and so on. We had questions at the summer’s outset about how we would deal with a sick student—who would provide care? How would they get home, if they had one to go to?”

“I bet you’ll see a kind of mishmash next year” between in-person and virtual mentorship programs, Sloan continued. “It’s wait and see [and] play by ear, but I would not be surprised to see a continuation of it.”

Even after the pandemic, remote mentorship networks can be valuable for their wide reach, especially to underrepresented groups that might otherwise not find these programs accessible.

But remote programs come with their own, often technical, challenges. “Every week, something would go wrong in a pretty big, frustrating way,” so some trial and error was necessary, Sloan said.

“Keep things simple until you’re more comfortable,” she advised.

GEO REU also provided resources to mentors and program directors for moving REUs online with tips on engaging virtually to help ease the transition.

As with any successful mentorship program, communication and time were key. In the GEO REU mailing listserv, program directors and mentors from around the country shared their experiences and emphasized the importance of using different means of communication like texting, videoconferencing (e.g., Zoom), and online chatting (e.g., Slack) to maintain contact between students and mentors.

However, Sloan noted, giving time to students was doubly important when mentoring remotely. “We knew we don’t want to have them on Zoom all the time,” she said. “Because that’s death.”

Despite the challenges inherent in building connections in a new remote format, the experiment seems to have worked. In surveys she sent out after her virtual professional development workshop series ended, Sloan found that most of the students had had a positive experience and found the program valuable for their development.

“I think the takeaway for me was that it was successful, and I didn’t know if it would be,” Sloan said. “It was more successful than I expected.”

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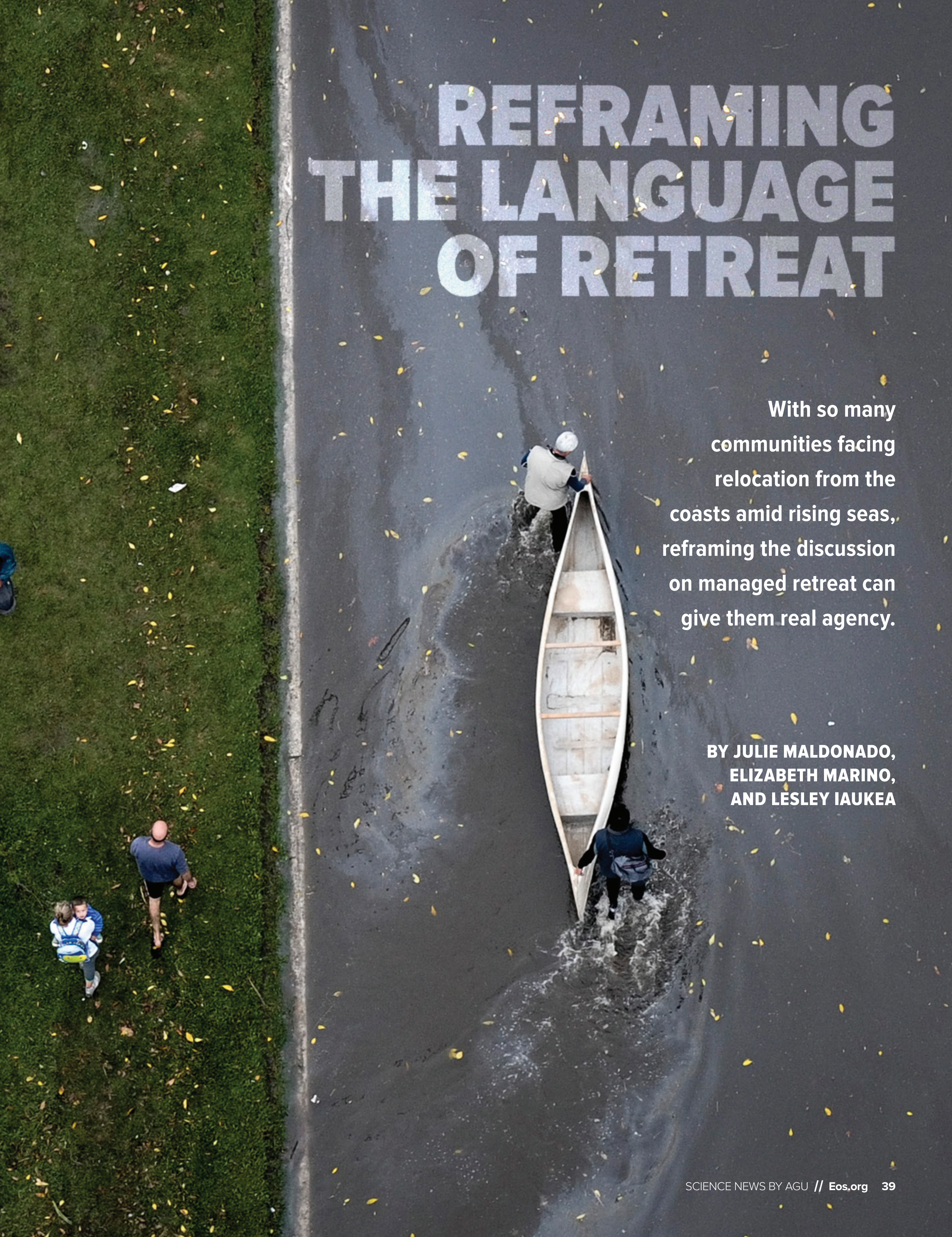

REFRAMING THE LANGUAGE OF RETREAT

With so many communities facing relocation from the coasts amid rising seas, reframing the discussion on managed retreat can give them real agency.

BY JULIE MALDONADO, ELIZABETH MARINO, AND LESLEY IAUKEA

When faced with the looming effects of climate change along coasts—larger storms, rising seas, flooding, and eroding shorelines—arguing to promote linguistic framing of climate change–driven migration may seem like a fool's errand. Does anyone care what it's called if hundreds of millions of people globally—up to 13.1 million people in the United States alone [*Hauer et al.*, 2016]—relocate from coastlines en masse before 2100? Should anyone spend time considering how to title the newest report about climate-driven migrations when what are needed are data, analysis, policy changes, and cultural shifts that will safeguard the lives, livelihoods, infrastructure, and economies forced to deal with that migration? Does it really matter whether people are "retreating" or "relocating" when it's still unclear how to deal realistically with the ocean rising up to 1.8 meters above the ground on which our homes are sitting?

We think it does matter.

Implicit in terms like managed retreat, forced migration, community relocation, and others are assumptions about who is deciding what is appropriate adaptation and how those decisions influence, suggest, or require compliance. How and, especially, by whom these plans are developed will have substantial impacts on affected or relocated people's lives. These impacts are particularly critical for individuals in marginalized communities in the United States, who will likely endure disproportionate hardship from climate and environmental risks and who have historically suffered under decisions made by people outside their communities.

We want to start a discussion about the assumptions and implications conveyed by the various terms used to describe the anticipated large-scale movements of people and communities away from coasts.

How and, especially, by whom relocation plans are developed will have substantial impacts on affected people's lives.

MANAGED RETREAT

The most common term used to describe the movement of people away from coasts is managed retreat, a concept that emerged from coastal engineers. The term has been used largely to describe the physical movement of built infrastructure, and it only subsequently has included the physical movement of people. Also encompassed in the term are the policies that facilitate these movements. Recent scientific and policy research has tried to reconceptualize the idea of managed retreat so that it is more inclusive of social consequences—such as the cultural and psychological risks that accompany retreat—or has suggested actions such as reparations to address risk that has accumulated over time for specific disenfranchised populations [*Siders et al.*, 2019].

However, within the managed retreat framework—with its focus on buildings, property, city infrastructure, zoning, property rights, and the strategic planning and political will necessary to coordinate all of these—scientists use data to help governing authorities and businesses make plans and policies to entice municipalities, property owners, and developers away from coasts. Those making the plans and policies often suggest that such a mechanism saves people from both sea level rise and "their own bad decisions." At first blush, this is an enticing way to think about climate change adaptation, offering a "best solution"—and it is accurately titled as managing retreat. But the emerging use of eminent domain to remove people from coastal locations, such as along the U.S. East and Gulf Coasts, is an example of how managed retreat sometimes leads to plans of action that are enacted upon a citizenry instead of in partnership with a citizenry.

There are three critical flaws in this framework.

First, affected people are often missing altogether from policy and planning discussions about managed retreat, and when they are present, they are abstracted and homogenized. It is as though they do not have unique lives or histories, differences in bank balances, varying access to childcare, valid opinions, ancestral knowledge of place, or varying perspectives about what success looks like in their own lives and relocations. In some cases, people

The Isle de Jean Charles Biloxi-Chitimacha-Choctaw Tribe, whose community in the Mississippi Delta is shown here, has experienced land loss resulting from rising seas; increased hurricane intensity and frequency (and being cut out of state-led hurricane protection plans); extractive industries; river mismanagement; and hydrological, meteorological, and environmental disasters. The tribe has been working on community-led relocation for nearly 2 decades. Credit: Babs Bagwell, 2012

have been described as being part of the problem—obstacles to achieving the goals of managed retreat.

As social scientists who study community-led relocation, we can attest to the number of researchers, disaster response professionals, and journalists who have asked us about communities' "unwillingness to move," about the "stubbornness of some people," and about the onus of financing relocations "being on the individual." If managed retreat works against people's own assessments of risk, desires, and decision-making, it is not an inclusive adaptation plan, and it can further marginalize the very communities it is supposedly designed to support. What people think of their own lives, place, and culture matters.

For example, Indigenous Peoples, whose lands settlers stole and now inhabit—and who are on the front lines of climate displacement—are connected to the land through Indigenous worldviews that hold the land to be their ancestor. When displaced from the land, people become displaced from their culture. Indigenous Peoples understand this dynamic and can be resistant to moving for this very reason.

Second, the normative assumptions about "the best solution for the greatest number of people" wrapped up in the managed retreat language often leave out the very people who bear the most extreme burdens of the climate crisis. In a process managed by outside entities—especially powerful ones such as scientific institutions, governments, and corporations—speaking and acting for the people who are actually moving run the risk of continuing and expanding the historical oppression of rural, minoritized, Indigenous, and undocumented communities.

Consider the sacrifices of Indigenous communities on Bikini Atoll, who were moved repeatedly by the U.S. government for nuclear testing on the island and who today continue to experience effects of displacement and severe environmental and health devastation and injustices. Consider how the damming of the Amazon displaced more than a dozen Indigenous groups and how Andrew Jackson's purchase of Georgia led to the Trail of Tears death march for an estimated 60,000 Native Americans from east of the Mississippi River to what is now Oklahoma.

Affected people are often missing altogether from policy and planning discussions about managed retreat, and when they are present, they are abstracted and homogenized.

Today a number of tribal communities and Indigenous Peoples live on the Mississippi Delta lowlands, which are sinking as seas are rising. There are also Indigenous communities on low-lying islands all across the South Pacific. With a new era of relocation linked to climate change, we can anticipate these and similar communities bearing the burden of picking up their cultures and moving again. It is critical to allow these communities to create, invent, and decide their own futures.

Third, by not focusing on the lived experiences of people being relocated and on the differences among communities who need to move, there is a greater likelihood

Residents of Shishmaref on Sarichef Island in Alaska, as seen above, have been working for years on relocation plans because of growing threats to the community from storm surge, shoreline erosion, and thawing permafrost. Credit: Bering Land Bridge National Preserve, CC BY 2.0 (bit.ly/ccby2-0)

that resources will be disproportionately allocated away from politically marginalized and economically poor communities [*Siders et al.*, 2019; *Marino*, 2018] or that the provision of resources will stop once people are relocated.

When scientists, policy makers, and planners say managed retreat, their sights are trained on putting physical space between encroaching waters and communities—on retreating. To the point that people and infrastructure do leave, such efforts succeed. But there is so much that can be done better.

MORE INCLUSIVE LANGUAGE

Shifting from "managed retreat" to language that is more inclusive of who and what is included in "community" and that upholds the varying voices, opinions, knowledges, and lived experiences of those physically moving is more than a semantics issue; it also involves logistic and policy elements that can incite changes in practices related to people moving from coastal regions.

The term community-led relocation, for example, includes consideration of the complex tapestry of people who leave a place they have inhabited to settle in another, as well as the fact that these community tapestries are bound not by geography but by relationships and practice. "Community led" also highlights the importance of community engagement, input, and leadership in decision-making, visioning, planning, and implementation [*Marino et al.*, 2019].

Unlike with "managed retreat," "community-led relocation" encourages us to see that success means helping people to stay safe and healthy and feel satisfied in a new location. The term also encourages us to foster plans of action that emphasize the logistics of perpetuating culture after resettlement, such as considering how houses are constructed and how people physically dwell in relation to one another, as well as establishing community gathering spaces for cultural and ceremonial practices and ways to maintain food sovereignty and access to traditional foods, medicines, and subsistence practices.

Social scientists know that simply using the word community does not mean everyone within that designation agrees to a single or simple solution [*Faas and Marino*, 2020]. But framing sea level rise–driven migration as taking place within a community instead of as involving retreat from a territory allows space for dialogue to address solutions that make sense to the people moving as opposed to focusing on terminology originally meant to describe infrastructures and assets. If the people most affected by relocation are not

involved in the planning process, their needs—physical and cultural—are unlikely to be met. Their communities will be moved to places that are not set up for or prepared to accommodate their cultures, which is how cultural affirmations like Native languages, traditions, foundations, and ties to land and sustainability can be erased.

AN OPEN CONVERSATION

A critical question to consider is, How *do* people relocate with their cultures intact? If intact means immutable and unchanged, then it is impossible. However, Indigenous Alaskans and many communities throughout the Pacific, for example, have long traditions of migration. These communities show that dignity and self-governance in movement as a response to changing coasts are certainly possible—but only if local authority is central to the conversation.

Our intent here is not to prescriptively determine the language to associate with climate-driven relocation. Even with "community" attached to them, words like relocation can have deep-rooted negative connotations. Rather, we want to invite an open conversation to shift the framing from one of managed retreat to one that is more inclusive of people, cultures, and lifeways. If people do not see themselves in the framing, if it is being done *for* them as opposed to *with* them, the process reverts to adopting the historically problematic best solution.

As we've described, the best solution in the current framing of managed retreat is based predominantly on economic measures while discounting nonmaterial considerations like histories, practices, affective experiences, and ways of life that are essential in thriving communities.

Dignity and self-governance in movement as a response to changing coasts are certainly possible—but only if local authority is central to the conversation.

We recognize that no single framing will work for everyone. In determining how such framing can be more inclusive, it is critical for planners, engineers, scientists, policy and decision makers, and other professionals involved to engage in open and ongoing dialogue with community leaders and organizers who have long been working on and advocating for community-led, preventive actions. It is also critical to build flexibility into the relocation process to allow a community to decide for itself how best to enable its own physical and cultural continuity. In addition, as part of relocation planning, there needs to be an evaluative process to determine whether and how a community group was involved in decision-making at every step, from initial visions to planning to implementation.

The risks and challenges borne by communities at risk of displacement often are founded on centuries of injustices. The least that planners, engineers, scientists, and others involved in researching and implementing community relocation plans can do, collectively, is to create inclusive language and frameworks that promote just community relocations and resettlements.

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Researchers gather in a cave entrance at one of the archaeological sites they studied near Mossel Bay on the central southern coast of South Africa. When sea levels were lower, this cave would have looked out over a wide grassland. Credit: Kerstin Braun

Sea level changes have repeatedly reshaped the Paleo-Agulhas Plain, a now submerged region off the coast of South Africa that once teemed with plants, animals, and human hunter-gatherers.

A LOST HAVEN FOR EARLY MODERN HUMANS

BY KERSTIN BRAUN

Southern South Africa is well known for its scenic coastline of rugged cliffs and long, sandy beaches and for its fynbos, an extraordinarily diverse, Mediterranean-type assemblage of shrubs and other vegetation, most of which are endemic to the area. The region is also known for its long legacy of human inhabitation. Today it is home to numerous coastal communities interspersed among large population centers like Cape Town and Port Elizabeth, but the present-day coastline is also dotted with archaeological sites documenting 200,000 years of human activity.

These sites sit along the northern edge of the Paleo-Agulhas Plain, a piece of continental shelf the size of Ireland that was repeatedly exposed and submerged as sea levels changed through the Pleistocene and that today lies beneath the waves south of Africa. Scientists have long recognized that the Paleo-Agulhas Plain was an important part of the glacial landscapes—and one that shaped human populations—in southern Africa, but the environment and ecology of the plain have been largely unknown. That's changing, however, as researchers apply advanced methods and reveal archaeological and geological records that tell tales of feast, famine, and migration as the coastline advanced and retreated over many millennia.

For much of the past 200,000 years, the ocean was substantially lower than it is today, and the view from the caves and rock shelters that once hosted humans would have been quite different.

A community of early modern humans living amid the grasslands of the Paleo-Agulhas Plain, off the coast of present-day South Africa, is shown in this artist's depiction. Credit: Maggie Newman

Revealing Ancient Vistas

The highest sea levels were about 6 meters above the present level during the last interglacial phase, about 125,000 years ago, whereas the lowest were 129 meters below present levels during the penultimate glacial period, roughly 137,000 years ago. For much of the past 200,000 years, the ocean was substantially lower than it is today, and the view from the caves and rock shelters that once hosted humans would have been quite different.

Near the caves, inhabitants would have looked out over a wide, mostly flat plain resembling the grasslands of modern eastern Africa more than the fynbos shrublands of the current coastal lowlands. The ancient grasslands were dissected by rivers that flowed south from the mountains of the Cape Fold Belt and had wide floodplains covered in woodlands and lush wetland vegetation [*Cowling et al.*, 2020].

Diverse herbivores roamed the grasslands, woodlands, and wetlands in large herds [*Marean et al.*, 2020]. Large grazers, like the now extinct giant buffalo, whose curving horns protruded a meter from either side of its head, remained in the open grasslands, whereas zebra, wildebeest, blue antelope, and hartebeest took advantage of the open grasslands and tall wetland grasses. Browsers like giraffe, black rhino, bushbuck, and kudu, as well as mixed browser-grazers like springbok and eland, preferred the more closed habitats of the floodplains. The wetlands and rivers provided a home for reedbucks, hippos, and Nile crocodiles.

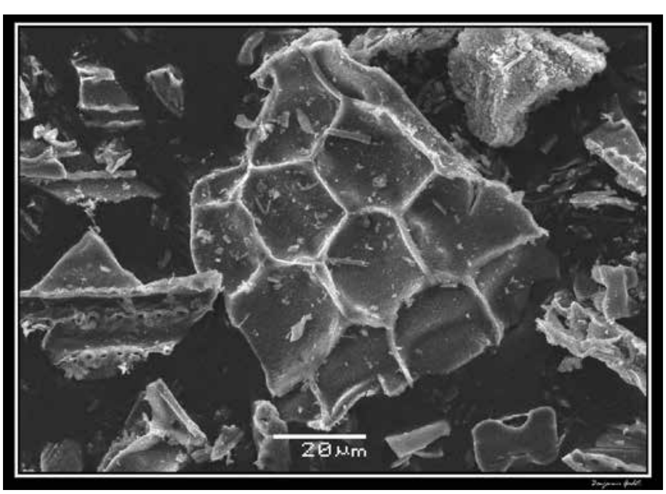
On the Paleo-Agulhas Plain, fynbos shrublands were found mostly on the outer shelf at the height of glacial periods when sea levels were more than 100 meters below where they are today. These plant communities were specifically adapted to the limestone substrate of what's now the deeper continental shelf. The repeated flooding and exposure of the Paleo-Agulhas Plain left a legacy of coastal dune deposits scattered across the landscape. Outcrops of these dunes cemented by carbonates were interspersed with the grasslands on the plain and covered by mosaics of fynbos and subtropical thicket vegetation. These vegetation types supported the less diverse and less numerous large mammal communities that are also present on

The giant buffalo Pelorovis antiquus *had a 2-meter horn span. This fossil skull is on display at Kenya's Nairobi National Museum. Credit: Bjørn Christian Tørrissen, CC BY-SA 3.0 (bit.ly/ccbysa3-0)*

the current coastal lowlands, namely, grysbok and bush duiker [*Marean et al.,* 2020]. Elephants moved between the different habitats on the plain and farther inland, where today's coast is.

Revealing the environments of the Paleo-Agulhas Plain is part of an ongoing transdisciplinary collaboration including researchers from South Africa, the United States, and Australia [*Cleghorn et al.,* 2020]. The effort began with scientists, including myself, reconstructing the physical environment of this region: its geology, soils, and climate and the dynamic effects of sea level changes. Collaborators then mapped vegetation distributions and large mammal habitats on the basis of the physical environment.

Local scientists recruited descendants of ancestral coastal Khoisan tribes for modern foraging experiments because of their experience in marine foraging for personal consumption. In these experiments, the tribespeople harvested shellfish and plant foods in previously defined coastal marine habitats and fynbos plant communities. By recording the amount of food harvested by each person in a defined amount of time, each shellfish habitat and plant community could be assigned an average "return rate." For marine foraging, the main driving factors of return rates were tides, weather conditions, and coastal habitat type [*De Vynck et al.,* 2016]. Plant foraging experiments showed that food resources were unevenly distributed and that hunter-gatherers would have profited from detailed knowledge of the locations of calorie-dense resource "hot spots" [*Botha et al.,* 2020].



Phytoliths extracted from elephant grass are seen in this electron micrograph. Similar phytoliths were found in archaeological sites studied as part of an international collaboration to understand the Paleo-Agulhas Plain. Credit: Benjamin Gadet, CC BY-SA 3.0 (bit.ly/ccbysa3-0)

We integrated these results with knowledge about the distributions of vegetation and other resources, such as raw materials for stone tools, to produce a resource landscape that informs computational modeling efforts to simulate the behaviors of people on the landscape.

Modeling Climate and Mapping Vegetation

Environmental changes during and between glacial and interglacial periods had profound impacts on the Paleo-Agulhas Plain and its surroundings. The most significant were from sea level variations, which exposed and submerged the plain twice in the past 200,000 years [*Fisher et al.,* 2010].

The climate, on the other hand, seems to have remained stable along the present-day southern coast compared with climates in the southern African interior. Paleoclimate modeling of conditions at the Last Glacial Maximum (LGM), roughly 21,000 years ago, suggests only mild temperature decreases over the Paleo-Agulhas Plain and along the present-day southern coast [*Engelbrecht et al.,* 2019].

Fynbos vegetation grows on South Africa's central southern coast near the city of George. Fynbos plant communities on the present-day coastal lowlands have not changed much since the Last Glacial Maximum. Credit: Kerstin Braun

This modeling also showed only small changes in annual rainfall amounts along the southern coast, although the seasonality of rainfall has varied considerably. Most of South Africa and the Paleo-Agulhas Plain received more winter rainfall during the last glacial period than they do today because of a northward shift of the westerly wind belt [*Engelbrecht et al.,* 2019]. The prevailing westerly and northwesterly winds brought about by this shift led to downwind effects along the southern flanks of the Cape Fold Mountains and the present-day central southern coast that reduced winter rainfall [*Engelbrecht et al.,* 2019].

Researchers mapped the vegetation from 26,000–19,000 years ago, around the time of the LGM, using field data on the distributions of geological and soil substrates combined with paleoclimate modeling [*Cowling et al.,* 2020]. Because the vegetation that grows in an area depends strongly on the underlying bedrock and soil, which typically remain stable over long periods of time, the vegetation on the present coastal lowlands has not changed considerably since the LGM. The grasslands and floodplain vegetation on the exposed Paleo-Agulhas Plain, however, comprised a set of habitats that are now almost completely absent from the region [*Marean et al.,* 2020].

Reconstruction by Proxy

A range of proxy methods provides independent reconstructions of past climate and vegetation in the region, with results that can be compared with model outputs and map projections. For example, colleagues and I determined ratios of the stable isotopes of oxygen (^{16}O and ^{18}O) preserved over millennia in stalactites and stalagmites from coastal caves to track changes of rainfall seasonality from 113,000 to 19,000 years ago [*Braun et al.,* 2020].

Carbon stable isotope ratios (^{12}C and ^{13}C) from the same stalactites and stalagmites, as well as in fossil mammal teeth and ostrich eggshells, can yield information about the abundance of tropical grasses (which use the C_4, or Hatch-Slack, carbon dioxide fixation cycle) versus shrubs, trees, and temperate-region herbs and grasses (which use the C_3, or Calvin, cycle) growing in the soil above the coastal caves and in

> The grasslands and floodplain vegetation on the exposed Paleo-Agulhas Plain comprised a set of habitats that are now almost completely absent from the region.

the animals' diets. Phytoliths, microscopic silica particles produced in different characteristic shapes and sizes in plant cells, are also useful as a proxy for the abundance of tropical C_4 grasses compared with C_3 trees, shrubs, and temperate-region grasses [*Esteban et al.,* 2017]. They are commonly found in the sedimentary sequences of archaeological sites.

Stable carbon isotope analyses of large mammal teeth from the LGM indicate that at Nelson Bay Cave, near Plettenberg Bay on the current southeastern coast, grazers mainly ate C_3 grasses that grew there when winter rainfall was prevalent [*Sealy et al.,* 2020]. This observation is supported by the paleoclimate model, which predicts that winter rainfall dominated the Paleo-Agulhas Plain near Nelson Bay Cave at this time [*Engelbrecht et al.,* 2019].

Several proxy records gathered along the central southern coast in the area surrounding Pinnacle Point near Mossel Bay offer information about an earlier cool phase known as marine isotope stage (MIS) 4, which lasted from about 72,000 to 59,000 years ago. Oxygen and carbon stable isotopic ratios measured in stalactites and stalagmites suggest that summer rainfall increased and more C_4 grasses grew during this cool phase than during warmer periods [*Braun et al.,* 2020]. Carbon isotopic ratios in large grazer teeth and ostrich eggshells, as well as phytolith assemblages, support the hypothesis that C_4 grasses were more common during MIS 4, although ratios detected in small mammals (mostly vlei rats) suggest that C_3 plants were also still abundant in the vicinity of Pinnacle Point.

The proxy results suggest that conditions downwind of the Cape Fold Belt were similar during MIS 4 to those indicated by paleoclimate modeling for the LGM. This work thus highlights that the archaeological sites where humans dwelt long ago were positioned in a transition zone between two ecological realms: the fynbos farther onshore, which was dominated by C_3 plants, and the grasslands of the Paleo-Agulhas Plain, with their high abundances of C_4 grasses.

A path wends through Fynbos vegetation near the Nelson Bay Cave archaeological site on the Robberg Peninsula. This vegetation tends to be rich in plants that produce bulbs and tubers, some of which are edible. Credit: Kerstin Braun

Changes to the Menu

Finding food and water would have occupied much of the time for hunter-gatherers. Water was readily available on the Paleo-Agulhas Plain in the closely spaced rivers and wetlands and from groundwater seeps [*Marean et al.,* 2020]. Locating food resources in the region would have mainly involved foraging for plant foods, gathering shellfish, and hunting large mammals, but the availability of each of these changed through time.

Fynbos vegetation is very rich in plants that produce bulbs and tubers, but not all of them are palatable, and some are even poisonous. Food resources amid the fynbos are clustered in specific vegetation types and in areas recently affected by wildfires [*Botha et al.,* 2020], which trigger seed sprouting in some plants. Skilled gatherers with knowledge of edible plants and where and when they cluster would have been able to gather plenty of food, and they may even have set wildfires to increase supplies [*Botha et al.,* 2020].

Fynbos plant communities near the present-day coast have not changed much since the LGM, but the Paleo-Agulhas Plain, when it was exposed, offered substantial areas with mosaics of fynbos and thicket vegetation [*Cowling et al.,* 2020], which can be especially productive for foraging, in part because of the softer soil, which makes it easier to dig up bulbs [*Botha et al.,* 2020]. Although fynbos vegetation was widespread during the LGM, the efficiency of plant foraging may have been limited compared with foraging during interglacials because individual bulbs would have been smaller with the lower concentrations of carbon dioxide in the air (a minimum of about 180 parts per million, compared with about 290 before the Industrial Revolution and 400 today) [*Faltein et al.,* 2020].

Archaeological assemblages suggest that habitat loss did not cause local extinctions of grassland species; rather, they survived as refugee species in decreased numbers.

Hunting expeditions likely would have been more productive on the Paleo-Agulhas Plain than on the present coastal lowlands because populations of large mammal faunas were denser amid grasslands and floodplains of the plain than in the fynbos. Sea level changes, however, considerably affected the size of large-mammal habitats, with only small remnants of grasslands remaining during full interglacials when sea levels were high.

Archaeological records from the Holocene—an interglacial beginning about 12,000 years ago—across the region suggest that people did, in fact, hunt fewer of the animals associated with the habitats on the Paleo-Agulhas Plain, probably because these species were less abundant or went extinct. Archaeological assemblages from interglacial MIS 5 (~128,000–72,000 years ago), however, suggest that habitat loss did not cause local extinctions of grassland species; rather, they survived as refugee species in decreased numbers.

These assemblages also show that shellfish like mussels and snails were a reliable and productive source of protein for hunter-gatherer diets at times. Shellfish are more perishable than larger animals, so early humans probably gathered only what they could eat the same day. The coast was within the 10-kilometer daily foraging radius from the cave dwellings on what is now the central southern coast when the sea level was less than 60 meters below the present level [*Fisher et al.,* 2010].

Lower-than-present sea levels meant that rocky shores were absent and sandy beaches, interspersed with reefs of cemented dunes, were much more common. In the present-day foraging experiments, these reefs yielded high returns of shellfish when tides and weather were favorable, but returns were very low on beaches [*De Vynck et al.,* 2016]. The common occurrence of sand mussels in archaeological shell middens, however, suggests that Pleistocene hunter-gatherers foraged effectively on beaches nonetheless.

A Picture of the Past

The resource landscape developed for hunter-gatherers provides the natural boundary conditions for an agent-based computational model that simulates the movement of people on the landscape. An initial model representing interglacial conditions suggests that in the absence of the abundant large-mammal fauna on the Paleo-Agulhas Plain, people were heavily dependent on plant foraging and exploited marine resources when possible. Overall, the viable population density was only two people per 100 square kilometers, similar to that of today's Montana or Wyoming [*Wren et al.,* 2020].

During intermediate conditions and glacials, the resource landscape would have looked quite different. At intermediate sea levels, people were still able to access coastal resources and forage for fynbos plants, while the Paleo-Agulhas Plain provided more game for hunting. In glacial phases, marine resources would have been out of reach for people living on the present-day coast. During these periods, fynbos plant communities, although still abundant, may have provided less food. It is thus likely that during these times, people relied heavily on hunting large mammals of the Paleo-Agulhas Plain.

As a result of the collection of research described here—and of the large, transdisciplinary collaboration, which has allowed us to resolve far-reaching and comprehensive questions—we now know that the Paleo-Agulhas Plain was far more than an extension of the coastal lowlands of today's southern African coast. Rather, the plain was its own unique ecosystem, affected by exceptional dynamic changes of climate and exposure on glacial-interglacial timescales. These dynamics, in turn, shaped habitats for vegetation, animals, and our human hunter-gatherer ancestors, for whom the plain represented the most productive foraging environment in the region—and one that helped sustain them for tens of thousands of years.

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Fernie Garcia

THE TWO-YEAR ON-RAMP

By Jenessa Duncombe

This community college in Texas has figured out how to guide its students into geoscience careers.

Marissa E. Cameron was always fascinated by science and dreamed of becoming an astronaut, but after her first year studying at the University of Texas at El Paso, nothing felt right. She left school to try the workforce for a few years, landing in a job in retail.

"There were people that told me that I made a big mistake," Cameron said.

Now Cameron works as a planetary scientist at NASA's Jet Propulsion Laboratory, performing landing site reconnaissance for future mission concepts for Jupiter's moon Europa. What made the difference? Community college.

The geosciences recruit far fewer community college students into 4-year degrees than other science, technology, engineering, and math (STEM) fields. But some schools are changing that.

El Paso Community College (EPCC) is one such school and has emerged as a model for other 2-year institutions looking to recruit and prepare the next generation of geoscientists. At its peak 2 years ago, the El Paso program produced 8% of geoscience associate's degrees awarded annually nationwide. Cameron credits her time at EPCC with her career success.

One of the champions of the program is Joshua Villalobos, a dean of instructional programs and the campus dean of EPCC's Mission del Paso campus. Villalobos grew up in El Paso and attended both EPCC and the University of Texas at El Paso (UTEP). When Villalobos first joined the EPCC faculty, the geology program was defunct because of a lack of students.

Villalobos knew that students wanted a chance to be geoscientists. They simply needed a path. Only a few community colleges have dedicated geoscience majors, according to the American Geosciences Institute's (AGI) 2018 workforce report—yet students have a growing interest in the discipline, and the workforce needs new personnel. By 2026, AGI estimates a surplus of 118,000 geoscience jobs due to retirements.

Villalobos also realized that community college students could be a critical population to recruit into the geosciences, particularly given that the discipline is the least racially and ethnically diverse STEM field. Hispanic, Black, and Native American students are overrepresented at community colleges compared with 4-year institutions.

"As the United States' population begins to change, we need to have a geoscience community that's reflective of that population," said Villalobos.

Villalobos, along with a team of faculty, deans, and advisers, built a new pipeline for community college students in El Paso. Could their model be a template for others?

Getting a (Booted) Foot in the Door

Cameron took her first geology class with Villalobos on a whim to fulfill her general science requirement. She'd started taking early-morning and night classes at EPCC while working full-time and wasn't sure what she wanted to do but knew that she needed a change.

She had always liked the Earth and space sciences: Her father took her rock collecting as a child and would set up a telescope to peer at the stars. But she didn't know what career options, if any, existed in the discipline. She'd never met a geologist.

Often, learning about careers takes place outside of the classroom, which can leave students with a hazy picture of their future careers. To counter that, Villalobos dedicated the final slide of each lecture in his introductory geology class to career spotlights. Lectures on mineralogy ended with information on mineralogists, sediment lectures concluded with sedimentologists, and so on. Students were even tested on scientific career paths. Learning about professions "really opened up the possibility" that geoscience could be a real career, said Cameron.

Villalobos also disseminated career and salary information to student advisers and displayed it prominently at the top of the school's online degree plan.

Advice on careers in physical sciences can be key to students' desire to earn a baccalaureate. In a survey of 708 community college geoscience students in the *Journal of Geoscience Education,* career discussions with students positively correlated with higher intent to transfer to a 4-year school in the geosciences.

> **In each lecture, Villalobos dedicated the final slide to career spotlights.**

In addition to a lack of career information, Villalobos said that community college students can face another hurdle: cultural perceptions of a "successful" career.

"For most minority families, if you have the opportunity to send one of your children to college, you're going to want them to be a doctor or a lawyer, things that are within the cultural mental framework of what success is," Villalobos said. Three in 10 community college students are the first in their families to pursue higher education.

Geology and geophysics students from El Paso Community College gather around a ground-penetrating radar to survey a dried reservoir in El Paso, Texas. Credit: Joshua Villalobos

Language can be another barrier and can lead to misconceptions about geoscience. Researchers use the term fieldwork to describe research conducted in an outdoor environment, for instance, but in Hispanic cultures, "the term 'doing fieldwork' means that you are…getting a job literally in the field, like picking crops or digging ditches," Villalobos said.

The majority of students at EPCC and UTEP are Hispanic, and the campus Villalobos calls home is in an agricultural area. Parents of students started showing up at Villalobos's office asking whether their child could even get a job in geology. And why were their children working in the field?

Villalobos quelled parents' fears by listening to their concerns and explaining that studying the geosciences does lead to career opportunities. When doing outdoor work, Villalobos requires that students "dress like a scientist," with a notebook, hiking boots, and protective clothing.

"That proper gear is like your uniform," Villalobos said. "It's your symbol of being a geologist."

Pointing the Arrow

At community colleges, students can fall prey to "cafeteria-style learning," said Nikki Edgecombe, a senior research scholar at the Community College Research Center at Teachers College, Columbia University.

Students take a random mix of classes that don't necessarily lead to a degree, often basing their decisions on peers or scheduling, as opposed to the end result of graduation.

EPCC's program uses a different approach: The college offers a degree plan with seven geology and environmental courses and labs, as well as freshman- and sophomore-level math and science classes. This guided pathway harnesses students' excitement after their first geology class into a focused track and lets them save money if they want to transfer to a 4-year institution.

Villalobos knew that coursework was only the first step, however, and that a vital part of learning happened in the laboratory. Villalobos recalls washing beakers as an undergraduate in a geochemistry lab at UTEP and how much of a joy it was. Overhearing conversations between professors and graduate students introduced Villalobos to a new language and scientific world. Even though the work was menial to start, soon Villalobos was learning to operate scientific instruments and flying to Stanford University to run high-powered equipment.

The experience "cemented my desire to be a geologist," said Villalobos, and there was no reason EPCC students shouldn't have that chance too.

"High-impact learning experiences" can have a powerful effect on students, but community colleges generally don't have the resources to supply them. Grants are scarce, and faculty are up to their eyeballs

Opposite: Fernie Garcia

EPCC geology major Joshua Peterson studies his Brunton compass for a strike and dip measurement in the Franklin Mountains, Texas. Credit: Joshua Villalobos

teaching classes, sometimes six per semester.

Villalobos knew it was time to ask for help. The first step was applying for out-of-state funding from the University of Arizona for $2,000–$3,000 grants to increase the number of minoritized students in STEM. Villalobos used the money to pay two students to study a nearby wetland using simple field kits. The students enthusiastically trudged through the wetland each week, taking soil and water samples, and developed a hypothesis that the wetlands are partly fed by previously unidentified springs.

Using the small grants as a proof of concept, Villalobos secured a $200,000 grant from the National Science Foundation to build a research program. In the Student Opportunities for Learning Advanced Research in the Geosciences (SOLARIS) program, EPCC students completed one- or two-semester research projects, sometimes at the college and other times at UTEP. During the heyday of SOLARIS in 2017, EPCC had 70 students in its geology major, a large number even compared with 4-year institutions.

The geology classroom at EPCC has more than a few maps. Credit: Joshua Villalobos

The connection between EPCC and UTEP turned out to be key. After the start of Villalobos's pilot research programs in 2008, enrollment in UTEP's geology degree program quadrupled over 7 years, and the number in the environmental science degree program nearly doubled as EPCC students transferred to UTEP.

Building the Bridge

As an EPCC student, Cameron wanted to transfer to UTEP but wasn't sure she could afford it. She would be the first in her family to get a bachelor's degree.

She'd done everything right: finished her geology classes, completed research, and checked off her prerequisites. But when she thought about the higher tuition cost, "I was like, man, I got all this way, and I'm not going to be able to continue on."

The average annual 4-year public in-state college tuition was nearly 3 times as expensive as that of community college in 2019. And the cost is going up: Between 2008 and 2018, the price for undergraduate education rose 31%.

Fortunately, UTEP had a program called Pathways that paid undergraduates to conduct research. The money would just barely cover tuition. Because Cameron had already done research at UTEP through SOLARIS, she decided to take the leap into a bachelor's program.

Other than navigating costs, community college students eyeing a bachelor's degree must transfer their credits.

Transferring credit in the U.S. education system can be a headache. The Government Accountability Office investigated college transferring in 2017 and concluded that the process is a mess. Between 2004 and 2009, students lost an estimated 43% of their credits when they transferred, the report found, which wasted students' money, time, and financial aid.

Part of the issue is that schools fail to disclose transfer agreements, called articulation agreements, online. The Department of Education does not require them to do so. Some schools don't have articulation agreements at all.

EPCC and UTEP have such an agreement. The geoscience associate's degree at EPCC counts directly for 2 years at UTEP. This two-plus-two program makes a _ bachelor's degree that much faster and cheaper, said Villalobos.

Even better, by working together proactively, road bumps can be avoided.

For example, transfer students could lose a whole year if they start at UTEP without having taken chemistry. Geoscience students must enroll in a course that requires chemistry (mineralogy) in the fall of their junior year, and spring classes build on that knowledge. Therefore, EPCC students must take chemistry before transferring. To avoid pitfalls, advisers from both schools meet to coordinate their curricula, and they give each other a heads-up when changes occur, said UTEP geology professor Diane Doser.

EPCC geology professor Joshua Villalobos (bottom left) and students explore paleo-karsts on a sunny day in the Franklin Mountains. Credit: Joshua Villalobos

One Model Among Many

The success at El Paso inspired faculty at Texas A&M University to invest in their own program for transfer students.

About 5 years ago, the university eased its coursework requirements for transfer students. The changes increased admissions of community college transfer students to Texas A&M by 107% in the first year. "We saw that we were missing a large demographic," said former Texas A&M associate dean Chris Houser.

But there is no one-size-fits-all approach.

For one, El Paso is a bit of an anomaly. It's isolated from the rest of the state's education system in an "education desert," with EPCC and UTEP being the only public institutions of higher education in that corner of the state. By contrast, there are 32 community colleges near Texas A&M.

But the issue wasn't insurmountable: Texas A&M accepts introductory courses from surrounding community colleges without an articulation agreement, said Texas A&M dean Christian Brannstrom. Instead, the university offers a handout with recommended courses that community college students can take over a 2-year span to prepare them for university. The sheet declares "your degree at A&M starts at your community college." This year the incoming class has 40% community college students, said Brannstrom.

Still, could this approach work outside of Texas? There are three big challenges.

For one, Texas is a minority-majority state, and both EPCC and UTEP are Hispanic-serving institutions; the majority of El Paso's population is Hispanic or Latino. As research has shown, equitable and inclusive workplaces require more than simply increasing the representation of racially minoritized groups. People working in predominantly non-Hispanic white institutions must actively change the culture in those spaces to be inclusive and equitable.

Second, Texas has streamlined the transfer process by regulating which courses can be offered by community colleges. That isn't the case nationwide; some states allow community colleges to set their own course offerings.

Community college faculty member Eric Baer said that he would love to re-create the El Paso model, but his home institution of Highline College near Seattle exists in a completely different educational ecosystem, with unique course offerings and countless 4-year options nearby. He said that while standardizing course offerings makes for a clearer path, educators risk creating cookie-cutter students.

> **Texas A&M increased admissions of transfer community college students by 107% in the first year.**

Third, the El Paso model relied heavily on one-time grants. The SOLARIS program that led Cameron into space science is no longer around, although spinoffs are. "We're trying to be as creative as possible," said Doser, because "you don't always get funding to do the same thing over and over again."

"We're continuously searching for support," she added.

That doesn't mean that change is impossible. It takes time, said Villalobos. "A lot of people just want to jump right in and solve it within a semester or two. That's just not going to happen."

Start by understanding your students and your institution, learn how to collect data, and identify your community partners, Villalobos advised. "Once you get a grasp on all of those, then you can start laying down the groundwork for something truly spectacular."

For Cameron, the bridge from EPCC and UTEP came at exactly the right time. After dropping out of premed, she wasn't sure what she'd do. Now she dreams up space mission concepts for a faraway icy world. "Even now, thinking back on it, Joshua [Villalobos] and EPCC were the things that really set that path in motion."

Community college also taught her that a second chance is always possible. "It doesn't matter what's happened to you," Cameron said. "If you want to make things happen now, you still can."

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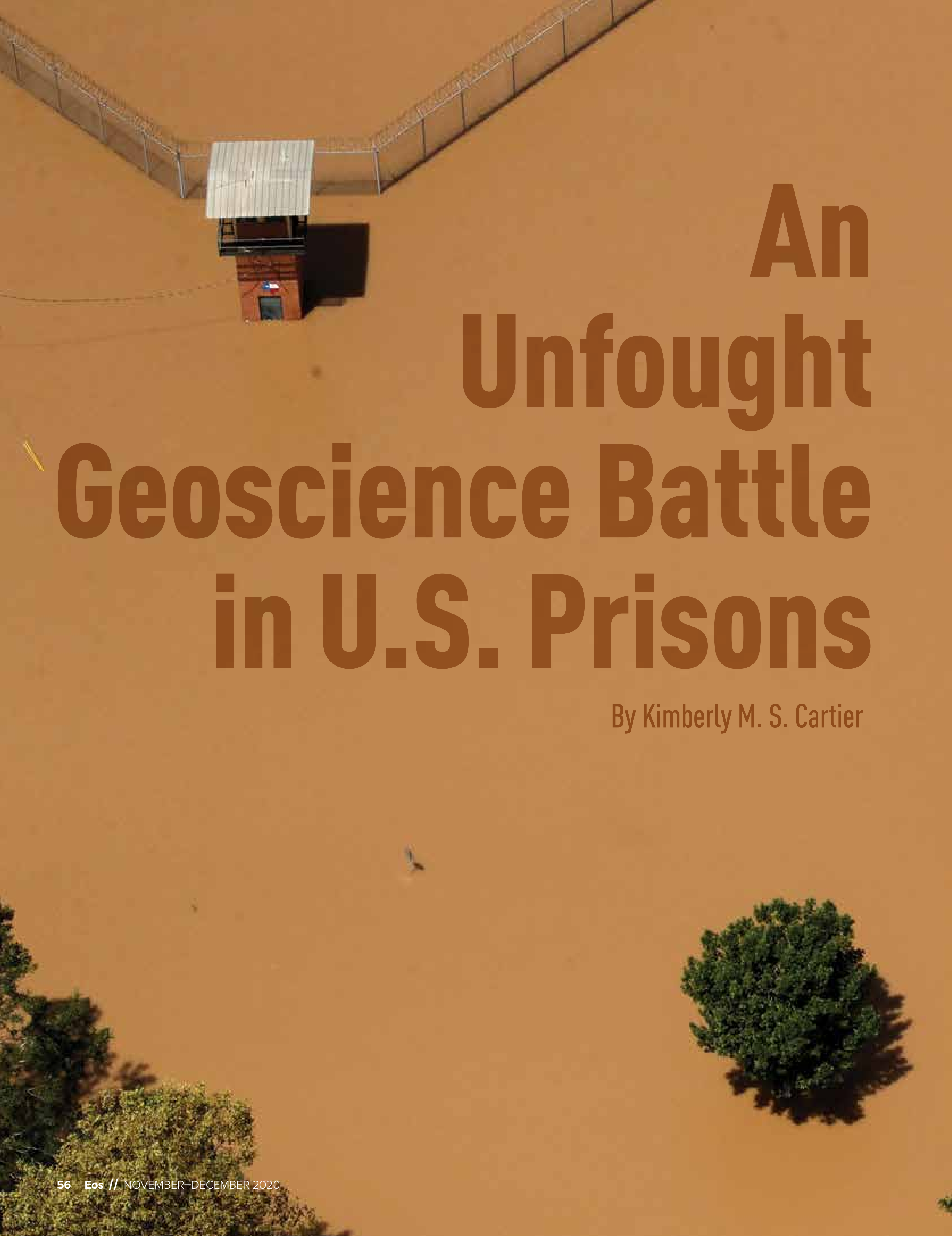
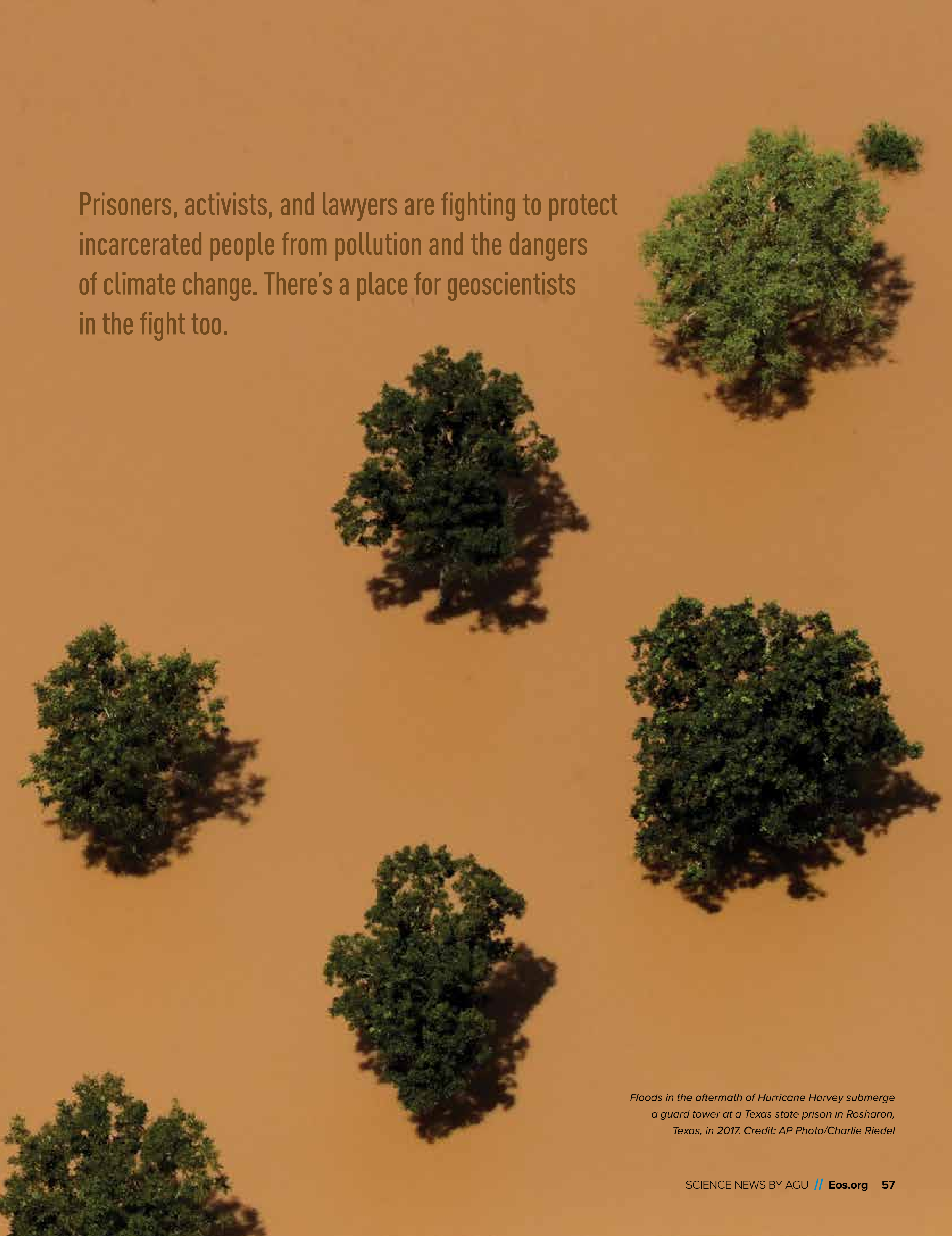


An Unfought Geoscience Battle in U.S. Prisons

By Kimberly M. S. Cartier

Prisoners, activists, and lawyers are fighting to protect incarcerated people from pollution and the dangers of climate change. There's a place for geoscientists in the fight too.



Floods in the aftermath of Hurricane Harvey submerge a guard tower at a Texas state prison in Rosharon, Texas, in 2017. Credit: AP Photo/Charlie Riedel

There is "absolutely" a place for geoscientists in establishing safe and humane conditions for incarcerated people.

The health and safety of incarcerated people in the United States are one front of the environmental justice movement, which recognizes that the structural inequalities built into society, particularly those based on race and socioeconomic status, are statistically connected to a person's access to a clean and healthful environment. Environmental justice affirms that all people have the right to clean land, water, air, and food. It demands environmental policy free of discrimination and bias and is based on mutual respect and justice for all people.

Incarcerated people have long spoken out and fought against unsafe and, at times, inhumane environmental conditions they've experienced inside detention facilities. They and those who advocate for them from outside lead that front of the environmental justice movement. Richard Mosley, for example, started experiencing health problems almost immediately after starting his sentence at State Correctional Institution (SCI) Fayette, located in LaBelle, Pa., south of Pittsburgh.

"Maybe the first or second day, my nose just closed up," Mosley said. "While I was there, I was noticing everybody was on allergy-type medicine. But I could barely breathe." Soon, respiratory problems started affecting his sleep, and he developed digestive issues. "My situation progressively just got worse.... It was just a nightmare."

Many other people incarcerated at Fayette have reported similar and more severe health problems that developed after they arrived on site: headaches, severe congestion, nosebleeds, rashes, hives, gastrointestinal problems. Cancer. After he got out, Mosley started fighting to close SCI Fayette. As a lead organizer for Put People First! Pennsylvania, he works with groups like the Abolitionist Law Center, the Prison Ecology Project, and the Campaign to Fight Toxic Prisons to bring this widespread environmental and racial justice issue into the public eye.

This recognition is needed, Mosley explained, because having deplorable conditions inside detention facilities is an environmental justice issue that isn't unique to just one prison or one state. "We're finding that this is what is going on around the country. It's not just limited to Fayette," he said.

Geoscientists should think about environmental justice in connection with their research, argued Fushcia-Ann Hoover. "Those relationships exist whether we acknowledge them or not. All of these things are always connected. And some of it is hidden, and some of it is not." Hoover is an urban hydrologist whose research is informed by environmental justice. She is a postdoctoral researcher at the National Socio-Environmental Synthesis Center in Annapolis, Md.

Although much of the current work related to prison ecology and health is done by people who work outside traditional geoscience channels—in sociology, criminology, environmental health, and law—their work shows that there is "absolutely" a place for geoscientists in establishing safe and humane conditions for incarcerated people, Mosley said.

For example, he said, SCI Fayette and many other prisons lack systematic monitoring of water, air, and soil quality. Such monitoring practices are familiar to geoscientists across many specialties. Any and all quantitative data can help support a legal case for prisoners' rights, Mosley added.

Beyond the need for data, scientists can also testify as expert witnesses in lawsuits challenging existing conditions, said Paul Wright, executive director of the Human Rights Defense Center in Lake Worth, Fla., and editor of *Prison Legal News.* So far, he added, they've been reluctant to do so: "Scientists have been largely absent from any discussions on criminal justice issues in general."

"As researchers within the geoscience community," Hoover said, "especially now we really need to be asking ourselves, 'What are the other connections within our work and within our research? And how is what I am doing affecting disenfranchised communities?'"

Nationwide Problem

The United States incarcerates more people, and more people per capita, than any other country. The country has 7,147 prisons, jails, detention centers, and correctional facilities that incarcerate 2.3 million people [*Sawyer and Wagner,* 2020].

Black, Latino, and Native and Indigenous people are overrepresented in this carceral system, a legacy of slavery and structural racism. After 1865, when the 13th Amendment banned slavery except for people convicted of crimes, southern governments created laws targeting Black people, incarcerated them en masse, and then sold their labor for profit. The southern Black Codes evolved into various vagrancy laws and then Jim Crow laws. Modern policing carried echoes of this structural racism into the post–civil rights era, for example, in "tough on crime" policies and the domestic "war on drugs."

The effect of these policies is that people of color are arrested and incarcerated at significantly higher rates than white people despite committing crimes at the same or a lower rate [*The Sentencing Project,* 2020]. One in every three Black boys and one in six Latino boys born today can expect to go to jail in his lifetime, compared with one in 17 white boys. Black, Native American, and poor women are overrepresented in incarcerated populations compared with U.S. demographics. The population of people incarcerated in the United States also includes asylum seekers and people who enter the United States without documentation.

The environmental conditions inside U.S. correctional facilities, therefore, have a significant health impact on already disenfranchised communities. This is an issue "that I know many, many men and women face throughout this country each and every day," said Matthew Morgenstern. "But because they're incarcerated, most voices or opinions aren't heard or people feel [they] don't matter."

Morgenstern detailed some of his experiences while serving time at SCI Fayette. He described being out in the yard and watching dump trucks carrying coal ash up a large hill across from the compound. When the vehicles weren't covered, "you'd be able to see dust coming off the backs of these dump trucks. Eventually, this dust would end up in the compound at Fayette. It was a daily occurrence to see a light film of a gray dust, especially in our cells."

At Fayette, many of the health issues inmates experience stem from that large hill. It's been a 2-square kilometer (500-acre) coal ash dump site since 1998 and was a coal processing waste site before that. The prison, built in 2003, lies 152 meters (500 feet) away.

Fly ash—the gray dust inside Fayette's cells—carries toxins into the air and is associated with heart and lung problems. The coal waste leeches toxic metals like lead, arsenic, mercury, and nickel into the ground and water.

"Water quality in prison, I think, is probably the leading environmental issue," said David N. Pellow, a professor of environmental studies at the University of California, Santa Barbara and director of the Global Environmental Justice Project. "It's rare to find a prison with healthy water…but it is exceedingly routine and normal to find prisons where the water is visibly, I mean to the human eye, visibly contaminated."

"In Fayette they call it tea water 'cause it's brown," said Mosley. "The water is bad, the air is bad, and the ground is bad. The soil is just sitting on top of…an excess of 50 million tons of toxic waste."

Fayette's inmates, including Morgenstern, were getting sick from the contamination, while the staff, the guards, and the guard dogs were given bottled water to drink [*McDaniel et al.,* 2014].

Monitoring contaminant levels in and around SCI Fayette would help the activists' case against the prison: "Our goal is to get the prison shut down and get everybody out," Mosley said. "Not just the prisoners. We want the guards out of harm's way, the staff out of harm's way, the guard dogs out of harm's way, because the site is toxic."

Something in the Water

The U.S. EPA collects and publicly releases data on many invisible contaminants found in water nationwide. It wasn't until

State Correctional Institution Fayette was built next to an existing coal ash and waste dump in LaBelle, Pa. LaBelle residents are pursuing a lawsuit against the owners of the dump site, and prisoners' rights groups are doing the same on behalf of those incarcerated. Credit: Robin Rombach/Copyright ©, Pittsburgh Post-Gazette*, 2020, all rights reserved. Reprinted with permission.*

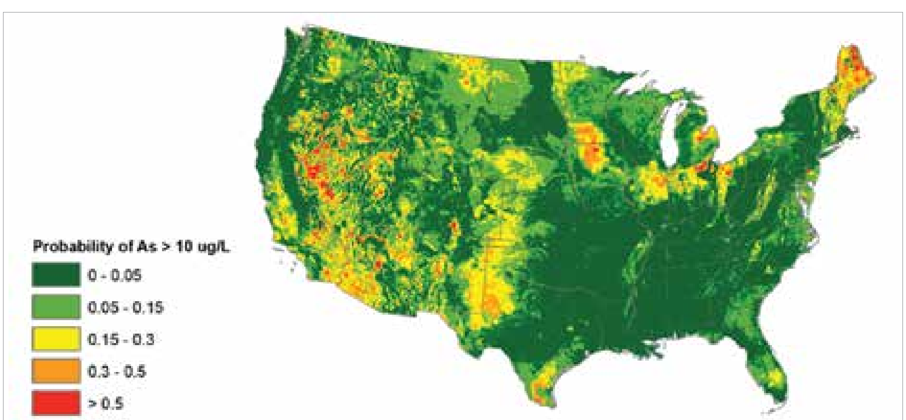
2017, however, that EPA included prisons as a category in its Environmental Justice Screening and Mapping Tool.

"One of our greatest accomplishments was a data victory with the EPA's Office of Environmental Justice," said Panagioti Tsolkas, cofounder of the Prison Ecology Project and the Campaign to Fight Toxic Prisons, two of the groups that fought for the EPA change. "Our hope is that scientists will take data tools like this and run with them, to better document conditions surrounding prisons."

However, despite data being available, "the health of U.S. incarcerated populations has been really largely ignored," said Anne Nigra, a postdoctoral researcher in environmental health sciences at Columbia University in New York. Nigra is lead author on the first nationwide research study of arsenic levels in community water systems [*Nigra and Navas-Acien,* 2020].

There are few "systematic, peer-reviewed studies about environmental injustice and environmental health impacts on incarcerated communities at all," she said, "whether it's drinking water, whether it's air quality, whether it's potential for allergens, or nutritional quality of the food."

For their study, the researchers gathered EPA data for about 37,000 community water systems serving the same population year-round. They compared arsenic concentrations of systems that supply only correctional facilities with those of systems that also supply residential communities.



Arsenic that enters drinking water is more likely to come from a natural groundwater source than contamination from pipes. Groundwater in the United States is most likely (warm colors) to exceed the Environmental Protection Agency maximum safe limit of 10 micrograms per liter in the southwestern states and in Maine. In those areas, water systems that serve only detention facilities report significantly higher arsenic levels than do nearby residential water systems. Credit: Ayotte et al., 2017, Fig. 2, https://doi.org/10.1021/acs.est.7b02881

"Water systems that exclusively serve correctional facilities in the southwestern U.S. had average 6-year arsenic concentrations that were twice as high as those reported for other community water systems" in the region, she said. The groundwater that supplies most water systems in the region has naturally occurring elevated arsenic levels because of the geochemical conditions in the aquifers. That's the leading source of arsenic contamination in the region, Nigra said, and it's relatively easy to filter out.

Despite this, "the odds of exceeding 10 micrograms per liter, [EPA's] maximum contaminant level, were also significantly higher for the correctional facilities, versus water systems that did not exclusively serve correctional facilities," she added.

Aging, Crumbling Infrastructure

The age of a detention facility can determine the type of pollution to which prisoners are exposed. Roughly two thirds of federal and state prison facilities were built less than 40 years ago, which reflects the start of modern mass incarceration policies. The remaining facilities were built at a roughly steady rate over the past 120 years, and there are nearly 100 currently operating facilities more than 100 years old (see bit.ly/prison-ages). Many compounds have old and failing structures with mold, asbestos, lead pipes, and other environmental issues common to older buildings [*Tsolkas,* 2019].

"With drinking water, one of the biggest concerns is always lead," Hoover explained. Lead pipes can be eroded by water sources that contain acidic or carcinogenic material. Unlined or untreated pipes can then bleed lead into the water supply, which is what happened at Genesee County Jail and in residential areas in Flint, Mich., she said.

In addition, aging facilities are being pushed past their capacity: The number of people incarcerated in the United States grew 500% in the past 4 decades, driven by mass incarceration at state and local levels of people of color [*The Sentencing Project,* 2020].

"The old prisons and jails keep getting older, with inadequate and overburdened water and sewage systems that appear to be failing much faster than they are repaired," Tsolkas said. And just as climate change magnifies other preexisting problems in communities around the world, climate-induced extreme weather events will likely overwhelm many prisons' water management systems.

"Particularly with climate change and the increase in intense storms, it becomes more difficult for the system to handle [stormwater] and process it," Hoover said. Stormwater "can back up into basements of old homes or basements of buildings like prisons, perhaps, depending on what their infrastructure looks like, whether or not they have sump pumps or some type of containment system to keep the water out."

"With flooding, where there are people, there is always a serious health hazard," as floodwaters can sweep up toxic chemicals, she added. "And in some cases, if you're operating under a combined sewer system, you have the addition of sewage that is mixed with the rainwater."

For example, at Parchman Farm (formally Mississippi State Penitentiary) the water "runs dark brown, dark red, has a lot of heavy particulate matter in it," said Paloma Wu, deputy director of Impact Litigation at the Mississippi Center for Justice, a nonprofit focused on civil rights advocacy and litigation that represents Mississippi prisoners in civil rights cases. "People will say, very consistently, that it smells like sewage. And that's been going on for a really long time."

Inmates, Too, Face Climate Change

Although the U.S. carceral system costs at least $182 billion per year, funding generally isn't going toward preparing facilities for climate change. In recent years, local, state, and federal correctional systems have spent a combined annual average of $3.3 billion (1.8%) on construction-related expenditures, including new facilities as well as renovations and repairs to existing ones [*Holt*, 2015].

Federal Bureau of Prisons (BOP) policy does encourage its facility managers to maximize water and energy conservation and reduce greenhouse gas emissions. However, policies regulating state and local detention facilities vary as widely as the politics of each state and municipality, explained Dustin McDaniel, the Abolitionist Law Center's director of operations.

While studying the intersection of climate law and criminal law, "it became very quickly clear the folks working on climate change weren't thinking about corrections at all," said Daniel Holt, who studied heat in U.S. prisons and jails as a visiting scholar at Columbia University's Sabin Center for Climate Change Law. He currently teaches history and law at a New York City high school. "And the notion of climate change, particularly as a public health issue for both inmates and staff, was pretty much just not on the radar of people working in corrections, either from a prisoners' rights standpoint or from a correctional administration standpoint."

In addition to more intense storms, carceral facilities will have to reckon with more extreme temperatures in summer and winter. Those in coastal areas must prepare for rising sea levels, and those in floodplains must prepare for flooding events. "The very first step is acknowledging that we have a problem," Holt said. "And the second step is to do a careful and comprehensive assessment of the problem in a detailed and localized way."

Preexisting Pollution

On-site pollution predates many detention facilities. Colocation of prisons and preexisting pollution—including landfills and waste sites—"is almost so commonplace, and usually in rural areas with limited media attention, that it often goes unnoticed," Tsolkas said.

"Environmental justice historically has focused on residential location and residential exposure," said graduate student Maggie León-Corwin. "Incarcerated popu-

"Particularly with climate change and the increase in intense storms, it becomes more difficult for the system to handle [stormwater] and process it."

Recommended Resources

Environmental justice advocates have gathered personal stories, case studies, and legal cases that demonstrate how environmental injustice, mass incarceration, and systemic racism are connected in the United States. Here are a few resources we recommend to learn more about America's toxic prisons.

Bernd, C., Z. Loftus-Farren, and M. N. Mitra (2017), America's toxic prisons: The environmental injustices of mass incarceration, *Earth Island J.,* earthisland.org/journal/americas-toxic-prisons/.

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Vazin, J., and D. Pellow (2019), Toxic detention: The trend of contamination in the American immigration system, special report, Global Environ. Justice Proj., Univ. of Calif., Santa Barbara, gejp.es.ucsb.edu/sites/default/files/sitefiles/publication/GEJP%20Special%20Report%202019_0.pdf.

Waters, M. (2018), How prisons are poisoning their inmates, *Outline,* 23 July, theoutline.com/post/5410/toxic-prisons-fayette-tacoma-contaminated?zd=NaN&zi=xdu2agrm.

Water quality and water management are two of the most pressing problems in old and aging detention facilities, including 119-year-old Parchman Farm in Mississippi. Insufficient, unmaintained, or damaged drainage pipes cause water to pool in and around the buildings (top, left and right). Pipes leading indoors or that bring water in (bottom, left and right) can get backed up, which leads to contamination. Credit: Mississippi State Department of Health

lations are easy to overlook" but still feel the effects of pollution.

León-Corwin is lead author of a study examining colocation of prisons in Oklahoma with EPA-reported Toxics Release Inventory (TRI) emissions. She is a Ph.D. student studying environmental sociology and social inequality at Oklahoma State University (OSU) in Stillwater.

Oklahoma incarcerates more people per capita than any other U.S. state. The team found that Oklahoma zip codes encompassing prisons have statistically higher levels of TRI emissions than zip codes without prisons [*Leon-Corwin et al.*, 2020].

Not by chance, areas of high emissions were also poorer and more rural. Wealthier communities reject having a prison or polluter built in their neighborhoods. And poorer communities sometimes welcome the facility for the jobs it provides, or they simply lack the political clout to stop it. "It's simultaneously 'not in my backyard' but also 'please, in my backyard,' both of which are tailored to placing prisons and facilities that release TRI emissions in economically disadvantaged communities," said Jericho McElroy, a graduate student in sociology and criminal justice at OSU and a coauthor of the study.

"There are still certainly issues of relegating those who are disenfranchised in our communities into similar spaces," Hoover said. Letcher County, Kentucky, is a prime example. Its economy plummeted after the end of mountaintop removal mining. The practice is associated with locally elevated rates of cancer, cardiovascular disease, and pulmonary disease. Letcher would have been the site of the most expensive federal prison in U.S. history, built atop a former coal mine and next to an active mine and coal sludge pond.

The location was no coincidence: "This is a business model across the country," Mosley said. "After the land has been depleted and resources have been removed, they sell it to the Department of Corrections or a landfill."

The site's approval prompted an extensive 3-year environmental impact review that led to a lawsuit filed by 21 federal prisoners from across the country, with support from groups like the Abolitionist Law Center and the Campaign to Fight Toxic Prisons.

In 2019, the prisoners won their case, and the Federal Bureau of Prisons withdrew its intent to build a penitentiary at Letcher. Prisoners and prisoners' rights activists won a major victory there, according to Pellow. "Prisoners could have been subjected to exposure to a whole host of hazards had this facility been built.... It's not just people living in residential communities who are fighting for environmental justice. Prisoners are really leading an important new front in the struggle for environmental justice. Seeing them as leaders in that cause is really important."

Ongoing Fight

Prisons, jails, and other government detention facilities are regulated by the Safe

Drinking Water Act, the Clean Air Act, and other federal environmental regulations, but case studies demonstrate that compliance and enforcement are lacking at facilities spanning the country. In a statement provided to *Eos,* the BOP refuted allegations of a lack of enforcement of environmental and health regulations: "BOP takes seriously our duty to protect staff and inmates in our facilities as well as surrounding communities. The BOP coordinates with federal, state and local environmental regulatory agencies with respect to environmental compliance, environmental studies, and water quality for our facility operations and inmate population." The agency stated that BOP policy "discusses temperature set points, ventilation, and cooling and heating systems. Additionally, BOP regularly reviews and takes steps to address environmental, health, and safety concerns in all of the BOP's correctional institutions."

What complicates matters, Tsolkas said, is that a large fraction of incarcerated people are held in county facilities that are controlled at local levels, not state or federal. That makes their conditions hard to track and target with litigation.

"If I would have told you this story a couple years ago," Mosley said, "you might have gone, 'Hmm, wow, wild story.' But nowadays, when you can turn on the news and see how people are being treated every day by government, by police, it's not a far-fetched story." Incarcerated populations have been disproportionately affected by racial injustice and the coronavirus pandemic.

"Fighting structural racism at every level is the tide that raises all boats," said Wu. "No institution is immune from perpetuating structural racism, and that's not something to make us feel bad about ourselves. It means that every one of us can improve the situation by fighting for the world we want to live in, in our own workplaces.... We can all do better in our own institutions to help dismantle structural racism. Including scientists."

"We can all do better in our own institutions to help dismantle structural racism. Including scientists."

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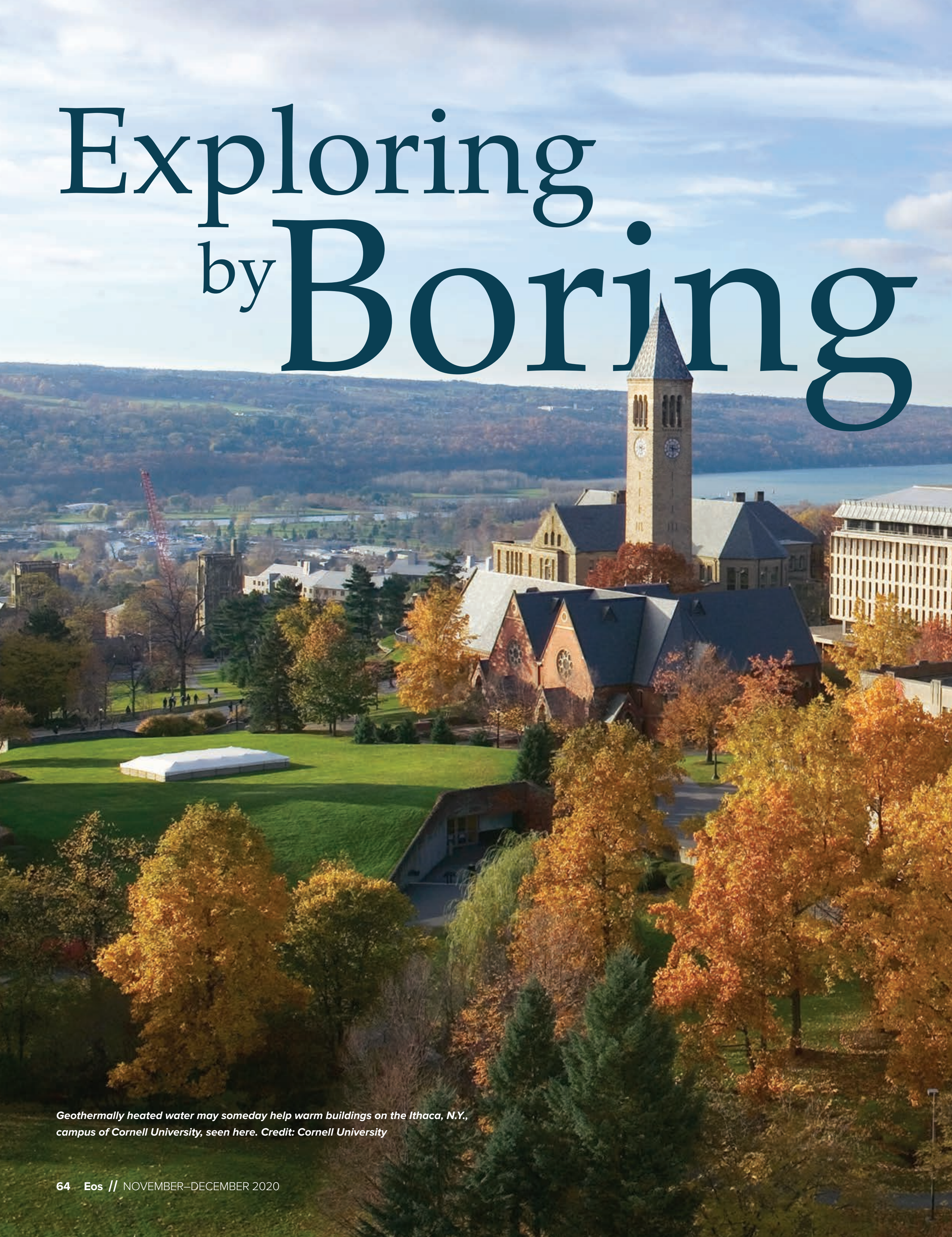
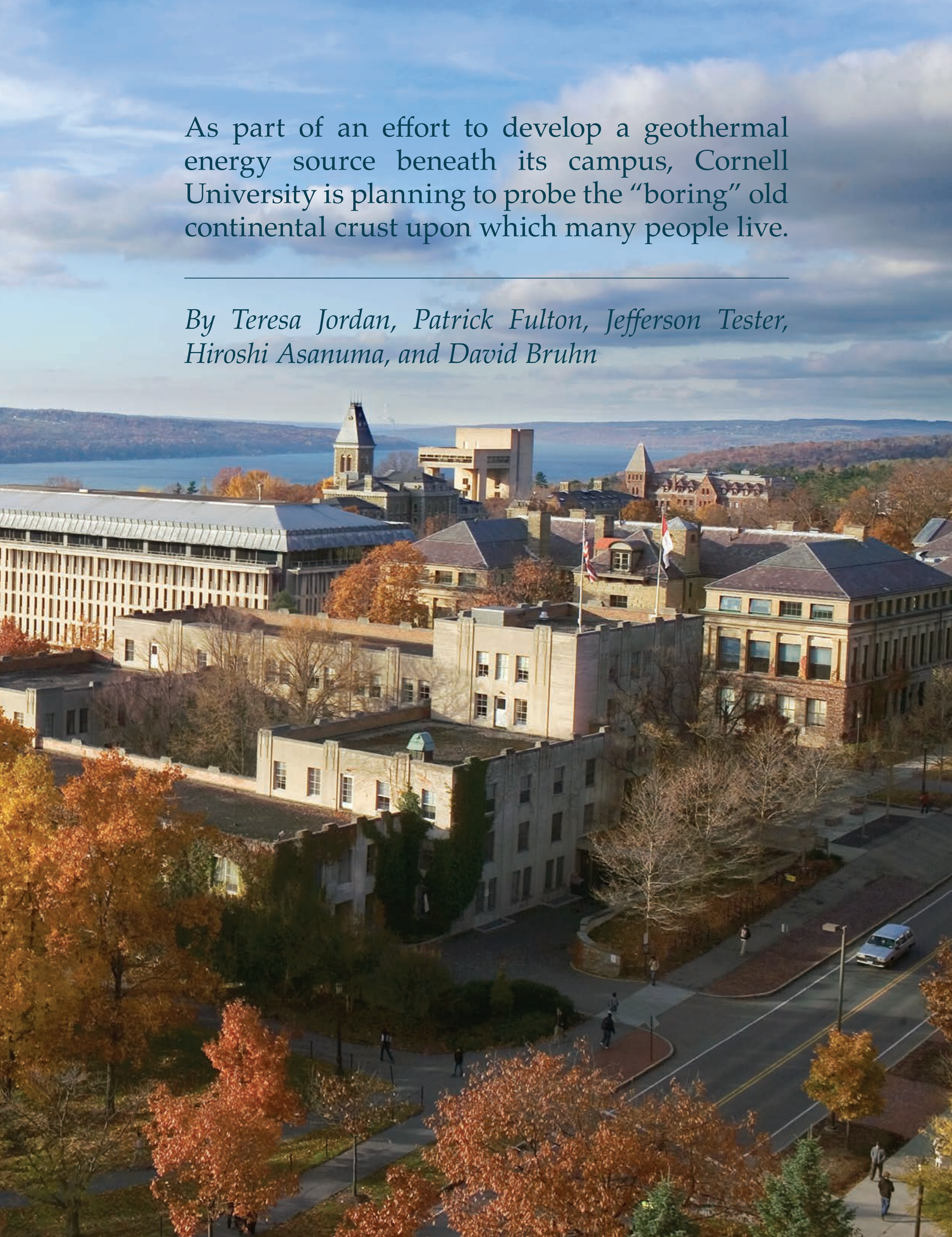
Exploring by Boring



Geothermally heated water may someday help warm buildings on the Ithaca, N.Y., campus of Cornell University, seen here. Credit: Cornell University

As part of an effort to develop a geothermal energy source beneath its campus, Cornell University is planning to probe the "boring" old continental crust upon which many people live.

By Teresa Jordan, Patrick Fulton, Jefferson Tester, Hiroshi Asanuma, and David Bruhn



In 2013, Cornell University adopted a target for its Ithaca, N.Y., campus operations to become carbon-neutral by 2035. New York State followed suit in 2019, pledging to zero out net carbon emissions by 2050. However, when they adopted these targets, neither Cornell nor New York had a plan for removing carbon-based energy sources from what they used to heat residential and commercial buildings (which accounts for 31% of total energy consumption in the state).

One possible approach, tapping geothermal energy, could help replace fossil fuels for direct use (as distinct from electrical power generation) for heating not only the Cornell campus but also the northern United States, Canada, and much of northern Europe and Asia. Such increased deployment of geothermal district heating—for example, providing a centralized supply of geothermal heat to multiple buildings via insulated pipes—could significantly lower global carbon emissions.

At Cornell, the Earth Source Heat (ESH) approach evolved to meet the need for carbon-fuel alternatives. ESH involves extracting water from hot rock using one set of wells, transferring the heat into an existing campus district heating loop, using industrial heat pumps to maximize extraction of heat from the geothermal resource, and returning the water to below ground through another set of wells (Figure 1).

At a scientific borehole planning workshop sponsored by the International Continental Scientific Drilling Program (ICDP) convened at Cornell University last January, attendees considered a plan to drill a pair of test wells to evaluate the potential of heating Cornell's campus buildings with geothermal heat extracted from a depth exceeding 2 kilometers. That pragmatic test plan also offers the opportunity to piggyback basic research studying the workings of continental crust onto the drilling operation. The ICDP-sponsored workshop allowed Earth scientists to explore how to turn this opportunity into an experiment of wide-ranging value.

We anticipate finding Paleozoic sedimentary and Precambrian metamorphic basement rocks that lie below Cornell. These rocks, like those at numerous other locations, are complex, heterogeneous, and anisotropic (Figure 1). Counterintuitively, the lack of anything geologically "special" about central New York—where levels of natural seismicity are also low—is a compelling attribute of this borehole project. To date, continental scientific drilling sites have been selected to investigate active tectonic or volcanic fea-

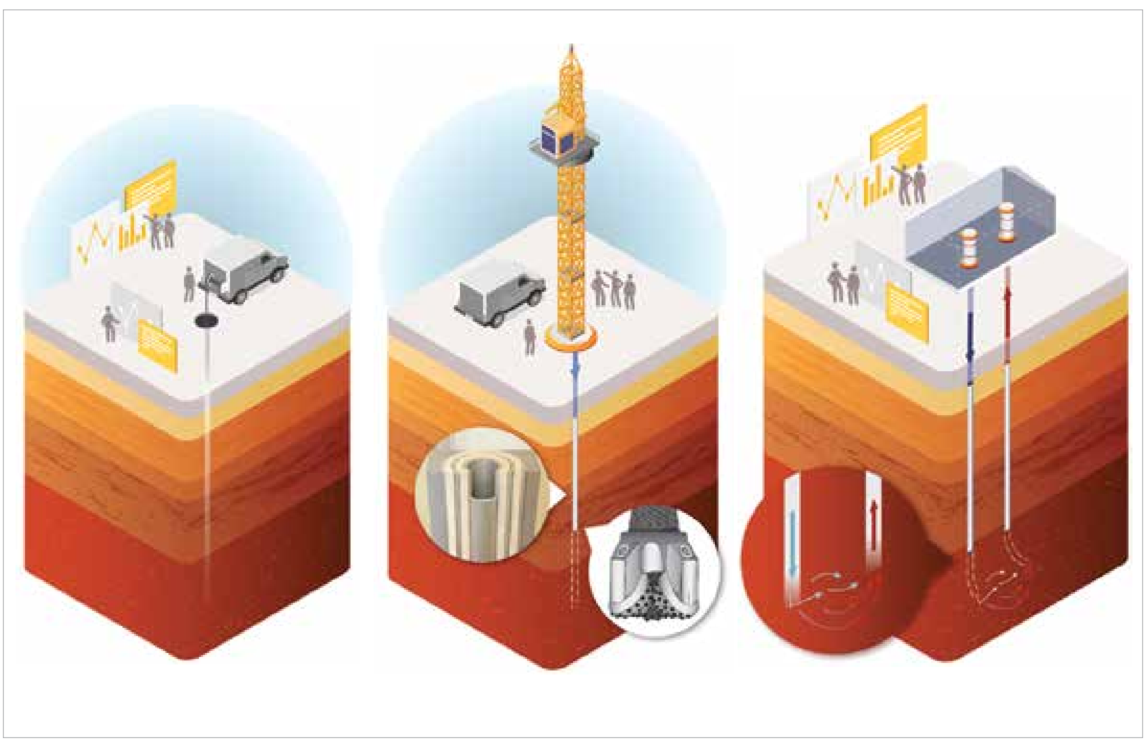


Fig. 1. Developmental stages of the Earth Source Heat (ESH) project are depicted here. In July, the U.S. Department of Energy announced funding for Cornell to drill a narrow test hole about 100 meters into the basement rock (bottom layer in the illustrations) (left). That hole will provide access to sample rocks and fluids and to study properties such as temperature. Tests to be conducted in the borehole (center) will permit analyses of geo-mechanical, hydrogeologic, and thermal properties and conditions. The goal for the ESH project is to extract geothermal heat (right) by pumping high-temperature fluids (red) from one borehole, transferring the heat into a campus heating loop, and returning cooler fluids (blue) to the subsurface via an injection borehole. Credit: Cornell University

tures, rare events like meteorite impacts, or climate history. Hence, there is uncommon value in investigating a "boring" (i.e., ordinary) location, whose results will be widely applicable.

Practical Problems with Geothermal Energy

Depth itself is not a major technical problem for the ESH project—across most stable North American continental crust, subsurface temperatures in the range of 50°C–100°C occur less than 3 kilometers below the surface, shallow enough to be reached economically with conventional drilling technology. However, geothermally heated water is used for district heating at only a few locations currently. Boise, Idaho, on the Snake River Plain, and some locations in Iceland are geologically unusual, with hot water situated near the surface. A few more thermally mundane places, like the Paris sedimentary basin in France, have rock structures at suitable depths through which fluid flows easily [*Lopez et al.,* 2010].

Even though the rocks at suitable depths beneath most of New York are sedimentary (and thus relatively porous), low permeability is unfortunately still an obstacle to implementing geothermal technology for district heating [*Camp et al.,* 2018]. In theory, the rocks can be stimulated to transmit fluids by interconnecting pores along natural networks of preexisting microfractures, through the use of fluid pressure to slightly disturb those fractures. However, such engineering approaches involve high financial risks because they may fail to produce adequate permeability to achieve energy extraction targets. Furthermore, drilling, artificial permeability construction, and fluid cycling all cause perturbations in the subsurface that may be associated with seismic risk. Overall, the lack of fundamental scientific and engineering understanding of the rocks and the coupled risks result in high costs and slow progress.

Following years of economic and technical feasibility analysis of its ESH approach, Cornell is positioned to advance an initial demonstration project for extracting 100 gigawatt hours of geothermal heat per year, enough to satisfy about 20% of campus needs. However, until deep boreholes can access the subsurface, we lack key data needed to design a geothermal system and to assess financial, technical, and seismic risks.

As a research-focused land grant university, Cornell has three integrated motivations for drilling test boreholes: to achieve its carbon neutrality goal, to demonstrate and lower the risks of a technology with potential for wide deployment, and to foster basic research.

The ICDP workshop assembled 35 visitors and 26 Cornell faculty, technical staff, and students from diverse specialties (but with little shared background knowledge), including borehole engineering, regional geology, induced earthquakes, geothermal engineering, and hydrology. About 90% of the workshop was spent in group discussions of key science questions and borehole design considerations rather than on individual presentations.

A New Generation of Geological Investigation

Five broad research themes that an Ithaca borehole would facilitate emerged from the workshop discussions:

- fluids and elemental cycling
- poromechanical behavior across a range of length scales
- controlling subsurface fractures and fluid flow
- deep life
- subsurface evolution of the Appalachian basin and its basement.

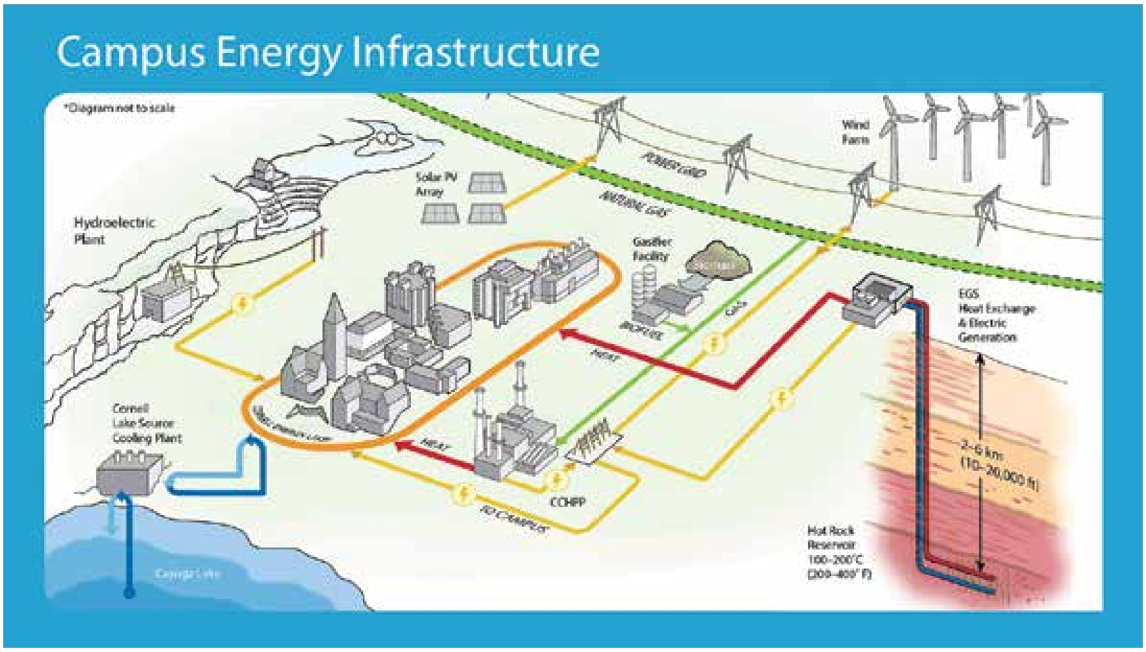
The first three themes are tightly coupled, and because improved knowledge is needed for societally critical activities including energy production and seismic risk assessment, they are likely to be at the core of successful efforts to raise funds for multimillion-dollar drilling projects. Exploration of the latter two themes would be enabled by accessing subsurface fluid and rock samples from a borehole, and findings in these themes might influence the other topics.

Cornell is positioned to advance an initial demonstration project for extracting 100 gigawatt hours of geothermal heat per year.

The common root of the first three themes is complex hydrologic, thermal, chemical, and mechanical relationships and processes—natural and human-induced—acting over timescales ranging from very short (days) to geological. Workshop participants focused on describing the experiments, measurements, and samples needed to underpin scientific advances in understanding the hydrogeology of old, tectonically inactive crust and of the physical controls affecting seismic hazard within continental plate interiors.

One hypothesis posits that the continental crust is at critical failure condition everywhere [e.g., *Townend and Zoback,* 2000]—that rocks underground are always close to failure by fracturing. This scenario can keep certain fractures open as permeable pathways, but it also means that the rocks are highly susceptible to small stress perturbations. Having a kilometers-deep borehole that provides vertically continuous data about stress magnitudes and orientations, pore fluid pressures, and temperatures in the context of lithologic and fracture properties would allow scientists to probe this hypothesis.

Workshop attendees were very interested in the possibility of gaining a better understanding of poromechanical behavior and the processes affecting stress and strain near the interface between the Paleozoic



Current and envisioned future energy sources to help Cornell University meet its goal to become carbon neutral by 2035, including geothermal heat from the ESH project, are illustrated in this campus diagram. Credit: Cornell University

sedimentary rocks and the Precambrian crystalline basement. Fiber-optic sensing along the length of the borehole, along with measurements of the physical properties of rock samples, could provide insights into the mechanical behavior of the subsurface at multiple scales. These insights are important for understanding induced seismicity and mitigating hazards.

Attendees were also enthusiastic about the opportunity to retrieve core samples that could spur a new generation of geological investigation into the thermal history of the rocks beneath upstate New York. This investigation could fill knowledge gaps about what happened to the rocks from the end of deposition in the Devonian (420–360 million years ago); through the burial, fluid flow, diagenesis, and fracturing of the Alleghanian orogeny; to the mid-Mesozoic emplacement of kimberlites and the topographic readjustments and denudation of the Cenozoic (66 million years ago to present).

Although no geobiologists participated, the workshop participants agreed that sampling could enable study of life-forms found amid the lithologies and conditions that a borehole would traverse. Discussions at the workshop revealed that the Cornell site offers even higher research value if the vertical profile of the thermal, hydrological, mechanical, and chemical properties of the subsurface could be determined at a pristine location not yet subjected to subsurface manipulation, and then monitored through time as the geothermal project progresses.

Where Science and Engineering Challenges Intersect

A major question about a Cornell borehole, one where science and engineering considerations intersect, is whether it should have a narrow or wide diameter. Regardless of diameter, each borehole to 3 kilometers or greater depth will cost several million dollars. Because a wide-diameter borehole down to an exploratory target depth of 4–5 kilometers could serve later as an operational well accommodating a higher flow than a narrow hole, a case can be made for such a hole, which could also facilitate extensive testing and sampling. An alternative strategy is to drill an initial narrow borehole that would allow studies of geologic context and in situ characterization. Later, this borehole could serve as an observatory for downhole monitoring of such things as temperature, pressure, seismic activity, and fluid chemistry.

The risks of these two alternatives are markedly different. A wide-diameter borehole intended to be used later for energy production would require much of its length to be cased with cement. However, some critical rock properties and conditions should be measured or sampled in an uncased borehole, and much of the equipment for permanent monitoring would need to be installed prior to casing. Moreover, several borehole experts foresaw this scenario leading to high costs and the high technical risk of losing the operational well if wall rock collapsed and refilled the hole.

Drilling a narrow hole to 4–5 kilometers also comes with significant practical, costly challenges. One such challenge is the limited availability of companies and equipment capable of drilling and coring such a hole at a cost-effective rate. Discussions about the back and forth between science goals and borehole operational goals revealed scenarios that may translate to significantly higher borehole costs and to compromised plans that reduce the scientific scope.

Another alternative emerged from these discussions: A narrow borehole that reaches only 100 meters into the basement would have lower costs and risks than a deep hole. This narrow-hole design would still allow seismological and hydrological experiments to document subsurface conditions before and after artificial permeability construction in a neighboring well, and after a geothermal field begins production. With this approach, the reduced risk to the integrity of a wide-diameter borehole, which could then be cased immediately to protect against collapse, could plausibly lower expenses enough to enable a three-borehole setup. This setup, incorporating one narrow, intermediate-depth hole and two wide (and cased) full-depth boreholes, might not cost much more than two wide boreholes dug with numerous workarounds and compromises.

A Promising Start to the Work Ahead

Following the ICDP workshop, Cornell University sought funds from the U.S. Department of Energy (DOE) to drill a narrow borehole through the sedimentary rocks and about 100 meters into the crystalline basement. And at the end of July, DOE announced selection of Cornell's project for funding. The funds awarded should be sufficient to bore the hole; to obtain several hundred meters of continuous core and spot cores; to analyze pressure, stress, strain, and hydrological and rock properties; and to install permanent monitoring systems.

With this foundation, Cornell and experts like those who participated in the workshop can address many of the scientific and engineering challenges laid out above. Yet some of the fascinating questions articulated at the workshop will require companion projects. We will need to obtain additional samples, install other types of sensors, extract and analyze data shortly after drilling and during years of observation, and conduct complementary experiments and geophysical surveys. Those added-value projects will require that experts lead efforts to seek, in collaboration with Cornell, funds for the worthy, complementary projects. The university is also committed to broad and rapid public dissemination of all data extracted from the borehole.

The ICDP-supported borehole planning workshop, which assembled interested parties with diverse backgrounds and broad expertise, has helped jump-start progress toward using geothermal energy to meet the university's carbon neutrality goals. The initial idea was to use a geothermal energy borehole as a chance to piggyback some fascinating scientific research onto a practical project. The ICDP workshop revealed that it is also an opportunity to increase the probability that the ESH project itself will be successful because of the "boring" companion science.

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How Forest Degradation Affects Carbon and Water Cycles

Forest degradation, including the kind of logging pictured here on Pirititi Indigenous land in the Brazilian Amazon, can significantly affect energy, water, and carbon fluxes in forests. Credit: Felipe Werneck/IBAMA, CC BY 2.0 (bit.ly/ccby2-0)

Tropical rain forests provide ecosystem services well beyond their bounds. The Amazon, for example, acts as both a sink for carbon dioxide and a fountain of water vapor into the atmosphere that later falls as rain or snow, sometimes thousands of kilometers away. But human activities and climate change are major threats to these services.

Many studies have sought to understand how deforestation, which has soared again in many parts of the Amazon, affects carbon sequestration and evapotranspiration. Meanwhile, forest degradation, which includes logging, understory fires, and forest fragmentation, may affect as large an area as deforestation does, yet its effects on water, energy, and carbon cycles in tropical forests are less well understood.

That's at least in part because forest degradation is heterogeneous and because many degraded plots are in remote regions and on privately owned land, making field data difficult to gather. But in a new study, *Longo et al.* used high-resolution lidar data collected by aircraft to overcome some of these accessibility challenges.

The researchers fed both lidar data and ground observations into an ecosystem demography model to compare water, energy, and carbon fluxes between the forest and the atmosphere in both degraded and intact regions of the Amazon forest spanning precipitation gradients. The lidar data revealed forest structure variability across five regions in the eastern Amazon (one in French Guiana and the rest in Brazil), each with different precipitation patterns and histories of land use change, to capture the diversity of degraded forests.

The model indicated that during a typical dry season, evapotranspiration and gross primary production were 34% and 35% lower, respectively, in degraded forests than in intact forests, whereas daytime surface temperatures were 6.5°C higher on average. However, during extreme droughts, the effect of degradation on these fluxes was much less apparent. In other words, intact and degraded forests behaved similarly when facing extreme water and heat stress.

The same pattern held true for fire risk: In a typical year, degraded forests were drier, warmer, and more susceptible to fire, but during droughts, intact forests were just as prone to fire, highlighting the critical role of climate variability in flammability.

Although the model had limitations—for example, it didn't consider variations in soil depth and composition, which can markedly affect these fluxes—the study advances the use of remote sensing technology for tracking structural change in degraded forests as well as our understanding of how human disturbances beyond deforestation impact energy and carbon balances in the Amazon. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2020JG005677, 2020)
—**Kate Wheeling**, *Science Writer*

Interpreting Neural Networks' Reasoning

Neural networks are everywhere in modern science, providing insights into such complex topics as facial recognition, cancer research, and risk management, among others. The machine learning technique uses networks of computational nodes working together to find patterns in massive data sets and make predictions on the basis of those data.

Neural networks may be useful in identifying meaningful relationships in the increasingly large and high-quality data sets available in the geosciences. But their application in those fields has been limited so far by the fact that the internal reasoning the networks use to make decisions and predictions is not always apparent.

In a new study, *Toms et al.* apply two new methods for interpreting neural networks: backward optimization and layerwise relevance propagation (LRP). Both methods help researchers identify which inputs are most influential in a neural network's decision-making process, which could make the technique more applicable to the geosciences, where understanding a network's reasoning may be critical for validating its predictions.

The team first applied both methods to a simple task: identifying whether a specific sea surface temperature (SST) pattern was indicative of a positive or negative phase of the well-studied El Niño–Southern Oscillation (ENSO). Team members trained the neural network on SST data from 1880 to 1990 and tested it using data from 1990 to 2017. The network identified the ENSO phase accurately 100% of the time.

Next the team applied the methods to a more complex task: predicting how sea surface temperature anomalies will impact seasonal temperatures. They trained the network on data from 1950 to 2000, tested it on data from 2000 to 2018, and found that the neural network approaches were more accurate than a traditional, regression-based approach.

Machine learning studies are becoming more common in the geosciences, but this one was the first to apply an LRP technique to the field. The authors show that the machine learning techniques can provide valid predictions, confirming that their output matches our understanding of the physical processes driving Earth systems and setting the stage for future studies that could use these techniques to identify as yet unknown relationships hiding in geoscience data. (*Journal of Advances in Modeling Earth Systems (JAMES)*, https://doi.org/10.1029/2019MS002002, 2020) **—Kate Wheeling**, *Science Writer*

A GOLDen Way to Study Space Weather

One of NASA's newest missions, called Global-scale Observations of the Limb and Disk (GOLD), is revealing how the upper fringes of Earth's atmosphere affect space weather by observing atmospheric airglow in unprecedented detail. In a new study, *Eastes et al.* report early data from the mission, including observations of how neutral gases in the thermosphere interact with charged particles in Earth's ionosphere and how these interactions respond to disturbances in Earth's magnetic field caused by solar storms.

GOLD was launched into geostationary orbit in 2018 aboard a communications satellite and began making routine observations in October of that year. The instrument measures wavelengths of ultraviolet light emitted by excited atoms and molecules at altitudes of 100 kilometers or higher when they relax to lower energy levels. These emissions phenomena include aurorae as well as much fainter yet steady airglow across the night sky.

From its vantage over the western Atlantic, GOLD observes airglow across the full disk of Earth every 30 minutes, as well as in the thin ribbon of atmosphere, called the limb, surrounding it. Occasionally, when a star passes behind Earth, the instrument takes advantage of the starlight passing through the atmosphere to measure the density of oxygen in the air at different altitudes based on the light it absorbs. GOLD also collects valuable temperature readings and observations of the ratio of oxygen to molecular nitrogen, as well as of how these characteristics change during geomagnetic storms.

Early observations of Earth's nightside from the mission have yielded surprising discoveries about airglow over the equatorial region, where large, continent-spanning stripes of emissions tend to form. This "equatorial anomaly" is far more dynamic than expected, with its brightness and appearance changing rapidly even during quiet periods between geomagnetic storms.

The Global-scale Observations of the Limb and Disk instrument (circled) appears at the bottom of the SES-14 communications satellite in this artist's illustration. Credit: NASA/CIL/Chris Meaney

The authors suggest that all told, GOLD's observations should help scientists develop better models of the thermosphere-ionosphere system and advance our understanding of space weather effects on Earth. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1029/2020JA027823, 2020) **—Mark Zastrow**, *Science Writer*

Steadying Mid-Ocean Ridge Spreading Rates

Every so often, Earth's geomagnetic field reverses, with magnetic north and south swapping places over the course of a few millennia. Researchers have tracked these reversals, which occur every few tens of thousands to millions of years, at mid-ocean ridges, where tectonic plates are pulling apart. As lava erupts at these ridges and solidifies to form new ocean crust, it records the orientation of the planet's magnetic field, creating alternating blocks of rock that are magnetized in opposite directions and that generate magnetic anomalies that can be measured by ship surveys. Combining these magnetic signatures with radioisotopic dating of the magnetized rocks has provided timelines for past reversals called geomagnetic polarity timescales (GPTSs).

Malinverno et al. update the GPTS for a period stretching from late in the Cretaceous, roughly 84 million years ago, until the end of the Eocene, 33 million years ago.

Previous GPTSs assumed that ocean spreading rates in the South Atlantic were constant or smoothly varying over time. But in data collected at other mid-ocean ridges, spreading rates appeared to change over time, sometimes erratically, creating uncertainty in the GPTS. Here the researchers used up-to-date magnetic anomaly data collected during 154 ship tracks across the North and South Pacific, South Atlantic, and Indian Oceans, as well as Monte Carlo computational methods, to smooth out spreading rates across all the ocean basins, thereby minimizing spreading rate variations and reducing uncertainty in the GPTS.

The findings contribute to researchers' understanding of the history of ocean spreading. In particular, the study revealed a major global change in spreading rates between 50 million and 45 million years ago. Around that time, the Indian subcontinent slammed into the Eurasian plate, slowing tectonic spreading in the Indian Ocean. At the same time, spreading rates roughly doubled in the South Atlantic and North Pacific, coinciding with the timing of a bend in the Hawaii-Emperor seamount chain. The results could also help resolve timescale inconsistencies in astrochronology studies, the authors note. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1029/2020JB020034, 2020) **—Kate Wheeling,** *Science Writer*

Ancient Sea Levels in South Africa May Offer Modern Analogues

The concentration of carbon dioxide in Earth's atmosphere as of June 2020 exceeded 416 parts per million, a level not seen since the mid-Pliocene warm period approximately 3 million years ago. Indeed, the entire Pliocene (5.33–2.58 million years ago) serves as a potential analogue for our present and future climate.

Scientists often turn to the stratigraphic record to understand Earth's history. Geological proxies like fossilized flora and fauna indicate that temperatures during the Pliocene were about 2.7°C–4.0°C hotter than those in the preindustrial era. Coastal rocks and sediments can also help identify the Pliocene's elevated sea levels from a time when polar ice extents were drastically smaller than today.

In a new study, *Hearty et al.* delved into the stratigraphic record to determine how high the ocean rose the last time carbon dioxide levels eclipsed 400 parts per million, investigating ancient coastal deposits along the western and southern coastlines of the Republic of South Africa. The South African coast was comparatively stable during the Pliocene and subsequent Pleistocene, so the unjostled rocks there offer optimal marine exposures and clear indicators of past sea levels. However, elevations measured in the field must be corrected to account for past vertical land motion.

This location near the Olifants River on the Atlantic coast of South Africa exhibits some of the most detailed stratigraphy of a Pliocene sea level stand from roughly 4.5 million years ago that was more than 25 meters above modern sea level. The water at that time rose above the white rocks seen in the foreground and in the haze farther down the coast. Credit: Paul Hearty

The team scoured the coastlines for sites where geologic records of past sea levels have been preserved and analyzed marine shells collected from these deposits using strontium dating. Once the authors identified optimal exposures, they collected high-accuracy GPS data to measure the 3D coordinates of key geological features to within a few centimeters.

Three of the 17 surveyed sites provided reliable age data, establishing that average sea levels during the Pliocene were between 15 and 30 meters higher than the present waterline. The results revealed two prominent topographic zones. The first zone is about 25–35 meters above current sea level and corresponds to conditions from approximately 4.5 million to 3 million years ago. The second zone is 15–20 meters above modern sea level and represents sea level about 1 million years ago, during the Pleistocene.

The authors note that ice sheets are highly vulnerable during warming climates. Their findings suggest that global sea levels are likely to undergo dynamic changes in the future because of rising carbon dioxide concentrations. The researchers also point out that their data set can serve as a baseline against which to compare future studies of global mean sea level. (*Paleoceanography and Paleoclimatology*, https://doi.org/10.1029/2019PA003835, 2020) **—Aaron Sidder,** *Science Writer*

Air Temperatures Ideal for Carbon Uptake by Subtropical Plants

More green on Earth means less carbon in the atmosphere. A photosynthesizing plant captures carbon in the air, in the form of carbon dioxide (CO_2), and converts it into plant matter. As CO_2 levels rise, ecosystems generally grow more efficient at capturing carbon. However, as temperatures rise, that efficiency wanes.

This feedback between the efficiency of plant carbon sequestration and air temperature has been demonstrated in the tropics, in models, and in studies at leaf level. *McGowan et al.* investigated this relationship on Bribie Island, a barrier island off the east coast of Australia near Brisbane, setting up sensors in three subtropical ecosystem types: a wetland, a swamp, and a pine plantation. The researchers recorded an array of environmental data, from weather and radiation levels to soil temperature and water content.

From these data, the scientists calculated that the optimum temperature range for photosynthesis, and thus for CO_2 uptake, in these environments is 24.1°C–27.4°C. And they found that when temperatures exceed this optimum window, which they often did during the study, an ecosystem's ability to capture CO_2 drops sharply. This trend was especially visible during dry periods. The monoculture of the pine plantation did not handle hot or dry conditions well. The natural wetland ecosystem, in contrast, was the most productive of the three sites and responded best to changing conditions, likely because of its natural diversity and dense vegetation, the authors note.

Earth's temperature continues to climb, and experts predict that the subtropics will experience less rain as the climate warms. In the face of these changes, the ability of plants in subtropical ecosystems to scrub carbon from the air will decline, the authors say. They suggest that similar research is needed in other climate zones and ecosystems to develop a more complete picture of plant-climate feedbacks. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2020JG005678, 2020) **—Elizabeth Thompson,** *Science Writer*

More Warming Means Worse Impacts from Runoff and Drought

A campground floods at Christina Lake in British Columbia, Canada. Credit: Thomas_H_foto, CC BY-ND 2.0 (bit.ly/ccbynd2-0)

Scientists have shown that warming global temperatures can lead to increases in extreme precipitation events—and therefore to increased surface runoff from soils unable to absorb heavy rainfall and snowmelt—as well as to aggravated droughts resulting from decreased precipitation and increased evapotranspiration. Understanding the likely timing and locations of future floods and droughts will be imperative in protecting people and managing risk.

In a new study, *Zhai et al.* use an established surface runoff model, called variable infiltration capacity, in combination with the latest climate projections from global circulation models to forecast global surface runoff and droughts and to compare differences in these forecasts between 1.5°C and 2°C warming scenarios, the targets for maximum warming established in the Paris Agreement.

The team reports that outcomes in their modeling are worse across the board for the 2°C scenario: Annual runoff is expected to be higher, water retention in terrestrial ecosystems is expected to be lower, and droughts and floods are expected to increase in frequency. The scientists identify Mexico, the western United States, western Europe, southeastern China, and the West Siberian Plain as likely candidates to experience increased droughts with the added warming. Meanwhile, Alaska, northern Canada, and much of Asia are expected to experience increased flooding hazards.

The researchers extended their analysis to determine how many more people would be affected under 2°C versus 1.5°C warming, as well as the added burden on gross domestic product (GDP). They calculated that globally, droughts would affect an additional 0.5% of the population; floods, an additional 4.9%; and droughts and floods, an additional 4.9% under 2°C warming relative to under 1.5°C warming. The scientists also found that the changes in runoff with 2°C warming versus 1.5°C warming would have widespread impacts on the affected economies, with droughts affecting an additional 4.6% of GDP globally, floods affecting an additional 2.4%, and both droughts and floods affecting an additional 5.7%.

Considering the severity of these projected human and economic impacts, the researchers point out the importance of trying to limit further warming of Earth's climate. (*Earth's Future*, https://doi.org/10.1029/2019EF001398, 2020) **—David Shultz,** *Science Writer*

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Tracking Air Pollution from Ghana's E-Waste Site

People burn wires, cables, circuit boards, and other discarded items to recover copper at the Agbogbloshie electronic waste site in Ghana. Credit: Muntaka Chasant, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

Plumes of black smoke are often seen rising from the Agbogbloshie electronic waste (e-waste) site in Accra, Ghana. The acrid clouds contain particulate matter and other pollutants that pour into the air above the capital city from two waste-burning areas at the site. But air pollution data to track these plumes and their effects are limited in Ghana and throughout Africa; only six of the continent's 47 sub-Saharan countries report levels of airborne particulate matter—the inhalable pieces of pollution that can wreak havoc on the human body.

Kwarteng et al. look to augment Ghana's limited air pollution data by using moderate-cost sampling methods to quantify exposure to particulate matter less than 2.5 micrometers ($PM_{2.5}$) and less than 10 micrometers (PM_{10}) in diameter for the waste site's thousands of employees and the densely populated communities nearby. The team measured upwind, on-site, and downwind PM concentrations using gravimetric and optical instrumentation to sample both upwind background levels of air pollution and contributions of the waste site while also accounting for local meteorological conditions.

$PM_{2.5}$ and PM_{10} levels were both significantly higher at the waste site than background levels, and 24-hour $PM_{2.5}$ levels considerably exceeded both World Health Organization and Ghanaian EPA exposure guidelines. The team found that 24-hour $PM_{2.5}$ levels at the e-waste site averaged 88 micrograms per cubic meter (μg/m^3), or 57 μg/m^3 higher than the average background level of 31 μg/m^3; the authors note that background levels were largely attributable to biomass burning and traffic emissions. Downwind of the e-waste site, $PM_{2.5}$ levels were 57 μg/m^3 (or 26 μg/m^3 higher than background). World Health Organization and Ghanaian EPA exposure guidelines for 24-hour $PM_{2.5}$ are 25 and 30 μg/m^3, respectively.

According to the authors, the study demonstrates that an approach combining gravimetric and optical measurements can provide a relatively low cost way for countries to monitor pollution levels in complex urban environments. (*GeoHealth,* https://doi.org/10.1029/2020GH000247, 2020) **—Kate Wheeling,** *Science Writer*

Sudden Oak Death Taking a Toll on U.S. West Coast

Nearly half of forest ecosystems around the world face "stand-replacing disturbances"—hazards that threaten to kill all of the trees in a localized region, such as fires, extreme weather, and disease. The spread of nonnative insects and pathogens has also reshaped North American forests, and today a disease outbreak is sweeping along the U.S. West Coast.

Sudden oak death, caused by the plant pathogen *Phytophthora ramorum*, has reached epidemic proportions in California and Oregon since it first arrived in the San Francisco Bay Area in about 1990. But the regional extent of both the disease and related tree mortality is not clear, hampering forest managers' responses to the epidemic and to other threats, as die-offs can increase fuel loads and fire severity, reduce forest productivity, and convert forests from carbon sinks to carbon sources.

Cobb et al. modeled the infection and mortality rate in forests facing *P. ramorum* invasions by combining observations from plot networks on the ground, geospatial data, and existing data sets describing tree cover and pathogen distribution. The pathogen can infect the leaves and stems of more than 130 species of trees, shrubs, and ferns, but in the new study, the authors focus on the four most affected tree species: California bay laurel, tanoak, coast live oak, and California black oak.

The team monitored more than 10,000 stems across several hundred plots in California and Oregon, tracking infections, climate, and topography to determine how various factors influenced disease progression in all four species. As of 2012, some 166.2 million stems within the study plots were infected. The majority (95.2 million) were bay laurel stems, which can typically survive *P. ramorum* infections, making the species a major source of infection for other trees.

Given the mortality rates for the other three species, the authors estimate that the disease has killed nearly 48 million stems in the past 20 years, including nearly 39 million tanoak stems alone. That's a mortality rate on par with other mass tree die-offs in the western United States due to drought and insect outbreaks, the authors note. Invasive pathogens tend to grow exponentially, meaning that these problems are likely to compound in the coming decades. But prevention and treatment programs in Oregon involving culling infected trees could serve as an inexpensive and effective model for the region to keep the plant pathogen in check, according to the authors. (*Earth's Future*, https://doi.org/10.1029/2020EF001500, 2020) **—Kate Wheeling,** *Science Writer*

The Lasting Legacy of Phosphorus Buried in Lakes

Phosphorus is one of the most biologically important elements for life on Earth and is thus ubiquitous in many crop fertilizers. Following heavy rain, particulate phosphorus often runs off field crops into nearby bodies of water, where it can dramatically alter the health of aquatic ecosystems over time.

Environmental regulations have reduced phosphorus discharges to some aquatic ecosystems to improve water quality, but despite the reductions, many systems have not experienced water quality improvement. This may be because of the internal release of accumulated, or legacy, phosphorus in sediments, which can drive eutrophic conditions—with low oxygen levels and excess nutrients—which are often hazardous to native aquatic animals.

To better understand how and in what forms phosphorus accumulates in lakes, scientists have conducted studies in which they artificially add the nutrient to a controlled experimental lake. In one such lake in Ontario, Canada, known as Lake 227, in the International Institute for Sustainable Development Experimental Lakes Area, researchers have used phosphorus to transition the aquatic environment from oligotrophic, or relatively oxygen rich and low in nutrients, to eutrophic.

Lake 227 at the International Institute for Sustainable Development (IISD) Experimental Lakes Area in Ontario, Canada, seen here, is the site of a long-running controlled eutrophication experiment. Credit: IISD Experimental Lakes Area

In new research, *O'Connell et al.* used a combination of sediment cores and laboratory analyses to track changes in sedimentary phosphorus forms during and after the transition. The sediment cores represented a natural history of the lake's relationship with phosphorus, showing the rates at which the element had been buried in the sediment as well as the elements with which it had formed complexes.

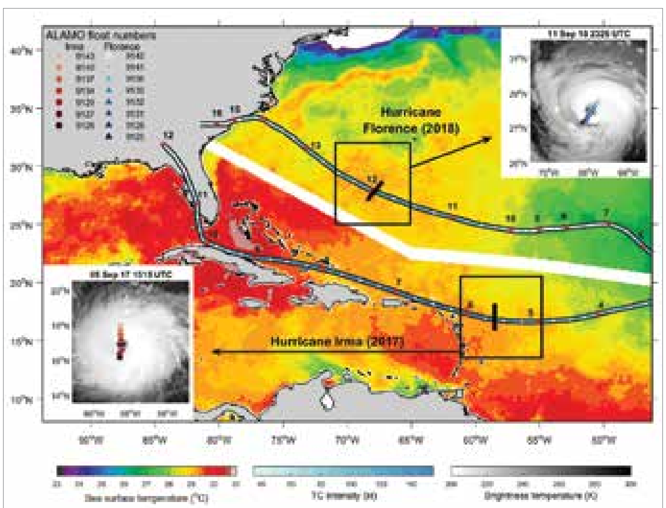
Prior to eutrophication of Lake 227, most of the phosphorus existed in an organic form in the lake sediment. As the lake transitioned to eutrophic conditions, the rate of phosphorus burial increased overall, with much of the increase attributable to phosphorus bound to humus, the dark-colored soil fraction that's rich in organic matter. The researchers found that the humic phosphorus was usually bound in iron-humic complexes, especially with ferric iron (Fe^{3+}). They note that the large quantity of Fe^{3+} found in the sediment suggests that the organic carbon–rich sediment stabilizes this oxidation state of iron, preventing it from being reduced to other forms even in highly reducing conditions.

The researchers also observed that much of the phosphorus added to Lake 227 is stored in reactive forms, meaning that the lake could remain eutrophic for years even without external phosphorus loading. They conclude that eutrophication may thus have far-reaching consequences in the future because of legacy phosphorus. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2020JG005713, 2020) **—David Shultz,** *Science Writer*

The Perils of Computing Too Much and Thinking Too Little

Emanuel, one of the most recognized and accomplished scientists in the field, reflects on the importance of theory for atmospheric, oceanic, and climate science. In so doing, he sounds an alarm about the perils the neglect of theory pose for the advancement of our science. As high-performance computing dominates an increasingly broad spectrum of activities—also in the educational sphere—there is danger that inattention to theory will produce researchers who use these vast resources ineffectively and that the opportunity for true breakthroughs, which come from new ideas, will be diminished. (https://doi.org/10.1029/2019AV000129, 2020) **—Bjorn Stevens**

What the Upper Ocean Looks Like During a Hurricane and Why It Matters

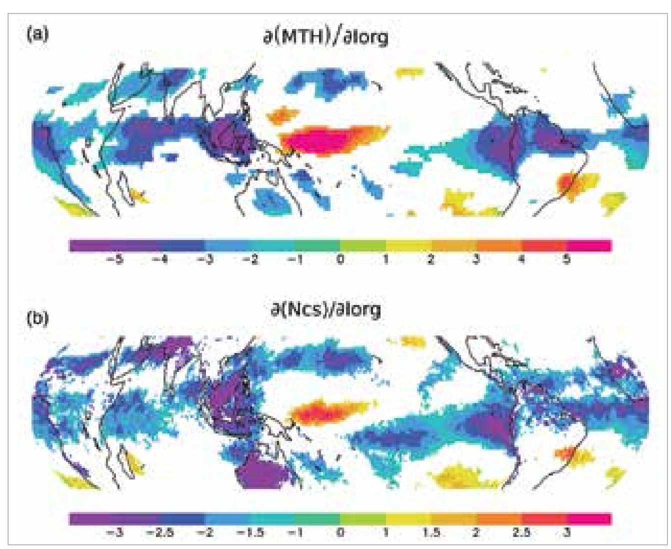


Locations of Air Launched Autonomous Micro Observer (ALAMO) floats relative to the tracks of Hurricanes Irma (2017, black circles) and Florence (2018, black triangles) and prestorm satellite-derived sea surface temperatures (°C, shaded) below and above white line, respectively. Locations of inset satellite infrared brightness temperatures (K) are indicated (black squares), as are the ALAMO positions when Irma (red circles) and Florence (blue triangles) crossed the float array. TC = tropical cyclone; kt = knots. Credit: Sanabia and Jayne, *2020*

Tropical cyclones leave cooler surface ocean temperatures in their wake, as a result of intense mixing of the upper ocean. Details of this upper ocean structure under two hurricanes are revealed in high-resolution measurements presented by *Sanabia and Jayne*. These unique measurements, derived from a variety of sensors deployed on floats, capture the space and time variability in the across-path asymmetry in ocean mixed layer properties and show the importance of salinity in controlling this structure. The view of the upper ocean provided by these measurements allows improved understanding of that layer's influence on the intensity of the hurricane, which in turn contributes to better forecasts of hurricane intensity. (https://doi.org/10.1029/2019AV000161, 2020) **—Eileen Hofmann**

Can We Observe How Cloud Clustering Affects the Radiation Budget?

Understanding what controls the tropical radiation budget is of great importance, as it offers guidance on estimating climate sensitivity to greenhouse gas increases. Both observations and climate models have well established that the tropical radiation budget is significantly influenced by lower-atmospheric stability. More recently, modeling studies have suggested that the degree of cloud clustering could also influence the radiation budget. *Bony et al.* present the first observational study that confirms the influence of convective clustering on the radiation budget at the scale of the tropics. More clustered deep convection is associated with enhanced radiative cooling, as the free troposphere is drier and more heat is emitted to space. The observations reveal that lower-atmospheric stability and convective clustering are complementary and equally important for modulating the tropical radiation budget. This emphasizes the importance of determining how the stability and cloud clustering will change with future warming. (https://doi.org/10.1029/2019AV000155, 2020) **—Sarah Kang**



Variations in (a) midtropospheric relative humidity (in %) and (b) clear-sky net radiation (in watts per square meter) congruent with the degree of cloud clustering. Enhanced organization of convection is associated with drying and radiative cooling over most of the tropics. Credit: Bony et al., *2020*

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15. **Extent and Nature of Circulation**		**Average No. Copies Each Issue During Preceding 12 Months**	**No. Copies of Single Issue Published Nearest to Filing Date**
a. Total Number of Copies *(Net press run)*		18,591	19,449
b. Paid Circulation *(By Mail and Outside the Mail)*	(1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541 (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)	12,325	13,043
	(2) Mailed In-County Paid Subscriptions Stated on PS Form 3541 *(Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)*	0	0
	(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	5,231	5,725
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c. Total Paid Distribution *[Sum of 15b (1), (2), (3), and (4)]*		17,556	18,768
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	(2) Free or Nominal Rate In-County Copies Included on PS Form 3541	0	0
	(3) Free or Nominal Rate Copies Mailed at Other Classes Through the USPS (e.g., First-Class Mail)	52	54
	(4) Free or Nominal Rate Distribution Outside the Mail *(Carriers or other means)*	334	132
e. Total Free or Nominal Rate Distribution *(Sum of 15d (1), (2), (3) and (4))*		386	186
f. Total Distribution *(Sum of 15c and 15e)*		17,942	18,954
g. Copies not Distributed *(See Instructions to Publishers #4 (page #3))*		649	495
h. Total *(Sum of 15f and g)*		18,591	19449
i. Percent Paid *(15c divided by 15f times 100)*		97.85%	99.02%

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Date: 09/28/2020

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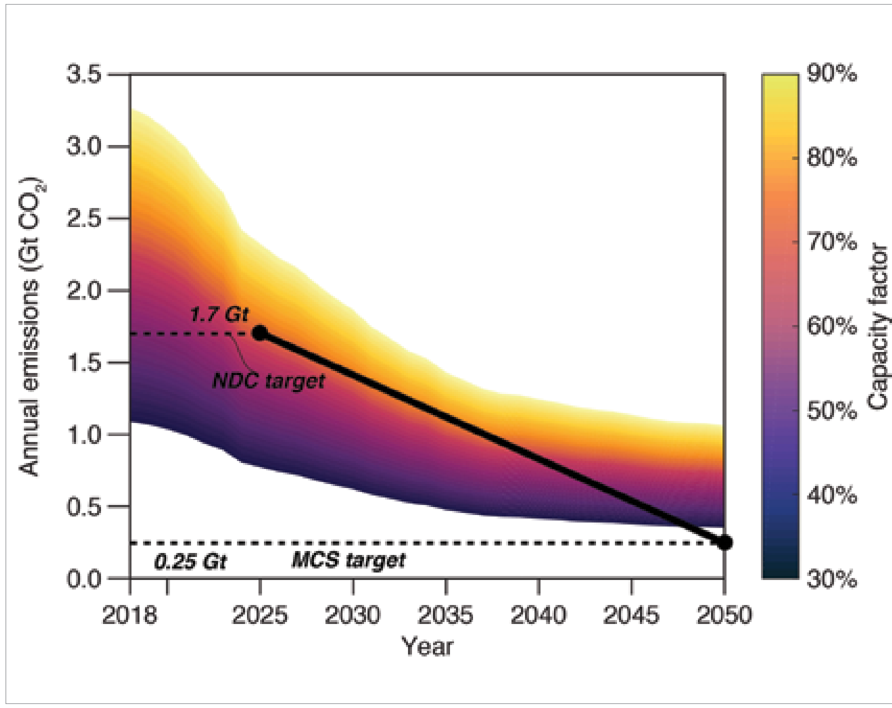
Committed U.S. Power Emissions Incompatible with Paris Agreement



Future CO_2 emissions (in gigatons) from currently operating coal- and gas-fired plants will depend on the average lifetimes and utilization of those plants. If existing plants operate over historically average lifetimes, then pledged reductions in U.S. power-related emissions (its Nationally Determined Contribution (NDC), denoted by the upper black dashed line) can be met at the current average capacity factor (60%) in 2025 but must decrease by a third to 40% or below to meet the NDC target in 2050. (MCS is the mid-century strategy released by the U.S. government in 2016 for achieving its NDC for the Paris Agreement.) Similarly, if existing plants operate at average capacity factors, plants must retire within 35 years to meet the NDC for 2050. Credit: Shearer et al., *2020*

From 2000 to 2018, carbon dioxide (CO_2) emissions from the U.S. power sector decreased by 24%. This is primarily attributed to increased use of natural gas for electricity, as gas-fired plants emit roughly half the CO_2 per megawatt hour of coal burning plants. In a novel analysis, *Shearer et al.* examine the long-term implications of the natural gas boom from the perspective of "committed emissions"—the cumulative future CO_2 emissions from fossil fuel energy infrastructure assuming average lifetimes and utilization rates. They find that the relative decrease in committed emissions is much smaller than the decrease in annual emissions, due to the rapid increase in newer gas-fired power plants. Methane leakage would further reduce this offset. If operated as historically, currently operating coal and gas plants are incompatible with U.S. pledges under the Paris climate agreement, requiring a substantial reduction in the capacity and/or lifetimes of these plants—even if no new fossil capacity is added. (https://doi.org/10.1029/2020AV000162, 2020) **—Don Wuebbles**

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Interdisciplinary

Harvard University

Bullard Fellowships in Forest Research

Harvard University awards a limited number of Bullard Fellowships annually to individuals in the biological, social, physical and political sciences and the arts to promote advanced study or integration of subjects pertaining to forested ecosystems. These full-time residential fellowships allow mid-career individuals to foster their scientific and professional growth and to contribute to research on forests at Harvard.

A major goal of the Bullard Fellowship program is to enhance research activities at Harvard Forest and build long-term collaborations that connect Harvard Forest with other parts of the University. Fellows can be based at the Harvard Forest or associated with other departments and centers at Harvard, such as the Department of Organismic and Evolutionary Biology, the Harvard University Center for the Environment, and the Arnold Arboretum.

Fellowships are for 6–12 months, with a maximum stipend of $60,000 for a full-year Fellowship. Awards are not intended for graduate students or recent postdoctoral candidates; Fellows are expected to be in residence throughout their fellowship. Harvard Forest is committed to establishing and maintaining a diverse and inclusive community that collectively supports and implements our mission.

Additional information is available on the Harvard Forest website (https://harvardforest.fas.harvard.edu/mid-career-fellowships). The deadline for applications is December 15th.

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At the Institute of Geosciences, Geology section, Faculty of Mathematics and Natural Sciences of the Rheinische Friedrich-Wilhelms-Universität Bonn a

W3 Professorship for General Geology

is to be filled by October 1st, 2021.

The future holder of the position has to be capable of teaching a broad range of areas in Geology. We are looking for an internationally recognized scientist with an outstanding track record in innovative research in the area of General Geology, who is concerned with the effects of both geodynamic and surface processes on the geosphere.

It is expected that the professorship will establish an internationally visible research team and actively participate in the conception and implementation of research projects in the field of interdisciplinary Earth system research with the Department of Geology (Sedimentology, Hydrogeology) and the other departments of the Institute (Geophysics, Geochemistry/Petrology, Paleontology and Meteorology), the Geoverbund ABC/J as well as the other departments of the University of Bonn and contribute to the transdisciplinary research areas of the University of Bonn. In addition, an active role in academic management is explicitly expected.

Teaching is an integral part of the professorship. The applicant should cover the entire range of geological processes B.Sc. and M.Sc. study programs of the institute and contribute to the further development of the study programs. The teaching should be field focused and include the teaching of laboratory analytical methods. Excellent didactic skills and teaching experience are required.

The prerequisites for recruitment are governed by § 36 HG NRW.

The University of Bonn actively supports diversity and equal opportunities. The University of Bonn has been certified as a family-friendly university and offers a dual career service. Its aim is to increase the proportion of women in those fields in which women are under-represented and to place a special focus on promoting their careers. Therefore, the university specifically requests applications from suitably qualified women. Applications will be handled in accordance with the Equal Opportunities Act of North Rhine-Westphalia. Applications from suitably qualified people with severe disabilities that have already been verified or from people with an equivalent status will be particularly welcomed.

Applications with the usual documents (curriculum vitae, research profile and plan, teaching portfolio, list of publications, copies of university degrees and certificates) should be sent by **November 15th, 2020** to: **Fachgruppe Erdwissenschaften der Math.-Nat. Fakultät der Universität Bonn, Meckenheimer Allee 176, D-53115 Bonn, Germany.** Please also send a digital copy of all documents (as one PDF file) to: **erdwissenschaften@uni-bonn.de**

icdp

The International Continental Scientific Drilling Program (ICDP)

Call for Proposals

The International Continental Scientific Drilling Program, ICDP coordinates and supports multinational endeavours in continental scientific drilling. The program focuses on themes of global geoscientific importance underpinning socio-economic challenges, including climate & ecosystem evolution, sustainable georesources and natural hazards, as outlined in the new ICDP Science Plan.

With this announcement, the ICDP invites Earth scientists to submit pre-proposals, workshop proposals and full proposals in which drilling is required to achieve critical research goals. This call is open to investigators from ICDP member countries (Austria, Belgium, China, Czech Republic, Finland, France, Germany, Iceland, India, Israel, Italy, Japan, New Zealand, Norway, South Africa, Spain, Sweden, Switzerland, The Netherlands, United Kingdom, and United States of America) as well as from countries considering membership in the ICDP.

Please note that ICDP provides operational support and allocates co-funding for drilling-related costs. This concept of commingled funding and international cost sharing, in addition to an exchange of technological capabilities and expertise, has proven very successful and positive reviews from ICDP typically serve as door-opener to acquire matching funds from national and other funding agencies. In the proposal evaluation process ICDP will consider scientific quality and global relevance, technical and financial aspects as well as equality, gender and contribution of early career scientists.

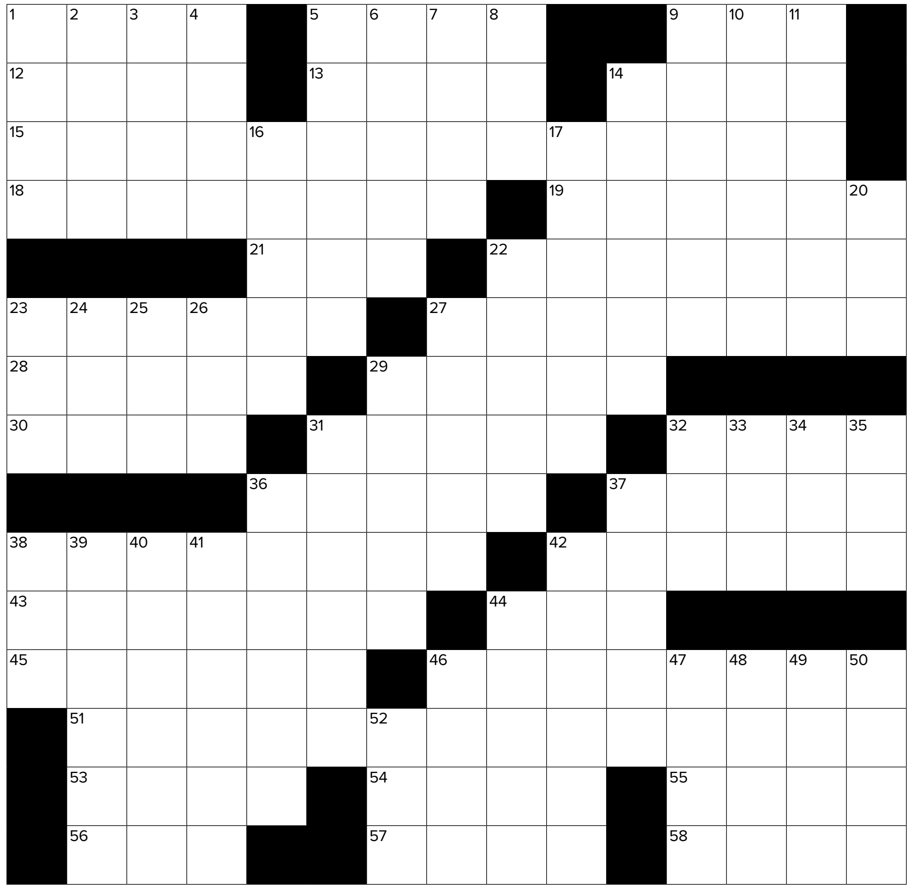
ICDP aims to foster joint projects with the International Ocean Discovery Program (IODP) and therefore cordially invites project proposals in which coordinated drilling on land and at sea is required (Land To Sea projects, L2S). ICDP and IODP have established a joint evaluation scheme for L2S-proposals to streamline and optimize the evaluation process and to encourage submission of such proposals. The respective pre-proposal and workshop proposals are open for submission by January 15 to ICDP, whereas L2S full proposals are invited to be submitted by October 1 to IODP.

Detailed information on the scope of the ICDP, the submission of proposals, proposal format, the process for developing a successful proposal, the grant conditions and the evaluation process is available at: **www.icdp-online.org/proposals**.

The deadline for submission of all proposals is **January 15, 2021**. Please submit a single file of less than 10 MB size **using the new proposal cover sheet** according to the guidelines via e-mail to the ICDP Program Office using: **proposal.submission@icdp-online.org**.

Geology Wordplay

By Russ Colson, Minnesota State University Moorhead



Find the answers at bit.ly/Eos-answers

ACROSS

1 Sandy deposits in bends of rivers
5 They might be apple or cherry
9 A way of handling coordinates in GIS
12 Includes the Himalayan, Ural, and Altai mountains
13 Of Green Gables, e.g.
14 What's left after an oxygen-starved prairie fire, perhaps
15 A volcano from the deep—or a device for draining diamonds?
18 Rain, but not the sea, chemical-wise
19 You may fail, but you ________
21 Another option, for short
22 Sallied forth
23 Something unusual
27 Just old dirt—or an ancient planetary system star?
28 What rivers do to a mountain or valley
29 What good intentions did to the road to hell?
30 With 32 across, a rock that doesn't belong
31 Sharpened
32 With 30 across, a rock that doesn't belong
36 Members of a Pueblo tribe
37 Fla. dino relative
38 All wet underground—or an upper room for no extra charge?
42 ________ and forever
43 A dinosaur (formerly) or lizard
44 Prefix for -active or -ton
45 Objects like the Ring Nebula and tree rings
46 Mineral luster typical of opaque oxides
51 They start out on top—or places with heroic powers?
53 Chooses
54 Complement to sciences
55 Surface feature typical of divergent plate boundaries
56 Unpubl. novels, e.g.
57 A place for oviraptor eggs, e.g.
58 Elems. 68 and 76, or sensual love

DOWN

1 Caspian Sea port important for oil production
2 An inverse trig. function
3 Edges of impact craters
4 Dutch island and stratovolcano of the West Indies
5 Not completely
6 A narrow embayment along a shoreline
7 Oklahoma hometown of former astronaut Owen Garriott
8 A collection of data
9 Enter
10 Using the letters from elems. 16, 27, 53, and 78, the genus of goldthread
11 Sound system term from Greek for "three-dimensional"
14 Did not destroy
16 Delight
17 Motivated by a spirit of conscientious environmentalism?
20 Alpine music form, without vowels
22 The wise computer user does this frequently
23 Tyrannosaurus or Oedipus
24 Were, but in the present
25 Actor/director Howard
26 A promise of fidelity
27 Don't do it when the storm hits
29 "If I need your help, I may just ______"
31 It rises
32 An observable and predictable pattern of behavior in nature
33 You might fail, but give ________ go
34 A mouse to a cat?
35 Units of time (abbr.)
36 Shout-out for Earth Science (abbr.)
37 Exhibit smug pleasure
38 Public service announcement (abbr.)
39 Inventor of a two-wheeled horse-drawn carriage of the same name
40 Sharp escalations, as of prices
41 Something a volcano does
42 Writer, architect, or musician, e.g.
44 Like mosquitos and roaches
46 A greater amount
47 Elem. 3 and 75, or pre-euro money in Italy
48 Yazoo tributary to a better known river with nearly the same name in western France
49 Facts and such, briefly
50 Complement to bnfts
52 Do it for gold

Monile from Malawi!

That greeting means "hello" in Chitumbuka, the local language spoken here in northern Malawi. Since 2012, I have worked with Mzuzu University as the manager of the Centre of Excellence in Water and Sanitation.

Where do we wash our hands? Many areas of Malawi are still lacking a piped water supply, which makes hand washing much more difficult.

The photo shows our awesome Girls' Science Day camp with area high school girls sponsored by an AGU Celebrate 100 grant for the 2020 International Day of Women and Girls in Science. We learned how to overcome this hurdle by making a three-part, low-cost hand-washing station. It consists of (1) the bottom portion of a 2-liter plastic bottle holding water; (2) the bottom portion of a 500-milliliter plastic bottle with holes punched into the bottom, used to "dip" water from the 2-liter bottle and sprinkle the water over hands; and (3) soap on a rope surrounded by the top portion of a 500-milliliter plastic bottle so the goats don't eat our soap!

We use our yearly camp at Mzuzu University to focus on local science that affects the communities the girls live in and to encourage these girls to develop new and better science, technology, engineering, and mathematics (STEM) solutions, for hand washing and beyond.

Rochelle H. Holm, Mzuzu University, Mzuzu, Malawi

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