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EOS

Earth & Space Science News

100 YEARS

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When natural disaster hits, geoscientists can help us move what we need where we need it most.

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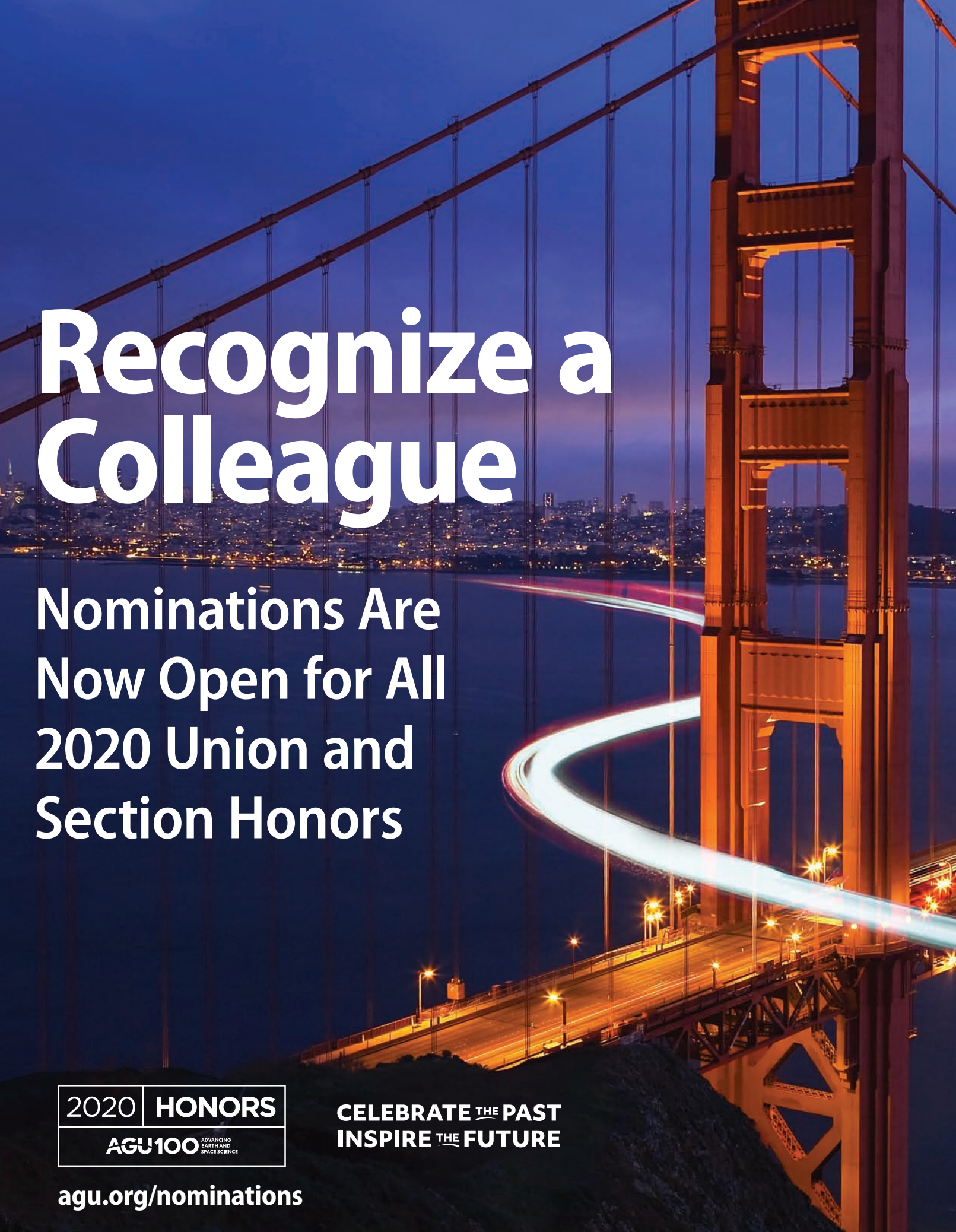

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For the Benefit of Humanity

Supporting the practice of science is only half of AGU's mission statement: "Our purpose is to promote discovery in Earth and space science for the benefit of humanity." Our membership believes it crucial to see science as more than an end itself—to increase our knowledge of the universe—or a practical advancement of our day-to-day lives. We must also embrace science as a means of continuing our own existence.

"Listen to the scientists" is a now common refrain of the youth climate movement, which fully recognizes that the world is going to change dramatically during the lifetimes of its young activists. They'll almost certainly suffer more frequent and intense natural hazards and all the associated fallout. The scientists they speak of work across geoscience fields and have started to look more and more at the implications of their research on our lives.

AGU recognized this ever-increasing convergent geoscience that was reporting on natural hazards and other environmental impacts to our health and safety. In 2008, we formed the Natural Hazards focus group. As the number of studies rose in health-related geoscience, AGU responded by launching the *GeoHealth* journal in 2016. Both the Natural Hazards focus group and the GeoHealth community were formalized into AGU sections in 2017.

This year is the second that geohealth is an official topic at our Fall Meeting, and we believe that all of our attendees will find enlightening, forward-looking science in the more than 40 sessions being convened. As we continue to celebrate AGU's Centennial, this issue of *Eos* looks at the study of natural hazards and the burgeoning field of geohealth.

Our cover story describes how scientists are helping communities in Puerto Rico after Hurricane Maria severely damaged the water distribution infrastructure (p. 22). A team began by testing water quality in neighborhoods around the country and then uploaded that data—along with helpful contextual information such as pipeline damage, power outages, and the availability of food and water aid—to a publicly available online platform called HydroShare. In its second phase, the scientists are training local water managers to share data and use the digital community as a resource to help them care for their neighbors.

Similarly, a group in Haiti is harnessing the power of community to monitor earthquake risk (p. 17). The country had no seismic network at all before the devastating 2010 earthquake, and the national system set up after has not proved entirely effective. Scientists are turning to a different solution: installing numerous "personal-sized" seismic instruments in houses and small businesses. Not only does the redundancy mean that even small quakes will get recorded if some of the equipment loses power, but the engagement required to install the instruments means that people become personally invested and knowledgeable about the hazards that threaten their communities.

Some truly optimistic news: Scientific innovation is turning some of the most toxic places in the world into environmental cleaning systems. Asbestos mines now sit idle in Canada, closed after the discovery of the material's disastrous health effects. Now these sites have the potential to pull carbon dioxide out of the air at significant scale. Read about how scientists are accomplishing this feat on page 36.

May we take inspiration from each of the scientists featured in this issue, as well as from pioneer Alexander von Humboldt (p. 26). We honor him, on the occasion of his 250th birthday, by continuing to use our scientific curiosity and drive to make connections across our fields not just about the way the world works, but the way in which we live in it.

Heather Goss, Editor in Chief

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Christine W. McEntee, Executive Director/CEO

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Cover illustration: juliars/stock.adobe.com; Design by Valerie Friedman

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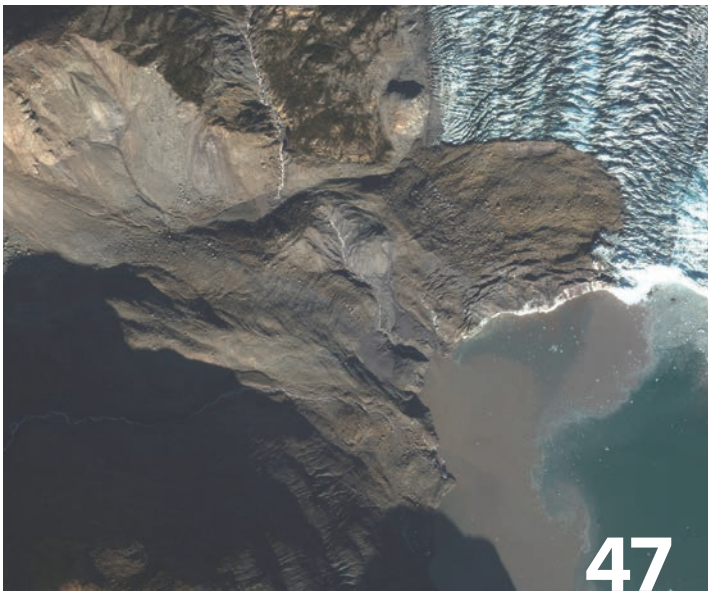

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"Glass Pearls" in Clamshells Point to Ancient Meteor Impact

These microspherules may hint at a previously unknown meteorite impact. Credit: Kristen Grace/Florida Museum of Natural History

Mike Meyer recently returned to investigating 83 mysterious objects from his past.

The identities of these microscopic objects, collected while sifting through fossilized clams in a Florida quarry in 2006, were unknown for more than a decade. Many of the glassy spheres, about 200 micrometers in diameter, are translucent, and others have frosty surfaces. Some have bumps or cracks on their surfaces, likely caused by the abrasive action of sand grains, said Meyer, an Earth systems scientist at Harrisburg University of Science and Technology in Pennsylvania.

More than a decade later, Meyer and coauthors of a study published in *Meteoritics & Planetary Science* analyzed the physical characteristics and elemental compositions of the mysterious microspherules (bit.ly/glass-pearls). They concluded that the curious objects "are likely microtektites or a closely related type of material."

Microtektites are tiny bodies of natural glass formed from terrestrial debris ejected during meteorite impacts.

Meyer estimates the objects to be 1–2 million years old on the basis of the current consensus on the age of the shell beds where they were found. However, the beads could have been transported from elsewhere before they were enclosed in the shells, introducing the possibility that they are even older.

An Unexpected Find

Meyer serendipitously discovered the silica-rich "glass pearls" when he was a University of South Florida undergraduate student participating in a summer fieldwork project led by Roger Portell, director of the invertebrate paleontology collection at the Florida Museum of Natural History and a coauthor of the new study.

Meyer and other students searched for benthic foraminifera enclosed in fossilized clams in a Sarasota, Fla., quarry. There, a 4.5-meter-tall section of the Plio-Pleistocene Upper Tamiami Formation was exposed. (The quarry is now sealed up and part of a development, according to Meyer.) Meyer and the other students collected eight sediment samples and used five different sizes of mesh to sieve the samples.

The microspherules were found only with a 98-micrometer sieve, the study notes. A paintbrush coated with gum tragacanth was used to remove the tiny structures from the samples and mount them on micropaleontology slides.

Right after happening upon the glass spheres, Meyer emailed researchers to ask whether any of them knew what he might have. Some experts told him that the microspherules were "weird looking." They suggested different techniques he might use to further study them, but those required expensive equipment and detailed analyses outside of the scope of the resources available to Meyer as a college student.

Meyer postponed his quest to identify the pearly unknowns.

A Reignited Search

After Meyer earned his doctorate and began working at Harrisburg University, he resumed looking for answers.

Coal ash and fly ash contamination were effectively ruled out as the source of the microspherules. Coal ash particles are usually between 0.1 and 20 micrometers in diameter and tend to have irregular shapes, the researchers wrote. "Fly ash is also more heterogeneous in composition," with higher concentrations of aluminum and iron than those of the tiny spheres.

Other types of contamination were also noted as unlikely sources, given that the specimens were found only in certain layers of raw sediment and within articulated shells.

The microspherules' spectroscopy data were compared with those of volcanic rocks, microtektites, and micrometeorites. "A volcanic origin is unlikely," the paper says, not only because there aren't any known volcanoes nearby but also because the microspherules have high sodium concentrations.

The microspherules' high sodium concentration also indicates that the objects are not micrometeorites. The sodium suggests that "significant evaporation has not occurred, ruling out micrometeorites, since they experience substantial heating and evaporation during atmospheric entry," according to the study.

Meyer and his coauthors ultimately suggest that the microspherules are microtektites from a previously unknown impact event. As for the high sodium concentrations, they could be explained by a meteor's impact into carbonate-rich sediments, a smaller impact, or one that occurred close to where the objects were deposited.

The study is "fascinating," but more work is needed to constrain the ages of the microspherules, study the specific cause of their high sodium concentration, and investigate the impact that may have created them, said Scott Harris, a planetary geologist at Fernbank Science Center in Atlanta, Ga., who wasn't involved with the study.

Additional specimens are needed for these analyses, and Meyer has asked Florida fossil clubs to share similar microspherules as they are found.

By **Rachel Crowell** (@writesRCrowell), Freelance Science Journalist

Combatting the Urban Heat Island Effect

Around the world, cities are often a few degrees hotter than surrounding rural areas. A recent study verified that across the world, the intensity of this so-called urban heat island effect depends on a city's population and how much rainfall it receives annually.

One key factor, according to lead researcher Gabriele Manoli, is how much water is exchanged with the atmosphere by a city compared with the surrounding land. "Evapotranspiration…is the process of transferring water from the soil into the atmosphere, regulated by vegetation," Manoli, an environmental engineer at University College London, told *Eos*. "This process has a cooling effect on the Earth's surface."

Adding green space to a city is a common strategy to mitigate urban heat. If a city has more greenery than the surrounding area, the urban heat island (UHI) intensity will be relatively mild, Manoli's team found. But the study suggests that if a city sits in a lush and verdant region, "vegetation still helps, but you need many more trees to get the same effect," he said.

Cool and Dry, Warm and Wet

"It was known that there are two general trends: The intensity of urban heat islands increases with population and…with increasing precipitation in the region," Manoli explained. "Population is a proxy for the size of a city, its form, activities, and infrastructures, while precipitation is a proxy for the local climate and vegetation characteristics."

The researchers sought to verify and explain these trends on a global scale, so they gathered summertime surface temperature data from more than 30,000 cities around the world. They compared the average temperature inside a city with that of the surrounding undeveloped area—the UHI intensity—and compared that to a city's population and amount of precipitation.

The team found that the population trend held up on a global scale. "The bigger a city is, the warmer a city is," Manoli said. UHI intensity also increased with precipitation but began leveling off when precipitation in a city reached about 1,000 millimeters per year.

If a city sits in a lush and verdant region, "vegetation still helps, but you need many more trees to get the same effect."

Why? As a city grows, it replaces the vegetation in undeveloped areas with urban surfaces and some amount of greenery. This alteration changes how that parcel of land exchanges water with the air and how that air flows.

"If a city is surrounded by a desert," Manoli said, "then the city can be cooler than its surroundings because it can have green spaces that transpire water, it can exchange heat more efficiently than the barren land, and so on."

However, "tropical forests transpire and cool down the surface much more efficiently," Manoli said. "In this case, removing the natural vegetation and substituting it with urban surfaces creates a large difference in evapotranspiration that contributes to more intense urban heat islands." This research was published in *Nature* (bit.ly/nature-heat).

Dan Li, an urban microclimatologist at Boston University in Massachusetts who was not involved with this study, called this "an important step toward bridging the gap between…urban scaling theory and the study of urban climate."

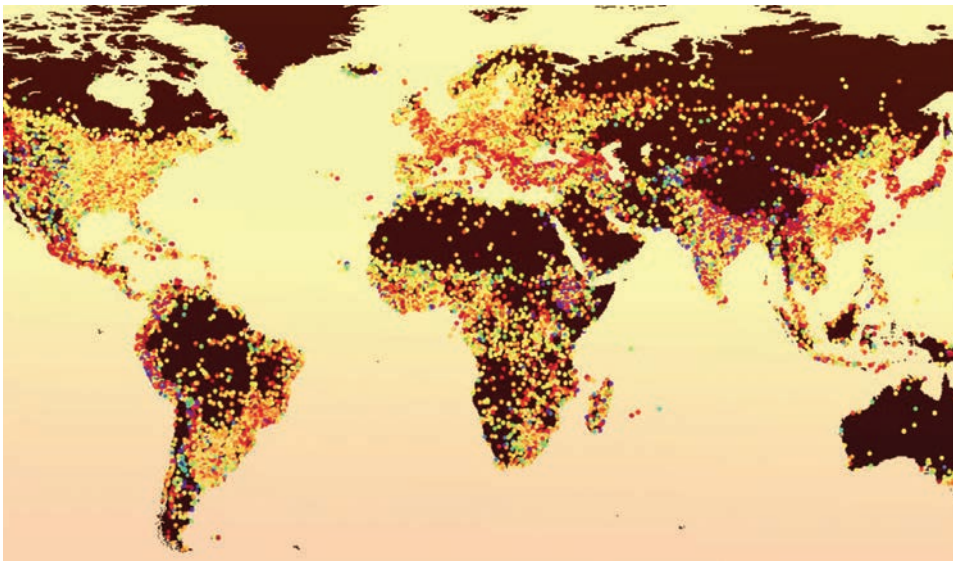
According to Li, the study suggests that "if we get a good sense of how urban population changes, we can have a first-order estimate of how the urban heat island intensity might change in the future." This claim will need to be verified by Earth system models that consider urban land expansion, he said.

Cooling Down Our Cities

These results emphasize the need for climate-sensitive urban planning and heat mitigation strategies, the team writes. "Of course, vegetation is beneficial for many reasons and can cool down a city," Manoli said. "But the amount of green space that a city needs to significantly reduce the UHI effect, in terms of percentage of the total area, varies depending on the local climate."

Strategies that increase green space and albedo will work best in drier climates like Great Britain's but not in regions like Southeast Asia. Those areas, the team suggests, should also incorporate other cooling methods like shading and ventilation.

"To combat the urban heat island effect, you need a number of strategies," Manoli said, "especially if you're in hot, humid places like the tropics."



This map shows the intensity of the urban heat island effect in 30,000 cities around the world, calculated during the cities' summertime. Warmer colors mark cities that are hotter than their surroundings, and cooler colors mark cities that are colder than their surroundings. Credit: Image by Gabriele Manoli, illustration by Beatrice Trinidad

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

Warming Oceans Could Make Our Brains Slower

Omega-3 fatty acids could be one reason that human brains evolved to be so powerful, but changing water conditions associated with climate change may reduce the amount of omega-3 available for human consumption. A new global tally of the omega-3 fatty acid docosahexaenoic acid (DHA) found that it will drop in availability by 10%–58% depending on how aggressively humans curb greenhouse gas emissions over the next century.

Humans get their dietary dose of DHA from eating fish and shellfish. The Food and Agriculture Organization of the United Nations recommends that infants consume 100 milligrams per day, and studies advise that adults consume between 50 and 500 milligrams per day (adult dosage is an active area of research). DHA helps with signal transduction in the brain; past research suggests that it aids learning in toddlers, and it may be linked with lower rates of Alzheimer's.

Fish will have lower amounts of DHA because of climate change, said Stefanie Colombo, an assistant professor in aquaculture nutrition at Dalhousie University in Halifax, N. S., Canada, and an author on the study published in *Ambio* (bit.ly/global-warming-DHA).

Fish get DHA from algae, tiny aquatic organisms that grow in fresh and salt water. Algae use DHA to moderate the fluidity of their bodies; when the water around them is cold, they avoid freezing by amping up their DHA. Because climate change is warming waters around the world, algae are producing less DHA. In a 2016 study, Colombo and colleagues found a "significant and powerful correlation" between increasing water temperature and the amount of DHA in algae.

The scientists took the research one step further in the latest study, modeling the total DHA in fish around the world over the next century under four different greenhouse gas emissions scenarios.

Under the scenario with increasing greenhouse gas emissions, which most closely aligns with today's emissions behaviors, they found that DHA could decrease by up to 50% in the next 80 years. "To me, that was the biggest number," Colombo said.

"An Underappreciated Risk of Global Warming"

High-latitude countries like Norway, Greenland, and Chile are projected to sustain enough fish yields to remain above the daily recommended dose of DHA in 2100. But the new model predicts that countries such as China, Japan, and Indonesia that currently produce enough DHA for their populations will have insufficient stores by the end of the century.

Countries in Africa that rely on inland fisheries will be hit the hardest. Lake and river waters are warming faster than the ocean, and countries that aren't affluent may not have access to trade or new technologies. Many African countries will produce less than 25 milligrams per person per day by 2100, far below the recommended intake for both infants and adults.

Technologies to combat a reduced amount of DHA are still in their early stages. Early trials on genetically modifying the oilseed in canola oil to include DHA are awaiting approval by U.S. regulatory bodies. Growing algae in controlled environments is often prohibitively expensive, Colombo said.

The new study "describes one of the most important threats for humans during ongoing climate change," said Martin Kainz, an ecotoxicologist scientist at WasserCluster Lunz in Austria who was not involved with the research.

Humans can't create their own omega-3 fatty acids but need it in the cell membranes of our neural tissues to facilitate signal transfer among cells. The projected decline in DHA availability "will thus have detrimental effects for human well-being and perhaps even for human evolution," said Kainz.

Irina Guschina, a research fellow in the School of Biosciences at Cardiff University in Wales who did not participate in the new study, said that the research raises awareness of an "underappreciated risk of global warming." She cautioned that the recommended dosage of DHA for adults is still being debated, however, and that other fatty acids like omega-6 are also important for human health.

Colombo said that how fish react to lower DHA still needs to be tested in the lab, including their metabolic response to warming temperatures. She plans to feed fish in tanks with different levels of DHA and increase their water temperature. "That's kind of a follow-up study that I probably wouldn't have done unless we did this model," she added.

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

Ancient Rain Reveals Long-Eroded Mountains

The supercontinent Pangea was formed from titanic collisions of landmasses that folded and lifted Earth's crust. Now researchers have pieced together evidence about the mountains created by these collisions, though they have long since eroded away.

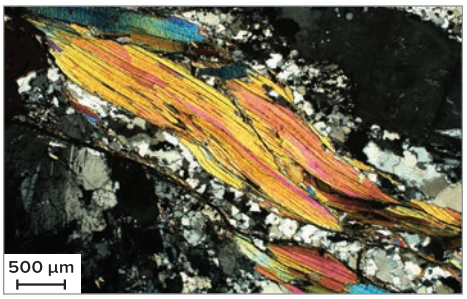
Using chemical measurements of 300-million-year-old precipitation from modern-day France, scientists have shown that the peaks situated roughly in the middle of Pangea were about as tall as the European Alps. Because mountainous geography affects atmospheric circulation, these results also shed light on the paleoclimate during the Carboniferous period, the researchers suggest.

In 2016 and 2017, Camille Dusséaux, a geologist at the University of Plymouth in the United Kingdom, and her colleagues collected granite in northwestern and southern France. The sites they sampled contained the eroded remnants of the Variscan mountain belt, a span of mountain ranges created when the continents of Laurussia and Gondwana converged hundreds of millions of years ago. The granite the researchers collected was once 3–12 kilometers underground. "The roots of the mountains are outcropping at the surface," said Dusséaux.

Dusséaux and her collaborators preferentially selected rocks in detachment zones, fractures in Earth's crust. Detachment zones function like conduits that allow precipitation like rainwater and snowmelt ("meteoric water") to percolate down, said Dusséaux.

Back in the laboratory, Dusséaux and her colleagues crushed the rocks and looked for muscovite, a mineral in the mica family. Because muscovite interacts with water, it records the chemistry of falling precipitation.

"The meteoric water goes down in the crust and exchanges with the muscovite," said Dusséaux. "That will change its hydrogen and oxygen isotope composition."



Chemical measurements of the mineral muscovite reveal ancient rainwater in French granite. Credit: Camille Dusséaux

Isolating Isotopes

That change is important because in a twist of physics, the chemical composition of precipitation reflects a landscape's topography.

Water molecules—each containing two hydrogen atoms and one oxygen atom—come in slightly different forms. Some water molecules contain ^{2}H, or deuterium, an isotope of hydrogen with one proton and one neutron in its nucleus (also known as heavy hydrogen), rather than ^{1}H, which contains only a proton in its nucleus. Water can also contain ^{18}O, an isotope of oxygen with eight protons and 10 neutrons in its nucleus, rather than ^{16}O, which contains eight protons and eight neutrons.

In clouds, heavier water molecules—those containing ^{2}H or ^{18}O—tend to condense before their lighter brethren and fall as precipitation. Therefore, a mass of air at higher elevation, which has condensed multiple times, tends to have fewer water molecules containing ^{2}H or ^{18}O.

"Every time precipitation forms, the air mass will become more depleted in heavy isotopes," said Dusséaux.

She and her colleagues found that the muscovite in their samples was relatively depleted in deuterium, consistent with the original meteoric water falling from a higher elevation (i.e., over taller mountains). Using known relations linking the prevalence of deuterium-containing water molecules and elevation, Dusséaux and her collaborators estimated that the elevation of the Variscan mountain belt was once comparable to that of the European Alps.

"No one had ever measured the hydrogen before," said Dusséaux. "This is the oldest hydrogen isotope composition of rainwater ever recovered."

Contributions to Climate Modeling

These paleoaltimetry estimates reveal more than just topography. They're also important for climate modeling because mountain ranges affect atmospheric circulation. For example, the contours of Himalayan peaks and valleys have been shown to affect monsoon precipitation.

In agreement with previous research, Dusséaux and her colleagues suggest that modern-day France was previously located near the equator, in a warm climate. These results, some of which were published in *Terra Nova* earlier this year, were presented at the 2019 Goldschmidt geochemistry conference in Barcelona, Spain (bit.ly/fluid-rock-interaction).

"This was a really well done study," said Page Chamberlain, a geochemist at Stanford University not involved in the research. A lot of research has focused on younger mountains, but no one had previously used this technique to study the Carboniferous period, he said.

Dusséaux and her team's methodology should be applied to other regions as well, said Chamberlain. "There are all of these mountain belts where I think this is the best approach."

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

Vintage Radar Film Tracks What's Beneath Antarctic Ice

Thwaites Glacier is part of the West Antarctic Ice Sheet. Credit: NASA/OIB/Jeremy Harbeck

Antarctic ice melts from the top down and the bottom up. Researchers and art historians recently digitized an archive of 1970s radar film that peers through the ice surface into the shapes below. The vintage measurements will let glaciologists and climate scientists track changes in the ice across double the time frame offered by modern radar data alone and will aid glacial melt projections.

"A lot of the changes in Antarctica are happening at the bottom," said Dustin Schroeder, a radar glaciologist at Stanford University in California who led the digitization project. "In the past, we were limited to 1 or 2 decades of modern digital data. But now we have this older record that can extend that back to 40 or 50 years," he told *Eos*. "And that time will just grow."

Peering Through the Ice

Radar sounding is "the geophysical method we use to map what the topography of the continent looks like under the ice sheet," Schroeder explained. "You send a radar pulse straight down from an airplane, and you look through the ice down to the bed…like a slice of layer cake."

> "I think in terms of luck, or prescience, we have film in some of the places we'd most want it."

The technique was groundbreaking for Antarctic research in the 1970s because "we didn't know what the continent looked like at all," Schroeder said. From 1971 to 1979, an international survey team flew along a 400,000-kilometer zig-zagging path across Antarctica, mapping beneath the ice and storing the radar profiles on 35-millimeter optical film. Much of that film had never been analyzed in detail.

Schroeder's team worked with art historians and Hollywood vintage film experts to digitize those film reels and archive them online for easy access. The team then combined those older radar profiles with modern radar and altimetry data to measure how the bottom of the Antarctic ice sheet has changed in the past 40–50 years.

With the longer radar timescale, the researchers found that the eastern ice shelf of Thwaites Glacier in West Antarctica has thinned faster than suggested by only 1 decade of data. The ice shelf lost 10%–33% of its thickness between 1978 and 2009 at a rate of about 40 meters per decade, faster than the 25-meter-per-decade rate suggested by modern data alone.

Another subglacial feature, a basal channel beneath the Filchner-Ronne Ice Shelf, remained relatively stable over about 40 years. That at least one feature remained unchanged after including the vintage radar demonstrated that the changes his team saw near Thwaites are real, Schroeder explained. These results were published in *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/ice-sheet-restored-records).

Learn from the Past to Model the Future

"Digitizing these old radar lines was a real service to the community," Leigh Stearns told *Eos*. Stearns is a glaciologist at the University of Kansas in Lawrence and was not involved with this study. "Being able to extend our record of observations, particularly of key variables such as ice thickness and basal condition, provides context for current ice sheet dynamics and helps parameterize ice sheet models," she said.

The digitization project is a "Herculean effort," according to Joseph MacGregor, a project scientist for NASA's Operation IceBridge. "Operation IceBridge's plans for its final Antarctic campaign…include potential repeats of these pioneering missions across the coastline of East Antarctica," he told *Eos*. "Repeating these flights gives us a chance to measure any ice thickness change over 4 decades."

The vintage radar film covers some of the most dynamic places in Antarctica, Schroeder said. "The Ross Ice Shelf is one of the densest areas covered by this old survey," he said. "I think in terms of luck, or prescience, we have film in some of the places we'd most want it."

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

EOS CENTENNIAL COLLECTION

Is Chicago Water Pollution Halting a Silver Carp Invasion?

Pollution from the Chicago Area Waterway System might be stopping an invasion of silver carp in its tracks. Recent research has found that heavily polluted water flowing south from Chicago might be overloading the fish's ability to process the toxins.

"Invasive silver carp at the leading edge of their invasion front in the Illinois River seem to be exhibiting responses consistent with their exposure to increased environmental contaminants," lead researcher Jennifer Jeffrey, a biologist at the University of Manitoba in Winnipeg, Canada, told *Eos*.

"This provides us with some important clues regarding what might be limiting this invasive species from continuing its progression toward the Great Lakes of North America, when little else has seemed to affect its pervasive spread," she said.

Silver carp jump in the Fox River in Illinois. Credit: Ryan Hagerty/U.S. Fish and Wildlife Service, CC BY 2.0 (bit.ly/ccby2-0)

A Stalled Invasion

Silver carp were introduced into the Mississippi River basin in the 1970s to combat algae growth. They aggressively spread upriver and were classified as an invasive species in 2007. But the invasion stalled about a decade ago in the Illinois River just north of its junction with the Kankakee River, about 65 kilometers downstream from Lake Michigan.

"There's a stark change in water quality at that point," coauthor Cory Suski, an ecologist at the University of Illinois at Urbana-Champaign, said in a statement. "That's right where the invading front stops."

This kind of abrupt halt is not typical for an invasive species. "Some invasive species thrive in degraded or disturbed habitats because in these situations they are less likely to encounter resistance from native species," explained Anthony Ricciardi, an aquatic ecologist at McGill University who was not involved with the study. "Native competitors may be better adapted to natural conditions, so when these conditions change, the natives lose their home field advantage."

"This fish never stops for anything," Suski said. The researchers wanted to determine whether something in the fish's biology could explain the coincidence.

Fish Versus Pollution

In 2016, the team captured fish from three locations along the Illinois River: one site at the leading edge of the invasion front and two downriver sites with well-entrenched populations. The team collected blood and liver samples from the fish to see whether specimens from different areas showed any physiological or genetic differences.

"We saw huge differences in gene expression patterns between the Kankakee fish and the two downstream populations," Suski said. "Fish near Kankakee were turning on genes associated with clearing out toxins and turning off genes related to DNA repair and protective measures.

"Basically, their livers are working overtime and detoxifying pathways are extremely active, which seem to be occurring at the cost of their own repair mechanisms," he said. "We didn't see that in either of the downstream populations." These results were published in *Comparative Biochemistry and Physiology, Part D: Genomics and Proteomics* (bit.ly/silver-carp).

When the Answer to a Problem Is Its Own Problem

Jeffrey said that to her knowledge, this is the only situation we know of where human activity has accidentally halted the spread of an invasive species. U.S. Geological Survey hydrologist William Battaglin, who was not involved with the research, agreed that this scenario might be unprecedented.

The researchers cautioned that they haven't definitively linked the water pollution to the changes in the carp's biology. It might yet be a coincidence that the water quality and the fish's biology show changes at the same location.

"Currently, we don't know how sensitive silver carp are to the contaminants that are coming out of the Chicago area," Jeffrey said. The team continues to research the possible connection between the toxins and the genetic changes.

"We're not saying we should pollute more to keep silver carp out of the Great Lakes. That's not it," Suski said. But Chicago area water managers should be aware of the potential connection as the region continues to clean up its waters. "Through the process of improving the water quality, which we should absolutely be doing, there's a possibility that this chemical barrier could go away," he said.

"Bottom line," said Ricciardi, is that "invasive species can exploit a major change in environmental conditions, regardless of whether such a change is considered an improvement or a deterioration in overall habitat quality."

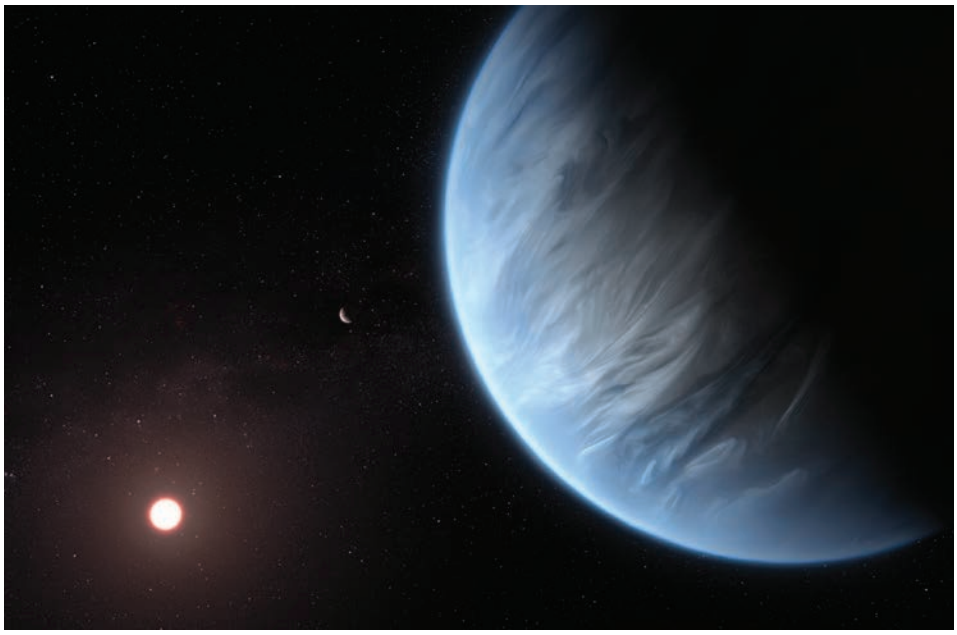
By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

Water Found in Atmosphere of Habitable Zone Planet

Astronomers have detected water vapor in the atmosphere of a planet that orbits within the habitable zone of its star.

"This is the only planet we know of outside the solar system that [has] the correct temperature to support water, has an atmosphere, and has water in it, making this planet the best candidate for habitability we know of right now," Angelos Tsiaras told reporters at a press conference in September. Tsiaras is an astronomer at University College London (UCL) in the United Kingdom and the lead author of a new paper on the planet.

This is also the first time that water vapor has been detected in the atmosphere of an exoplanet that is not a gas giant. The discovery was published in *Nature Astronomy* (bit.ly/Nature-water-exoplanet).



This depiction illustrates K2-18b, foreground, and K2-18c (crescent) orbiting their red dwarf star. Credit: ESA/Hubble, M. Kornmesser

Habitable, but Not Hospitable

K2-18b was discovered by way of the Kepler Space Telescope in 2015. A few months later, Björn Benneke, an astrophysicist at the University of Montréal in Canada who was not involved with this study, used the Hubble Space Telescope to observe the planet passing multiple times in front of its star at infrared wavelengths. This technique measures the chemical fingerprint of a planet's atmosphere as starlight passes through it. Tsiaras and his team analyzed those data with their own software when Benneke's data became publicly available.

The team found that water vapor left a strong signature in the planet's atmospheric spectrum. Of the hypothetical atmospheres that the team tested, "they all fit the data, but they all point to a significant concentration of water," as well as of hydrogen and helium, explained coauthor Jonathan Tennyson, also at UCL.

Benneke's team confirmed the detection of water vapor in a paper submitted to the *Astronomical Journal* and also show that water vapor might condense and rain down through K2-18b's atmosphere (bit.ly/arXiv-water-exoplanet).

> "Fundamentally, Hubble wasn't designed to do observations of exoplanet atmospheres."

"It's super exciting to have a first glimpse into the atmosphere of a planet this small," exoplanet researcher Laura Kreidberg told *Eos*. Kreidberg, of the Harvard–Smithsonian Center for Astrophysics in Cambridge, Mass., said that K2-18b might be "more like a mini-Neptune than a super-Earth because it still has some hydrogen in its atmosphere."

"This planet is not a second Earth," Tsiaras added, because it's twice the size and has 8 times the mass of Earth. It also orbits a cool red star less than half the size of the Sun.

"Even though it's in the habitable zone," Kreidberg said, "it's very different from the Earth, and it's not at all clear whether the planet is actually a hospitable environment for life to evolve [in]." Kreidberg was not involved with this study.

"The Limit of What We Can Do"

The atmospheric models suggest that water vapor could make up anywhere from 0.01% to 50% of the atmosphere's composition. The data are not precise enough to narrow down this range or to detect other molecules the atmosphere might have, the researchers found. "With the current data, we can only detect the existence of an atmosphere and the existence of water," Tsiaras said.

Thomas Beatty, an exoplanet atmosphere researcher at the University of Arizona in Tucson who was not involved with this research, said that for this system, "this appears to be the limit of what we can do with current facilities. Hubble is an amazing observatory, but…fundamentally, Hubble wasn't designed to do observations of exoplanet atmospheres."

Upcoming space-based telescopes "were designed from the ground up" to take more precise and accurate atmospheric measurements than is currently possible, Beatty said.

And as for telescopes on the ground, Earth's humid skies complicate the search for water elsewhere. "Ironically," Tennyson said, "the less like Earth this is, the easier it's going to be to do from the ground."

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

EOS CENTENNIAL COLLECTION

El Niño May Be a Culprit in Yemen's Cholera Epidemic

Increased rainfall in East Africa caused by a particularly strong El Niño and subsequent weather conditions may have helped usher in one of the worst cholera epidemics in modern history in war-torn Yemen.

"In Yemen, there is a catastrophic crisis in terms of human health and the availability of fresh water," said Shlomit Paz, head of the Department of Geography and Environmental Studies at the University of Haifa in Israel and author of a research note published in July in *Environmental Research* (bit.ly/Yemen-cholera).

Yemen has been embroiled in a civil war since 2015, and the cholera epidemic has been ongoing since 2016–2017. Cholera bacteria thrive in untreated water, and the Yemeni outbreak may be due to the breakdown of basic infrastructure (including water sanitation facilities) in the country. Estimates of more than 1.2 million infections make the Yemeni cholera epidemic the largest in epidemiologically recorded history, according to UNICEF and the World Health Organization (WHO).

A Yemeni child receives a cholera vaccination during a house-to-house immunization campaign in April. Credit: picture alliance/Getty Images

Early Outbreaks in East Africa

Cholera cases first started to pick up in Somalia and surrounding countries in 2016, coinciding with particularly heavy rainfall due to extreme El Niño conditions.

Paz said it's possible that the cholera bacteria that started the epidemic in Yemen migrated out of East Africa through human hosts, but they also may have been carried by small insects. Chironomids, small midges that spend their early life stages in water, are known to carry the disease and can transmit bacteria between water reservoirs, she said.

Strong winds blowing from the Horn of Africa across the Gulf of Aden in July, August, and September 2016 could have carried the midges northeastward to Yemen, Paz said. There, they may have infected water supplies that helped start the epidemic.

Colin Stine, a professor of epidemiology at the University of Maryland who was not involved in Paz's paper, isn't sure that midges would have been able to carry sufficient loads of cholera bacteria to cause the epidemic in Yemen. He agreed that the Yemeni cholera epidemic likely originated in East Africa but thinks it came from a human source rather than from midges.

Stine said that just one human can carry cholera bacteria in amounts orders of magnitude higher than many midges could.

> "It is very clear that climate change has a lot of effect on vector- and food-borne diseases."

"The weakness of the paper [is] that it doesn't have those kinds of calculations in it," Stine said.

Stine said it's hard to disprove the El Niño theory, but he pointed to a similar idea that circulated around a 2010 cholera epidemic in Haiti. Some researchers initially believed that weather conditions prompted by La Niña had a hand in causing the outbreak, but it was later found to have originated in a United Nations peacekeeping camp in the Caribbean country.

Regardless, Paz said that health authorities would gain a lot from monitoring weather conditions, especially because the warming climate will create ideal conditions for the rapid spread of disease.

"It is very clear that climate change has a lot of effect on vector- and food-borne diseases," Paz said. "In order to be prepared for such an epidemic, I think that first of all there is a need for constant monitoring and forecasting—collaboration between scientists and doctors."

Stine agreed that there should be more dialogue between environmental scientists and doctors tracking the spread of disease, though he's not sure how important this will be for monitoring the spread of cholera.

By **Joshua Rapp Learn,** Freelance Journalist

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Tropical Corals Are Migrating Away from Warming Waters

While millions of human refugees are expected to migrate in response to the climate crisis, much is still unknown about how other species, on land and underwater, will respond to changing conditions. A large international team of researchers recently explored how the worldwide geographical distribution of coral recruitment has been changing over time.

"Despite widespread climate-driven reductions of coral cover on tropical reefs, little attention has been paid to the possibility that changes in the geographic distribution of coral recruitment could facilitate beneficial responses to the changing climate through latitudinal range shifts," the researchers wrote.

The team's analysis, published in the *Marine Ecology Progress Series*, indicates that although global coral recruitment has declined by 82% and plummeted by 85% in the tropics since 1974, recruitment in the subtropics has jumped by 78% over that time period (bit.ly/migrating-coral).

"Thus, coral recruitment appears to be moving poleward," Mark Hay, an experimental marine ecologist at the Georgia Institute of Technology in Atlanta, told *Eos*. Hay, who wasn't involved with the report, added, "These data add to the increasing documentation of the 'tropicalization' of temperate systems."

First of Its Kind

The report is "the first of its kind at this scale," said Nichole Price. She's a benthic marine ecologist at the Bigelow Laboratory for Ocean Sciences in East Boothbay, Maine, and the lead author of the study.

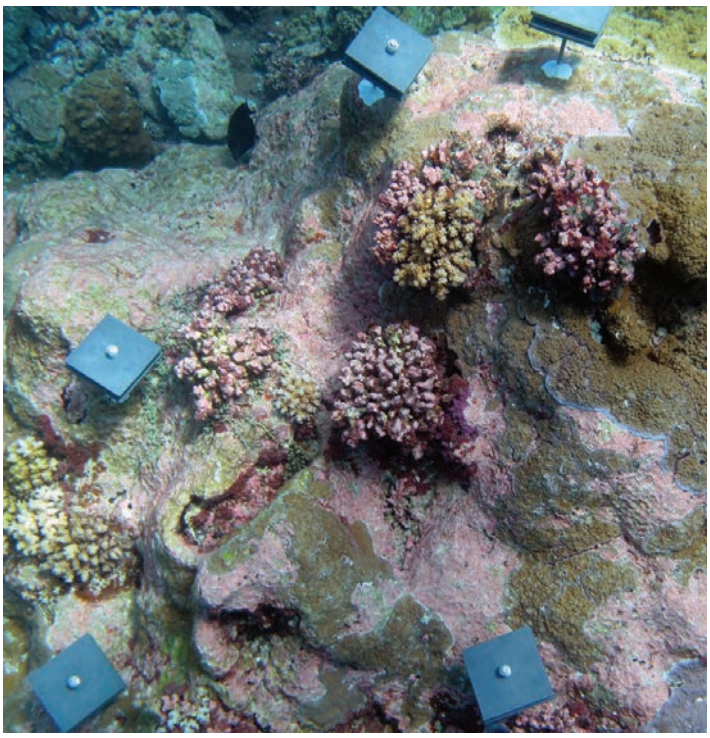
> "These data add to the increasing documentation of the 'tropicalization' of temperate systems."

"The novelty of the study is in its temporal and spatial scale, the broad extent of the data presented, and in focusing on a critical process (recruitment) that is rarely investigated over such scales," Hay wrote. "The study covered five continents, nearly four decades (1972–2012), and greater than 1,200 records of coral recruitment," he added.

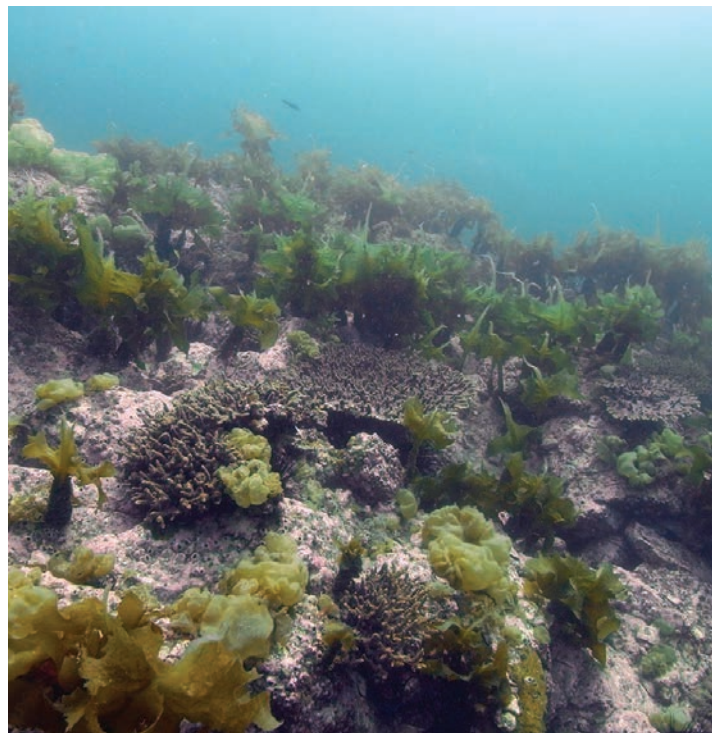
Price and her colleagues analyzed data from 92 studies (including 68 published and 24 unpublished) furnishing 1,253 records of coral recruitment.

The researchers examined studies focusing on recruitment to deployed settlement tiles. The team's main conclusions about coral recruitment trends were based on tiles that had been deployed for at least 3 months. Most of the included tiles were made of terra-cotta (or another ceramic material), with some composed of polyvinyl chloride, acrylic, or calcium carbonate. Their areas ranged from 0.01 to 1.5 square meters.

The majority of the tiles (96%) were deployed at depths of 20 meters or less. The analysis included only tiles deployed on fringing reefs, on barrier reefs, or in lagoons. "Following a period of immersion, the numbers of coral recruits (typically ≤1 cm diameter) settled on the tiles are counted under magnification, and are usually reported as density (i.e. number of recruits per area or tile) for each



This coral reef in the Palmyra Atoll National Wildlife Refuge in the Pacific Ocean has settlement tiles pinned to it so that researchers can quantify coral settlement on it. Credit: Nichole Price/Bigelow Laboratory for Ocean Sciences



This coral reef and seaweed are both growing in the waters off the coast of Nagasaki, Japan. Tropical reef-building corals and kelp don't naturally exist in the same locations, but that's changing with coral reef migration. Credit: Soyoka Muko/Nagasaki University

deployment," Price and her colleagues write in the study.

"For any large data compilation such as this" covering "global-scale patterns over multiple decades," researchers often encounter "issues of variance due to patterns being potentially confounded in time, space, methodologies, etc., but this is such a large data set and the patterns [are] clear enough that I find the documentation both convincing and useful," Hay wrote.

In addition, "the variance that is inevitable in such studies makes it more likely that real patterns will be missed rather than false patterns found," he noted.

Are Corals Finding Climate Refuge?

Though the tropical and worldwide declines in corals still outweigh the boost in subtropical recruitment, these results provide a "glimmer of hope," Price said. The numbers suggest that some corals "may find refuge" in the face of rising temperatures and other oceanic conditions ill suited to their survival, she noted.

Still, the long-term effects of relocation on corals are unknown. Differences in environmental factors in the subtropics, such as light availability and seasonal temperature variations, could affect coral populations, Price said. Researchers also don't know how interactions with other organisms, especially kelp, will play out.

Both kelp and reef-building corals behave as ecosystem engineers, constructing three-dimensional structures that serve as homes for other living organisms, Price noted. Only time will tell whether their habitation of the same space will lead to competition or some form of coexistence.

Another possibility? The climate crisis might also drive kelp species to migrate, Price said.

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

ARTIFICIAL INTELLIGENCE CAN SPOT PLANKTON FROM SPACE

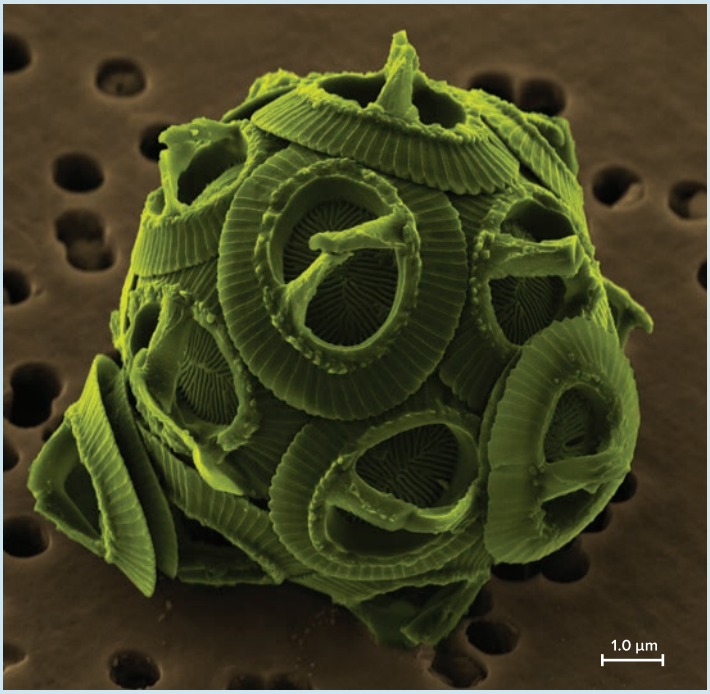
Scientists mimicked the neural networks of the brain to map phytoplankton types in the Mediterranean Sea. A study published in the *Journal of Geophysical Research: Oceans* presented a new method of classifying phytoplankton that relies on artificial intelligence clustering (bit.ly/satellite-plankton).

Phytoplankton blanket surface waters of the world's oceans, and pigments in their cells absorb certain wavelengths of light, like the chlorophyll that gives plants their green color. Viewed from space, the color of the ocean's surface changes depending on the phytoplankton growing there. In the Mediterranean Sea, where the latest study focused its efforts, an array of phytoplankton species bloom throughout the year.

Past research has mined satellite images of ocean color in the Mediterranean for common pigments found in phytoplankton. A combination of pigments can reveal a certain type of dominant phytoplankton in the area, like certain species of diatoms that can be spotted because of their unique orange pigment, fucoxanthin. But connecting the complex relationships between satellite image pixels, pigments, and phytoplankton types can make for a tricky analysis.

The latest study turns to artificial intelligence to parse the multidimensional data. The process mimics the brain's ability to take in new information and learn over time, giving the algorithm a chance to identify relationships in the data that may not be readily apparent. The algorithms cluster similar nodes of information near one another, creating a two-dimensional diagram called a self-organized map. The scientists trained two algorithms used in the study with 3 million pixels from satellite images and over a thousand measurements taken by boat in the Mediterranean.

The results show six types of phytoplankton and how they come and go by season. In winter, haptophytes and chlorophytes (both algae) are common in the western Mediterranean. In the summer months, the most abundant photosynthetic organism on Earth, the cyanobacteria *Prochlorococcus,* rules broad swaths of the sea. The new method revealed how the blooms changed over time, giving the scientists a way to ask questions about marine food chains and possible effects of climate change in the future.



This species of phytoplankton, Gephyrocapsa oceanica, *(seen here in a scanning electron microscopic image) grows in the Mediterranean Sea. Credit: NEON ja/Richard Bartz, CC BY-SA 2.5 (bit.ly/ccbysa2-5)*

The scientists called the new method "very general" in their paper and said that it could be applied elsewhere in the world's oceans.

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

EOS CENTENNIAL COLLECTION

Investing in Science to Improve Climate Risk Management

The Norfolk, Va., skyline as seen from across the Elizabeth River in 2016. Credit: Antony-22, CC-BY-SA 4.0 (bit.ly/ccbysa4-0)

Climate change caused by past and ongoing emissions from fossil fuel burning poses sizable risks for current and future generations through its impacts on multiple interacting sectors, including, for example, food and water supplies and public health [*O'Neill et al.*, 2017].

The extent of these risks is subject to deep uncertainties and tipping points, suggesting the need for flexible approaches to climate adaptation. One example of a deep uncertainty in our understanding of climate is the degree to which local and regional storm surge intensities are modulated by a warming climate [*Lee et al.*, 2017; *Wong et al.*, 2018].

In climate risk management, these uncertainties often affect estimates of potentially damaging impacts, thus amplifying the importance of the uncertainties [*Wong et al.*, 2017a].

Even with strong mitigation of anthropogenic climate forcing, communities will still need to adapt to impending changes resulting from historical greenhouse gas emissions. Successful strategies require the right information, such as observations of relevant environmental indicators, or signposts, to trigger needed changes in the approach, and updated risk assessments that account for new information.

Fundamental Earth science research provides a foundation for supplying this information. Integrating research about regional- and global-scale Earth system processes into adaptation planning can help identify strategies to manage climate risks in the face of the uncertainties to ensure sustainable and resilient communities. We illustrate this point with an example of decision-making to adapt to sea level rise in Norfolk, Va.

Protecting Norfolk: A Case Study

Consider the decision of how high to build a levee to help protect Norfolk, which sits along the Elizabeth River at the south end of the Chesapeake Bay. Suppose that decision makers seek flood defense systems to limit to 1% the chance that by the year 2070, floodwaters will overtop the levee in a given year, corresponding to an event with a 100-year return period. Planning to meet this target requires projections of sea level rise and storm surge. These projections hinge critically on assumptions about climate policies and the strength of physical feedback mechanisms governing, for example, ice sheet and storm surge dynamics [*Wong et al.*, 2017a].

According to our modeling, making seemingly reasonable assumptions about future flooding on the basis of recent historical tide gauge records alone could lead planners to suggest a levee height of roughly 2.5 meters (Figure 1, green curve). However, this choice of levee height could result in drastically higher (and arguably unacceptable) flooding risks if some of these assumptions fail. For example, if Earth's ice sheets respond rapidly and nonlinearly to increased climate forcing (as they have likely done in the past [*Wong et al.*, 2017a] and may be doing now [*Joughin et al.*, 2014]) and if storm surge frequency and/or intensity increase with a warming climate (which may be consistent with existing evidence [*Lee et al.*, 2017]), then the projected probability of floodwaters overtopping a 2.5-meter-tall levee rises to just over 5% per year (Figure 1, pink curve) in this example analysis. In other words, what might have been considered a once-in-a-century flood event would occur approximately every 19 years on average.

An alternative might be to build a levee high enough to defend against the perceived worst-case scenario. Using an example worst-case assumption established by the National Oceanic and Atmospheric Administration in the case of Norfolk might lead to construction of a levee roughly 4 meters tall [*Sweet et al.*, 2017]. This strategy might be logistically infeasible, however, and would likely require very large investments that some might feel could be better spent elsewhere.

How can we manage trade-offs between competing concerns given the deep uncertainties in our knowledge of climate? One approach is to hedge in the short term against immediate and foreseeable risks, then adapt as new information becomes available. By analogy, if a doctor tells you that you have an increased risk of heart disease, it might be prudent to adapt your behavior initially by moderately modifying your diet and exercise habits while leaving open the option to use more intensive approaches, such as prescrip-

Ultimately, the selection of a strategy requires balancing and compromising among diverse stakeholder perspectives and objectives.

tion medication, if your perceived risk does not decrease sufficiently in the future.

Health risks can be better managed with sustained observations (checkups, blood tests, etc.) and analyses. Similarly, climate risks can be better managed with sustained Earth observation systems and research, so that science can inform decisions. What does this mean for designing, implementing, and resourcing mission-oriented basic science?

For coastal flood risk management, several unknowns can be addressed by analyzing basic Earth science questions: (1) What are the impacts of possible future greenhouse gas emissions trajectories, including on relatively low probability but high-risk events? (2) Will the West Antarctic Ice Sheet (WAIS) collapse, and if so, on what timescale [*Joughin et al.,* 2014]? (3) What would be the resulting contribution of WAIS collapse to local sea level changes? (4) Are there detectable changes in the frequency and severity of storm tides? (5) Are storm tracks changing as a result of climate change? (6) What regions and metropolitan areas are more likely to be affected?

Designing adaptive strategies that can react to new information from Earth science observations can drastically improve future outcomes in the event of potentially damaging flood events [*U.S. Army Corps of Engineers,* 2014]. Current mitigation measures can be planned with an eye toward flexibility and expandability so that the full suite of appropriate options is available in the future. As an example, while new levees are being built or existing levees heightened, it might also be prudent to build them so that they can be widened and further heightened in the future.

In the Norfolk example, consider again a levee designed to defend against floods with return periods shorter than 100 years as of 2070 when the levee height—2.5 meters—is based only on linear extrapolation from the historical record (Figure 1, green curve). By comparison, even under relatively conservative model assumptions, considering a consistent storm surge pattern out to 2070 but ignoring the potential for accelerated West Antarctic melting (Figure 1, orange curve), that 2.5-meter levee would protect only against floods with a 46-year average return period, less than half of the target standard.

Integrating disciplines such as Earth science, statistics, and decision analysis into adaptation planning can help identify signposts that can be used to design monitoring systems and trigger potentially needed changes in strategy [*Haasnoot et al.,* 2013; *Weatherhead et al.,* 2018]. A simplified and potentially effective adaptive approach at Sewells Point, near Naval Station Norfolk, might involve the following steps:

First, heighten the levee in stages over the next few decades to maintain a 100-year protection standard against well-characterized risks—say, the nonaccelerated sea level rise scenario in Figure 1 (orange curve)—with enough width built in to increase the height in the future if necessary. Second, plan for transitions between scenarios (e.g., from orange to purple to pink in Figure 1) to avoid being locked into a single approach. And if the projected levee height needed to meet the target protection standard in certain scenarios is more than what might be tolerated on the basis of cost or aesthetic objections, the possibility of using other resiliency measures—elevating houses, property buyouts, or land use changes, for example—should be left open. Third, monitor signposts, such as changes in ice sheet dynamics and trends in regional tide gauge records, for indications that the local flood risk could change. Finally, update risk assessments and mitigation strategies with this new information.

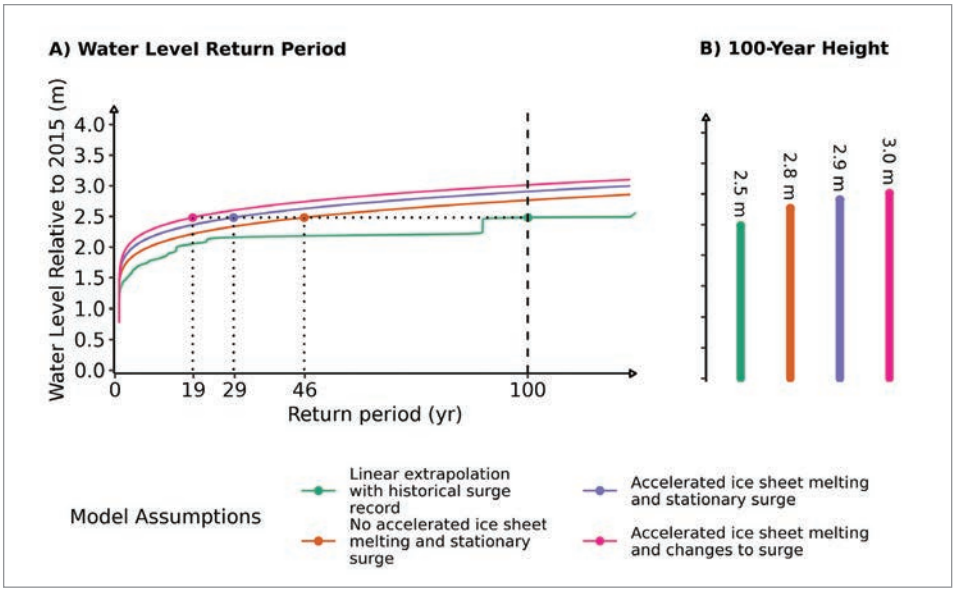


Fig. 1. Effects of deep uncertainties (about storm surge dependence on global mean temperatures) and positive feedbacks (triggering of rapid West Antarctic melting dynamics) on projected coastal flooding by 2070 modeled for Norfolk, Va. (a) Water height anomalies in 2070 (relative to 2015) plotted against return periods for four different sets of model assumptions. (b) Maximum water height of a flood event with a 100-year return period for each modeled scenario. Changing storm surge distributions are based on changes in global mean temperature. Mean sea level and global mean temperature projections were obtained using the Building blocks for Relevant Ice and Climate Knowledge (BRICK) sea level rise emulator from Wong et al. *[2017b]. Storm surge models were calibrated using data from Sewells Point in Norfolk. Land subsidence estimates are from* Kopp et al. *[2014].*

Effective Adaptation Requires Investment

Such adaptive strategies can drastically reduce risks and/or costs [*Haasnoot et al.,* 2013; *Yohe,* 1991], but they do require sustained investment to realize these benefits. The example outlined above requires investments in sustained Earth observations and analysis aimed at understanding and early detection of climate change impacts. Remote sensing observation platforms provide broad-based benefits [*Weatherhead et al.,* 2018], increasing the economic value of the gathered information. The benefits of such information are regional in the case of storm surge trends and global in relation to ice sheet observations.

Finally, various adaptation strategies can be analyzed and compared to shed light on the trade-offs associated with choosing among the strategies (trade-offs related to costs, externalities like property values, and flood hazards, among others). Ultimately, the selection of a strategy requires balancing and compromising among diverse stakeholder per-

spectives and objectives. Multiobjective decision analysis can help identify strategies that best navigate the often hard trade-offs that arise [*Kasprzyk et al.*, 2013], and careful articulation of objectives and trade-offs helps to improve the transparency of the decision-making process.

This article focuses on the issues of sea level rise and flooding affecting one example site. Similar plans would be required to address a wide range of other issues posed by the changing climate, which are likely to become more challenging if mitigation measures are not implemented.

Efforts to defend against climate-related risks benefit from sustained commitments to getting the right science, getting the science right, and getting the science to the decision makers. Investments in basic Earth science observations and research enhance our ability to identify meaningful signposts for adaptation, to understand the risks associated with tipping points, and to realize the benefits of sound risk management strategies.

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EOS CENTENNIAL COLLECTION

AGU100 ADVANCING EARTH AND SPACE SCIENCE

MONITORING HAITI'S QUAKES WITH RASPBERRY SHAKE

By Eric Calais, Dominique Boisson, Steeve Symithe, Roberte Momplaisir, Claude Prépetit, Sophia Ulysse, Guy Philippe Etienne, Françoise Courboulex, Anne Deschamps, Tony Monfret, Jean-Paul Ampuero, Bernard Mercier de Lépinay, Valérie Clouard, Rémy Bossu, Laure Fallou, and Etienne Bertrand

On 12 January 2010, a devastating earthquake put Haiti on the map for many of us who were unaware of the recurrent difficulties that the country has endured over the past decades. The *M*7.0 earthquake claimed more than 200,000 lives, and the damage amounted to about $11 billion, close to 100% of the country's gross domestic product.

Before the earthquake, Haiti had no seismic network, no in-country seismologist, no active fault map, no seismic hazard map, no microzonation, and no building code. The national seismic network that has emerged since then consists of 10 broadband stations (Figure 1) [*Bent et al.*, 2018], operated and maintained by Haiti's Bureau of Mines and Energy (BME). Although this network was a significant step in the right direction, it has not proved to be a panacea.

On 6 October 2018, a magnitude 5.9 earthquake struck northwestern Haiti, causing 17 fatalities and significant damage in the larger cities near the epicenter. Only one seismic station was operating at the time, a situation that has persisted for several years now. In spite of its contin-

A woman displays a Raspberry Shake seismometer. Poor-quality construction, typical of many neighborhoods in Haiti, is visible in the background. Credit: E. Calais

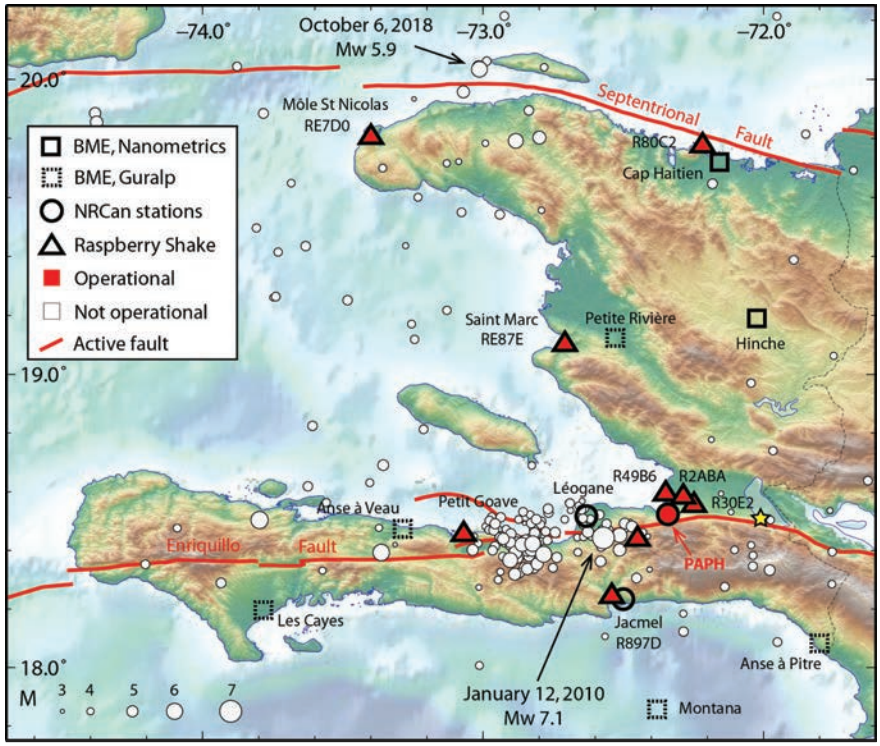

Fig. 1. Seismic stations in Haiti (symbols) and seismic activity as reported by the U.S. Geological Survey (white circles) from August 1946 to 14 January 2019. Natural Resources Canada (NRCan) broadband station PAPH (red circle), based in Port-au-Prince, is usually operational. The nine Raspberry Shake stations shown on this map (with their code names) were installed in January 2019 and were operational as of 15 February. The yellow star east of Port-au-Prince indicates the location of the M3.1 *earthquake shown in Figure 2. Stations RE7D0, RE87E, and R2ABA, which use wifi to connect to the Internet, are not observing the radio frequency interference noted by some RS hosts elsewhere who also use wifi to connect to the Internet. BME is Haiti's Bureau of Mines and Energy, which operates seismic instruments from two manufacturing companies.*

ued efforts, it is difficult for the BME to overcome the chronic lack of resources—financial and human—necessary to maintain such a high-technology system.

Piloting a Citizen's Seismic Network

As a result of resource limitations, seismologists in Haiti are able to provide only limited information to the public or to decision makers when earthquakes are felt. This reinforces the ill-founded perception that seismic monitoring is of little value, and it keeps the population in the dark about seismic hazard. As a result, citizens and businesses do little to protect themselves from future large events. The lack of reliable information also provides ground for fake seismonews, including the notion that earthquake prediction has already been around for years so that earthquake monitoring is irrelevant.

Interestingly, however, the public demands reliable information about earthquakes and tsunamis and their associated risks. They ask questions, want to be informed, and want to know how to prepare. Some would even like to be able to help improve earthquake knowledge in Haiti.

A citizen's network of small, affordable seismic stations could be a starting place for providing this information. Even though these instruments would most likely be concentrated in major cities, their redundancy would alleviate inevitable maintenance issues at any single station. Such a network would improve the ability of the Haiti seismic network to detect small-magnitude earthquakes on a continuous basis, resulting in a better understanding of earthquake distribution and fault behavior. In addition, installing seismometers in people's homes may be a way to initiate a conversation with the population to promote a culture of earthquake safety.

This is where Raspberry Shake (RS) comes into play [*Anthony et al.,* 2018]. This organization, founded using a Kickstarter campaign in 2016, provides affordable "personal seismometers" powered by small Raspberry Pi computers. The low cost of an RS station and the ease of installation and maintenance make it possible to imagine a situation in which perhaps as many as 100 citizens, businesses, or schools throughout Haiti host an RS station.

To do more than just imagine, we began a pilot project in January 2019, purchasing and deploying nine one-component vertical velocimeters (RS1D) throughout Haiti (Figure 1), four of them additionally equipped with 3-D accelerometers (RS4D). Except for one station located at the BME, all RS hosts are private homes or hotels. We selected these hosts from people whom we knew had quasi-continuous Internet access and electricity, the latter being a major issue in Haiti. This initiative is similar to the Quake Catcher Network [*Cochran et al.,* 2009], although the latter uses only accelerometers (quakecatcher.net).

Setting Up the Network

We set about creating our RS network by simply laying an RS instrument on the floor of the quietest first-story room we could find at each location. We connected them to power and Internet utilities, in six cases directly to the router via an Ethernet cable and in three cases via wifi. We made it clear to the hosts that the RS stations would use very little power and Internet bandwidth but that they should contact us if they suspected any issue. We also told them that they were free to disconnect the RS in case of a problem.

Several hosts asked whether their RS could serve to predict earthquakes or whether they would sound an alarm if seismic waves were coming. We made it very clear that this

Pierre Guild Mézile, an agronomist from Jérémie, the capital city of the Grand'Anse department in Haiti, stands next to the Raspberry Shake station installed in his home. Credit: Eric Calais

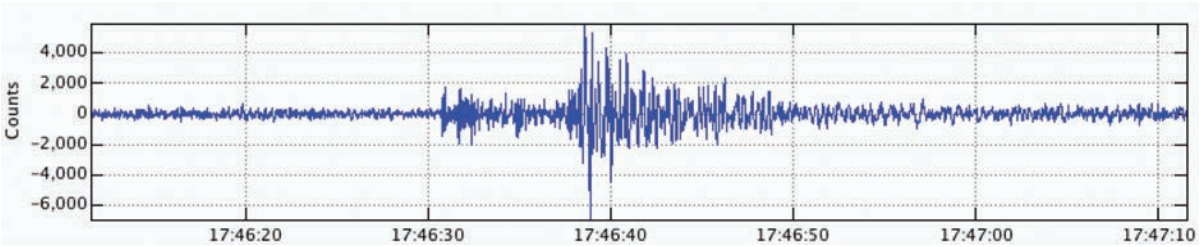

Fig. 2. Station R30E2, located in downtown Pétion-Ville, produced Haiti's first Raspberry Shake station recording of a local earthquake on 13 January 2019. This event was not reported by Haiti's national seismic network, but it was later reported by the Dominican Republic seismic network as an M3.1 *event (yellow star in Figure 1) along the Enriquillo–Presqu'île du Sud fault close to the border between Haiti and the Dominican Republic.*

was not the case and explained that we were mostly interested in the smaller earthquakes, the ones they never feel but that occur every day.

"What? There are earthquakes every day in Haiti?" was a common reaction. Yes, indeed, we told our hosts, and knowing where and how big the small quakes are tells us a lot about the future large ones. Many hosts asked how they could see the information. We showed them how to view the helicorder (which records data from the seismometer) from their smartphone or computer on their local network, but often, they were not impressed with the displays. Helicorder output is indeed difficult to read because most squiggles are not earthquakes. Clearly, we need to do more work on how to provide relevant and useful information to RS station hosts.

First Observations

Three weeks after the installation of the first RS, we could already make a few observations that would be useful for the next phase of our project and, we hope, for other similar projects elsewhere.

We have detected many events that occurred less than 100 kilometers from this first RS station. The first one (Figure 2), recorded on 13 January 2019, was later located by the seismological network of the Dominican Republic, which quoted its magnitude as 3.1. We also recorded a sequence of four events in northwestern Haiti the day after we installed another station; these events were not reported by any regional seismic network. Regional events show up very well too, for example, the *M*5.3 earthquake that struck the Dominican Republic on 4 February 2019. Even the *P* wave and *S* wave arrivals of teleseismic (distant) events are recorded, including an *M*5.6 earthquake that occurred in Colombia on 26 January 2019.

Noise levels are, of course, very different from station to station, unless tight seismological prescriptions are enforced. However, that is not the point of using low-cost RS stations at individual homes, businesses, or schools. Our hope is that the redundancy of RS stations within a small footprint—a city—will suffice to ensure the availability of enough reliable data. This remains to be investigated in a quantitative manner as more stations come online.

We noticed that reliability and continuity of service are issues, even though we tried our best to place the RS instruments at locations with continuous power and reliable Internet. One RS station host wanted to negotiate communication costs and, after a few days, apparently disconnected his station. Another station, located in a power-secure part of Port-au-Prince that had not previously needed power backup, is now experiencing regular blackouts. This underscores the importance of observation redundancy, with many stations at short distances from each other, because one never knows which one will have an issue and stop operating when an interesting earthquake occurs.

A Work in Progress

We were positively impressed by the response of civil society members and the private sector to this initiative. However, to gain the support of civil society, it is clear that we need to provide RS hosts with personalized information, such as "your RS instrument detected an earthquake of magnitude 2.5 located 50 kilometers away, in the area of…." A smartphone application would be a great way to provide this information in quasi-real time and keep station hosts engaged. It could also serve to broadcast information on earthquake preparedness and hence use the (fortunately long!) time intervals between large earthquakes to educate and promote earthquake safety.

With the lessons learned during this pilot experiment, our goal now is to push forward and engage the civil society and the private sector—at least those entities that can afford continuous power and Internet—to be a bigger part of this project. Expanding the project would provide more RS stations and thus redundancy and continuity of service. It would also engage RS hosts in a project that puts them at the center of the information chain. RS hosts will become information providers to scientists rather than passive listeners to scarce and unintelligible information.

Our goal now is to push forward and engage the civil society and the private sector to be a bigger part of this project.

It is our hope that as RS hosts and others become more aware of the earthquake issue, they will share information they will be privy to. We hope that they will become advocates for seismic monitoring, but more important, we hope that they will act to reduce seismic risk for themselves and their community.

Acknowledgments

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EOS CENTENNIAL COLLECTION

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Is My Water Safe

By Julia Hart, Christina Bandaragoda, and Gracieia Ramierz-Toro

On 20 September 2017, Hurricane Maria made landfall in Puerto Rico as a category 4 hurricane. At the time, Maria was the fifth-largest storm to hit the United States and the largest to hit Puerto Rico in over 80 years [*Cortés,* 2018]. Bisecting the island with sustained winds of 155 miles per hour (250 kilometers per hour), Maria left a trail of devastation in its path [*Cortés,* 2018] and would go on to claim nearly 3,000 lives [*Santos-Burgoa et al.,* 2018]. Heavy winds and flash flooding razed homes, businesses, and power lines, plunging Puerto Rico's nearly 3.4 million people into darkness and underscoring concerns about how we address vulnerability and adaptation planning and highlighting opportunities for transformative change [*Eakin et al.,* 2018].

In the weeks that followed Maria, a water crisis ensued. Without electricity, water could not be treated or distributed to people's homes; residents had no drinking water or water with which to bathe or flush a toilet. As a result, residents turned to potentially contaminated streams, rivers, and creeks, risking

After Hurricane Maria damaged Puerto Rico's drinking water supplies, National Guard soldiers from New York and Puerto Rico brought bottled water to residents of the city of Lares. Credit: Spc. Agustín Montañez, PRNG-PAO/Released

exposure to disease-causing bacteria like *Leptospira*. A month after the storm, several confirmed cases of leptospirosis, which can be fatal, were reported to the Centers for Disease Control and Prevention [*Rodríguez-Díaz,* 2017].

After Maria, widespread disruption of drinking water treatment and distribution systems, as well as a lack of information regarding water quality, posed a significant health risk in Puerto Rico. Thus, the hurricane demonstrated a need to strategically archive and disseminate data relevant to water quality and public health to both researchers and community members.

An interdisciplinary team of researchers sought to fill this need, with support from the National Science Foundation (NSF). The team included researchers from the University of Washington, Virginia Polytechnic Institute and State University, the University of Pennsylvania, Utah State University, Interamerican University of Puerto Rico, and the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI). These researchers developed an open-source

Hurricane Maria severely affected water treatment plants across Puerto Rico, like the one shown here in a rural community water system. After the hurricane, widespread disruption of drinking water treatment and distribution posed a significant health threat. Credit: Tim Sauder, Olin College of Engineering, CC BY 4.0 (bit.ly/ccby4-0)

research software infrastructure to support scientific investigation and data-driven decision-making following natural disasters, with a pilot project focused on drinking water and Hurricane Maria data. The team maintains that the scientific community can do more to reduce the cost and human impact of destructive hurricanes.

Getting Started

The first objective of this project was to collect water quality data from across Puerto Rico. Team members collected samples from drinking water, surface water, and wastewater systems in collaboration with public water supply utilities in early 2018. They analyzed the samples for microbial, chemical, and biological water quality parameters, including a comprehensive panel of opportunistic waterborne pathogens like Leptospira. Researchers also collated publicly available, spatially explicit data about property and infrastructure damage, landslide disturbance, power outages, and the availability of medical aid, food, and water from other databases.

The team's second objective was to build a cyberinfrastructure capable of integrating and disseminating these diverse data sets. Cyberinfrastructure simultaneously provides an accessible online platform, connects stakeholder communities, and houses the software tools necessary to advance computing and data analysis research needs. In other words, cyberinfrastructure provides the bridges, roads, and highways for the storage, analysis, and sharing of water data and all forms of digital information. Users (e.g., researchers, community stakeholders, and public utility managers) may navigate cyber highways to discover information about water quality, major public health concerns, or hydrologic modeling tools.

The bulk of field data collection and cyberinfrastructure development for this project is now complete. But the researchers will continue to add new data sources and time series data as they become available. Continuous cyberinfrastructure improvements (e.g., regular software maintenance) also ensure continued refinement of this data platform.

Managing the Data

The researchers used HydroShare, an online, collaborative platform, as a centralized cyberinfrastructure for all data relevant to Hurricane Maria water quality and recovery efforts. First launched in 2015, HydroShare is a data repository operated by CUAHSI that already boasts more than 3,000 users. It currently enables water researchers from around the world to upload and manage a wide variety of hydrologic data types, models, and code and to make this information available in a citable, shareable, and discoverable manner [*Horsburgh et al.*, 2016; *Yi et al.*, 2018].

The main advantages of this platform are sharing controls and accessibility. Anyone can become a HydroShare member and gain access to dozens of unique public data sets related to Hurricane Maria by joining the Puerto Rico Water Studies group. The team ensures high data quality by using data model templates for quality assurance prior to publication. Data incorporated from other sources or databases (collected independent of this project) rely on the quality assurance protocols of those sources to ensure high quality. Regardless of their source, the data are reported in a consistent, well-documented format, according to findable, accessible, interoperable, and reusable (FAIR) data principles [*Wilkinson et al.*, 2016]. These principles are designed to address some of the biggest challenges facing data-intensive science, including transparency, reproducibility, and reusability.

Although data transparency was a desired outcome of this project, this level of transparency could not violate the privacy of data contributors, many of whom were directly affected by Hurricane Maria. As such, water quality scientists and public health researchers alike contributed and published de-identified data at a spatial scale that protects individuals' privacy. For example, the team used publication steps in which users privately uploaded individual household or treatment plant records, but only county- or municipality-level spatial resolutions were published for planning, disaster response, and population health research purposes.

Potential Benefits

With so many diverse data sets available in one place, the HydroShare cyberinfrastructure facilitates an opportunity for unprecedented interdisciplinary research and new applications of data. In the future, population health researchers may use published, geospatially anonymous clinical records in conjunction with environmental data (e.g., data on surface water, groundwater, and drinking water quality) to identify populations that have experienced health-related impacts of Hurricane Maria. Meteorologists can compare the physical characteristics of the hurricane with pictures of the destruction using an interactive, digital story map. Hydrologists can explore how the island has responded to the hurricane ecologically (e.g.,

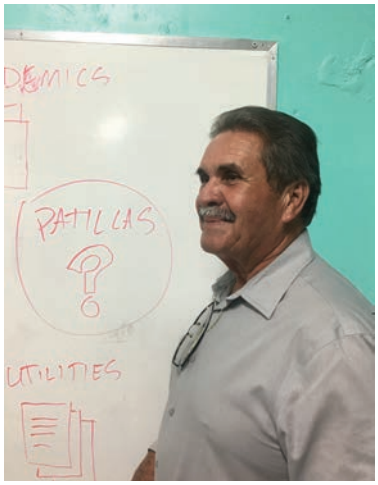
windblown deforestation) while simultaneously identifying areas newly susceptible to landslides. In this way, a centralized cyberinfrastructure provides a large, temporally and spatially explicit, and accessible platform for organizing and disseminating a "hurricane of data."

Cyberinfrastructure in Action

Scientists and other professionals aren't the only people to contribute to and benefit from this new resource. For example, Porfirio Fraticelli is a volunteer water system operator who has assumed the responsibility of providing safe drinking water to his small, rural community. The research team is currently training Porfirio and other community members in rural southeastern Puerto Rico to upload data from his potable water system directly to HydroShare.

Communication lines and Internet access are still limited following Hurricane Maria, so Porfirio travels to the nearest town to contribute and manage his own private data in HydroShare. He can choose when to make his data publicly available using a digital object identifier (DOI). Until that time, only members of his private HydroShare group, made up of community stakeholders, can view the data.

Publishing his data on HydroShare benefits Porfirio's community in two ways. First, it communicates the status of his community's water quality—temperature, pH, turbidity, alkalinity, and bacterial concentrations—to the government, researchers, and aid organizations. These variables help to answer the critical question, Does this community have safe drinking water? Second, uploading his data to HydroShare connects Porfirio's small, rural community to a network of communities and municipalities across Puerto Rico that are also contributing their own data. The resultant network of spatially explicit, high-quality data allows interdisciplinary researchers to investigate aquatic ecosystem, physical infrastructure, and public health recovery at broad scales and to deliver research products that may increase community resilience to future hurricanes.



Porfirio Fraticelli is a water system operator for a small, rural community in Puerto Rico. He participates in workshops and training to learn how to engage with archived hurricane data and increase his community's resilience to future storms. Credit: Christina Bandaragoda, University of Washington, CC BY 4.0 (bit.ly/ccby4-0)

An Unprecedented Opportunity

The data transparency, accessibility, and reproducibility provided by the cyber roads and highways of HydroShare facilitate an collaborative research on the new normal of intensified hurricane seasons. For example, HydroShare also houses digital information about Hurricanes Harvey and Irma, which illustrates its usability for myriad post–extreme event data storage, analysis, and sharing. Centralized cyberinfrastructure introduces a new system of data-driven decision-making in the weeks and months following natural disasters. This system is capable of tackling uncertainty and increasing community resilience to future extreme events.

Addressing real-time communications limitations or water quality concerns during a hurricane is beyond the scope of this project. However, future research, informed by cyberinfrastructure resources, will explore the development of low-cost wireless technology or mesh networks for real-time communication about drinking water and other resources.

To access data collected in this project, create a free HydroShare account online and search for the "Puerto Rico Water Studies" group under the "Collaborate" header. Public web pages linking to data resources are also available at cuahsi.org/projects (see Building Infrastructure to Prevent Disasters and Hurricanes 2017 Data Archive).

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THE SCIENTIST WHO CONNECTED IT ALL

By Thorsten W. Becker and Claudio Faccenna

The centennial of Alexander von Humboldt's birth was celebrated across the world in 1869. Around that time, the famed globe-trotting explorer and natural systems scientist was memorialized in numerous statues, and many institutions, geographic features, and communities—and nearly the state of Nevada—would come to bear his name.

But through much of the ensuing century and a half, Humboldt's global celebrity and status as a scientific luminary diminished, the latter as scientists increasingly eschewed the naturalistic approach of Humboldt

During and shortly after his lifetime, Alexander von Humboldt was celebrated around the world for his globe-trotting explorations and contributions to natural science. At the time, he was memorialized in numerous statues, such as this one in his native Berlin. Credit: George M. Groutas, CC BY 2.0 (bit.ly/ccby2-0)

Wherever he traveled, Humboldt went to great lengths and personal and monetary expense to conduct detailed geophysical and ecological measurements.

and others. Today, many in the United States and elsewhere have only recently rediscovered his ideas and the prominent role he played in establishing the modern natural sciences.

Wherever he traveled, Humboldt went to great lengths and personal and monetary expense to conduct detailed geophysical and ecological measurements. He also excelled at synthesizing the wide range of observations he collected. Although his brother Wilhelm is credited with establishing the modern university model combining research and education, Alexander is reasonably attributed as a founding father of systems science, which characterizes species and processes, for example, in terms of their interconnections rather than in isolation from each other.

This year, 14 September marked Humboldt's 250th birthday, offering an opportunity to revisit and celebrate his life and contributions to science. AGU is commemorating Humboldt with a new theme in *Geochemistry, Geophysics, Geosystems,* as well as with a Union session at the Centennial Fall Meeting in San Francisco next month (bit.ly/AGU-FM-Humboldt).

This painting depicts Humboldt studying Alstroemeria *flowers on his groundbreaking voyage to South America near the banks of the Orinoco River in Venezuela. Credit: Friedrich Georg Weitsch/Alte Nationalgalerie, Public Domain*

Humboldt sits in the library of his Berlin apartment in this mid-19th-century painting by Eduard Hildebrandt. Credit: Kunstbibliothek Berlin

Life of an Explorer

Alexander von Humboldt was born in Berlin to an established Prussian family in 1769, 2 years his brother Wilhelm's junior. Their father died when Alexander was 10, and their mother remained only a distant presence, with tutors likely instilling the adventurous spirit that Alexander displayed early on. He pursued an eclectic mix of studies, including languages, anatomy, geology, and astronomy at universities in Hamburg, Jena, and Freiberg. After settling on a mining degree and graduating from the School of Mines in Freiberg in 1792, Humboldt was appointed an inspector of mines near Bayreuth in Bavaria.

In addition to establishing a vocational training program and support network for miners, this appointment led to his first scientific study, in 1793, on vegetation in mines. This work brought him to the attention of the prominent poet Johann Wolfgang von Goethe, who was also a natural historian, and led to a life of science and intellectual exchange. Set free of his day job when he inherited his mother's fortune in 1796, Humboldt set off to explore the world at the turn of the century. Much of his subsequent life happened on the road and in the salons of Paris and involved discussions with many of the leading intellectuals of the time, from Friedrich Schiller and Louis Agassiz to Henry David Thoreau and Charles Darwin.

Humboldt made a number of important contributions across natural disciplines, establishing the field of biogeography and helping establish ecology and conducting meticulous measurements that informed sweeping theories, such as on links between topography and vegetation. In his life, he undertook two major expeditions, observations from which drove most of his discoveries.

The first—and more significant of the two—brought him to the Americas from 1799 to 1804 on a trip that would eventually change prevailing views of Latin America and its connections to the rest of the world. From its inception, this journey was different from other exploration efforts at the time: It was geared solely toward science.

Humboldt had his sights on data, looking to measure altitudes, temperatures, and the magnetic field; to draw geological cross sections; and to collect rocks, plants, and animals, all while trying to understand the culture of local societies. Most geographers at the time were more interested in defining political boundaries, giving little consideration to Earth's relief and morphology and often injecting heavy doses of subjective interpretation. Humboldt instead focused on nature and data, and his approach was original: By properly reporting reliefs on maps, he could describe the changing landscape and biogeosphere.

Among other contributions, Humboldt placed Andean flora and fauna into distinct climatic and topographic contexts and described human impacts on climate change as potentially affecting the evolution of society. Humboldt also established links with various notable figures from west of the Atlantic, including future revolutionary leader Simón Bolívar and, on a visit to the United States, President Thomas Jefferson, a fellow scientist who is said to have called Humboldt "the most scientific man of his age."

After his return to Europe, Humboldt spent much of the rest of his life placing the findings from his Latin American voyage into a global environmental context. His three volumes entitled *Relation historique du voyage aux régions équinoxiales du nouveau continent* (1814–1825) represent the first report of that expedition. He then expounded on this work in the five-volume *Kosmos*, which was based on a series of highly successful public lectures in 1827–1828.

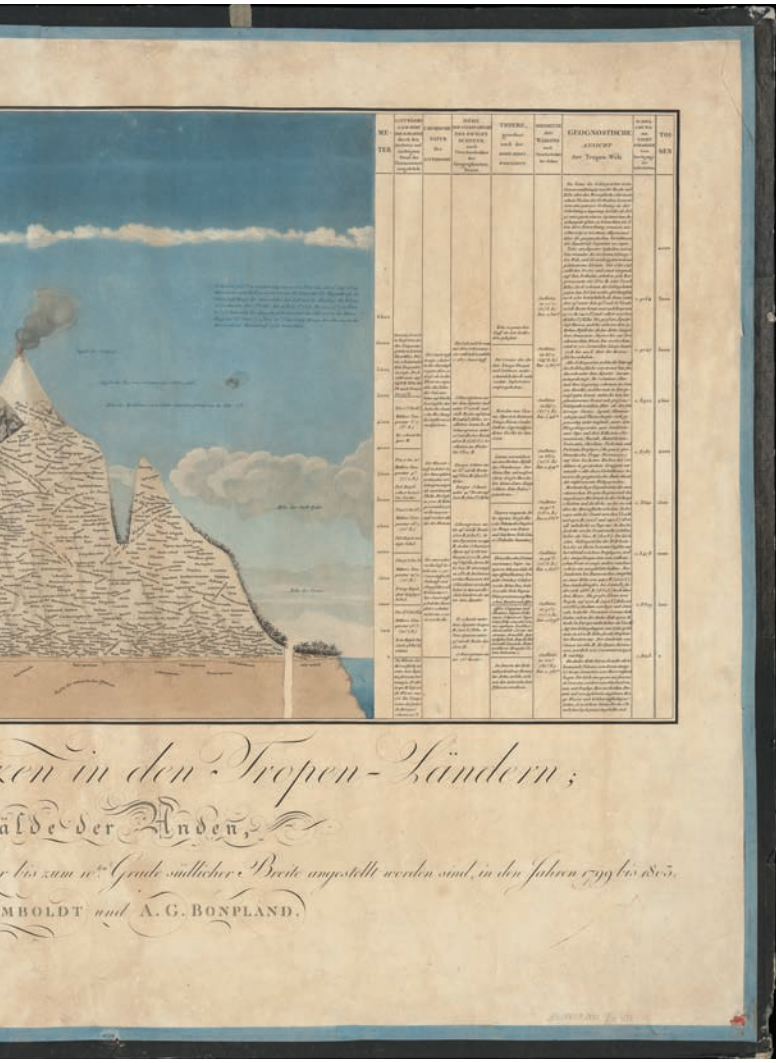
Humboldt and his colleague Aimé Bonpland annotated this cross-sectional illustration of Chimbo geography based on observations from their travels in South America. The figure accompanied t version at Eos.org.

After his return to Europe, Humboldt spent much of the rest of his life placing the findings from his Latin American voyage into a global environmental context.

Humboldt's second major expedition was to Russia in 1829, where he reached as far as the Altai Mountains. It represented a compromise after many failed attempts to venture farther to India and elsewhere in Asia. The immediate scientific insights from this expedition were comparatively limited, although he could claim the discovery of diamonds in the Urals and a number of geographic corrections.

A Revolutionary Thinker

By nature, Humboldt was collaborative and open to sharing data. And he continually revised and updated his own published works over his lifetime, emblematic of his interconnected and dynamic view of knowledge and its dissemination.



razo and Cotopaxi volcanoes (in present-day Ecuador) with detailed information about plant he pair's "Essay on the Geography of Plants," originally published in French in 1807. See a larger

Reading Alexander von Humboldt, we notice that his approach to science was revolutionary in many ways. First, Humboldt displayed an impressively high level of precision and accuracy in his data collection, paying particular attention to make sure measurements and sample locations were properly georeferenced. He was thus able to create the first global geomagnetic and temperature maps, paving the way to the establishment of general relationships.

Another fundamental aspect of his approach was his search to understand connections between natural processes and their feedbacks. For example, Humboldt analyzed spatiotemporal distributions of and possible connections between earthquakes and volcanic eruptions in great detail, in search of a general theory that could explain their individual causes as well as possible triggering processes. Quantitatively establishing such links in terms of stress triggering of volcanic conduit systems remains an unsolved question in geodynamics and volcanology.

Humboldt mixed travel narrative and descriptions of his emotional responses to natural experiences with discussions of his measurements and the theories he derived from them.

Humboldt appears to have much preferred Paris over Berlin for most of his life, although he ended up being employed by the Prussian court. He died in Berlin in 1859 nearly penniless but as one of the most famous scholars in the world. A German foundation in Humboldt's name and spirit was established soon after and to this day supports academics worldwide. Grants are given in the humanities and natural sciences for research in Germany and related collaborations abroad. (Both of the authors were lucky to have been Alexander von Humboldt Foundation scholarship beneficiaries.)

Humboldt appears to have been an overbearing talker and somewhat self-obsessed, yet he was also unselfish in his support of early-career scientists. He shared his data and samples freely and tried to establish an international and open network of scientists driven by a respect for human rights and equality. Contrary to the standard in modern scientific literature, Humboldt mixed travel narrative and descriptions of his emotional responses to natural experiences with discussions of his measurements and the theories he derived from them. Humboldt wrote that "Nature herself is sublimely eloquent. The stars as they sparkle in firmament fill us with delight and ecstasy, and yet they all move in orbit marked out with mathematical precision."

High-quality data and the search for a physical unifying theory represent the foundation of Alexander von Humboldt's innovative and creative scientific approach. The special theme in *Geochemistry, Geophysics, Geosystems* and the Union session at Fall Meeting will celebrate Humboldt's scientific discoveries. More important, we hope to build on his vision for understanding the Earth system as a whole in an open, diverse, and collaborative environment.

For those interested in learning more about Alexander von Humboldt, we recommend the brilliant reevaluation of his life offered in Andrea Wulf's biography *The Invention of Nature: Alexander von Humboldt's New World* (Vintage, 2015). This has more recently been joined by a beautifully illustrated graphic novel, *The Adventures of Alexander von Humboldt* (Pantheon Graphic Library, 2019), by Wulf and Lillian Melcher.

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▶Read the full story at bit.ly/Eos-von-Humboldt

LIVING IN FEAR OF RAIN

By Jenessa Duncombe

Every summer, monsoon rains come to southwestern India. In 2018, however, the deluge brought the worst flooding in a century.

The resulting destruction killed nearly 500 people, inundated cities, and collapsed bridges. The rains also caused thousands of landslides in the mountains after torrents loosened soils from hillslopes. These slurries of water, soil, rock, and vegetation overwhelmed villages, downed power lines, and cut communities off from receiving aid.

Then the monsoon returned with devastating force the following year, with the rains 400% above normal for a week in early

The swollen Cheruthoni River in the Idukki district of Kerala, India, as seen on 20 September 2018. Three open shutters of the Cheruthoni Dam gush water, and the wreckage of a bridge sits in the river downstream. Credit: I&PRD, Government of Kerala

In these photos taken on 5 September 2018 in the wake of a monsoon, a car makes cautious progress through flooded streets (left) and a home is submerged (right) in the Alappuzha district of Kerala, India. Credit: Thomas Oommen

August 2019. Back-to-back years brought flooding that would be expected only once every 100 years.

"People in Kerala have been shaken by this repeat event from last year. And they're starting to wonder if this could be the new normal," Thomas Oommen, associate professor at Michigan Technological University in Houghton, told *Eos*. "I sure hope it's not the new normal."

Following the disaster in 2018, Oommen led a team of geoscientists to the hardest-hit areas in the state of Kerala to assess the damage from landslides. Their ground survey uncovered the intimate link between human activities and the dangerous slides, where unbridled construction, mining, and cash crop farming left hillsides vulnerable to collapse.

The researchers worry that local governments won't act decisively to mitigate future hazards. Previous reports had indicated that many vulnerable areas should be excluded from future development, Oommen noted. "But there has been a lot of pressure from the political parties not to implement that," he said.

"I hope this second event has been a second wake-up call," Oommen said.

A Call to Action

Summer monsoon rains began to fall in Kerala in May 2018. In the months following, storm after storm brought 2.4 meters of rain to the state in just 87 days.

Oommen, who is from Kerala, watched the floods unfold from afar and knew that scientists needed to survey the effects of the rain quickly, while landslide scars were still fresh. In late August, after the first year's rains had ceased,

Flood victims flee rising waters in the Indian state of Karnataka on 8 August 2019. Credit: STR/Associated Press

(left) Debris from a landslide as seen on 20 August 2018 butts against homes in Idukki, stacking dirt and vegetation onto roofs. Credit: I&PRD, Government of Kerala. (right) Researchers found this large hole in a landslide photographed on 7 September 2018 and believe it is evidence of a subsurface piping, which can destabilize hillslopes. Credit: Thomas Oommen

he reached out to a fund sponsored by the National Science Foundation (NSF) to undertake rapid reconnaissance after disasters.

NSF agreed to send him and a team of landslide geoscientists—Sajinkumar K. S., Richard Coffman, and Vishnu C. L.—to the mountains of Kerala. One week later, Oommen packed his bags and boarded a plane to India.

A First Glimpse of the Floods

On 3 September 2018, the team of researchers met in the Kerala city of Thiruvananthapuram. Their first stop was 3 hours north, in the state's Alappuzha district, a region that sits along the coast between the inland Vembanad Lake and the waters of the Arabian Sea.

When they got there, the scientists were taken aback by what they found. "To our surprise, there were over 3,500 houses still flooded in the Kainakary area," Oommen said. They did not expect to see houses under water nearly 2 weeks after the rain abated, he said.

The region sits below average sea level, and an embankment between agricultural fields and the city had been washed away in the flood. As the city worked to rebuild the wall and pump out water, the damage showed: At houses where the water had receded, the scientists saw foundations starting to sink into the ground.

The paddy fields in Alappuzha, which inspired its reputation as the "Rice Bowl of Kerala," were almost ready for harvest before the monsoon came, said Oommen. Instead, they were destroyed by the rains.

But the floods were just one symptom of the downpours; another hazard lay upslope in the mountains. As landslide geologists, the crux of their fieldwork lay there.

Wreakage in the Highlands

The researchers drove east, toward the lush Idukki district of Kerala. Idukki lies within the Western Ghats, a mountain range draped with tropical forests that stretches along the west coast of India.

The unusually heavy rain from the monsoon had saturated hillsides of the Ghats during the summer months, triggering more than 1,000 landslides, according to initial reports that Oommen received from the government. Those estimates indicated that in Idukki alone, the slides had buried 161 structures and damaged thousands of others.

The landslides also "severely damaged or totally destroyed" the roads in Idukki, said Oommen, leaving towns stranded for weeks at a time. Traveling around the wreckage, often on roads reduced to one lane, the scientists saw loosened earth sluicing through villages and gigantic slides that left whole hillsides bare.

Mapping the Scars

The team of scientists set out to map some of the recent slides before the forest swallowed the evidence. "Being a tropical climate, all the manifestations of landslides will be erased very soon due to intense growth of bushy vegetation," said Sajinkumar, a member of the reconnaissance team and an assistant professor of geology at the University of Kerala.

At many of the slides, the researchers hiked through the forest, tracing the perimeter of the slide by foot and plotting the edges with GPS. They snapped photographs using a thermal camera to measure underlying moisture and drainage channels, and probed the ground using a cone penetrometer to check the soil's strength.

After examining roughly 40 slides and taking detailed measurements of nearly a dozen, the scientists noticed two distinct causes for the landslides, one natural and one human caused.

The natural cause was the simple reality of steep terrain bombarded with too much water. When the torrential rain fell on the Western Ghats, the water percolated into the soil and tried to flow downhill. In certain areas, dangerous subsurface channels called pipes formed. These pipes either quickly drained subsurface water, destabilizing hillslopes, or became clogged, creating a backlog of water that grew larger and larger until the entire slope gave way. In some places, the underground pipes "reached a maximum of 20 centimeters" in diameter, Sajinkumar said.

A massive landslide at Government College in Munnar, India, photographed as seen on 20 September 2018. Credit: I&PRD, Government of Kerala

But these types of natural slides were in the minority, Oommen noted. The researchers found that recent construction was the root cause of most of the slides. Slicing into the hillside to build new structures or open mining quarries transforms the runoff pattern and opens up new ways for water to seep underground. "The increased infiltration," Oommen said, "destabilizes the slope and leads to landslides."

Building on Shifting Ground

A study in *Natural Hazards and Earth System Sciences* in 2018 documented a steady rise in fatal landslides triggered by human activities, particularly in Asia (bit.ly/Eos-fatal-landslides). Oommen and Sajinkumar saw this playing out in near–real time, with construction practices aggravating the existing landslide hazards.

For example, a massive landslide near Government College in Munnar in Idukki sent soil cascading down the hillside, wiping out several newly constructed buildings, Sajinkumar noted. Fortunately, no one was injured in the landslide.

Sajinkumar said that officials at the college should hardly be surprised by the most recent slide on campus. A landslide had previously occurred there in 2005, destroying a building in its path. After the 2005 slide, Sajinkumar published a study diagnosing the type of slide (a "headward retreating landslide"), and he warned that the slope would likely fail again in strong rainfall.

"However, the college authorities extended the campus within the landslide scarp, forgoing the warning from previous studies," he said.

Rising Death Toll

The slide at Government College in Munnar came on the heels of other tragic losses in the community: More than a dozen monsoon-related deaths occurred during the month of August, including those of a family swept away by a landslide in the night.

The scientists visited the village of Panniyarkutty, where five people were killed when a landslide swept over several houses. When the team of scientists visited, residents were still searching for the bodies of three victims.

"While speaking with the neighbors of the deceased, we saw fear on their faces," Oommen said. "They are traumatized and live in constant fear of rain."

The researchers said that the cause of the deadly slide in Panniyarkutty was not immediately clear. They didn't find evidence of recent construction or natural piping. Oommen suspects that the area may serve as a valley that several slopes drain into, but he said that further hydrologic analysis is needed.

The researchers worried that the devastation might not be over for Panniyarkutty and other communities in high-risk zones when future monsoon rains come. Slopes on the verge of collapse, called aborted landslides, could become destabilized and grow into full landslides when another rainstorm strikes.

"These aborted landslides can get reactivated in this spell of rain," said Sajinkumar. Given the danger, he explained, "it is advisable not to have human habitations in these highly vulnerable areas."

However, families in Panniyarkutty face substantial difficulties trying to rebuild or relocate. "Many low-income families lost their homes, in which they had invested all their savings," said Oommen. "Due to the high population density," Sajinkumar added, "people are forced to occupy the hilly areas without accounting for the landslide susceptibility."

The Need for Science-Informed Policy

A report led by Indian ecologist Madhav Gadgil and released in 2011 called for restrictions on land use in the

Western Ghats, including a ban on mining. Oommen and his colleague Sajinkumar agreed that future land use limitations are necessary, saying that the absence of strong legislation and enforcements made the landslide risks worse in 2018. The researchers released an atlas of landslide danger in Kerala in 2017, pinpointing vulnerable slopes where construction should be avoided.

Despite the warnings, the government relaxed the requirements for mining following the 2018 disaster, according to Himanshu Thakkar, coordinator of the South Asia Network on Dams, Rivers and People. While mining is only one source of construction in the Western Ghats, the move suggests that the government is hesitant to curb development.

"There has not been much done. That's the sad part," Oommen told *Eos* in August 2019. He said that political will, both of the public and of the elected officials, is needed to prevent future risk. "Even the politicians don't want to do anything that the people don't want," he said.

The second wave of rain in 2019 unleashed another rash of landslides, killing more than 50 people in one landslide alone.

Oommen said that he is expanding his work to focus on bridging science with policy making. Following the flooding and landslides in 2019, he flew to Mumbai to consult on disaster management education and research.

A landslide in the Idukki district knocked this house off its foundation, as seen on 6 September 2018. Credit: Sajinkumar K. S.

"We have done some research, [and] we have identified some of the vulnerable areas," he said. "We need to actually lead this to action."

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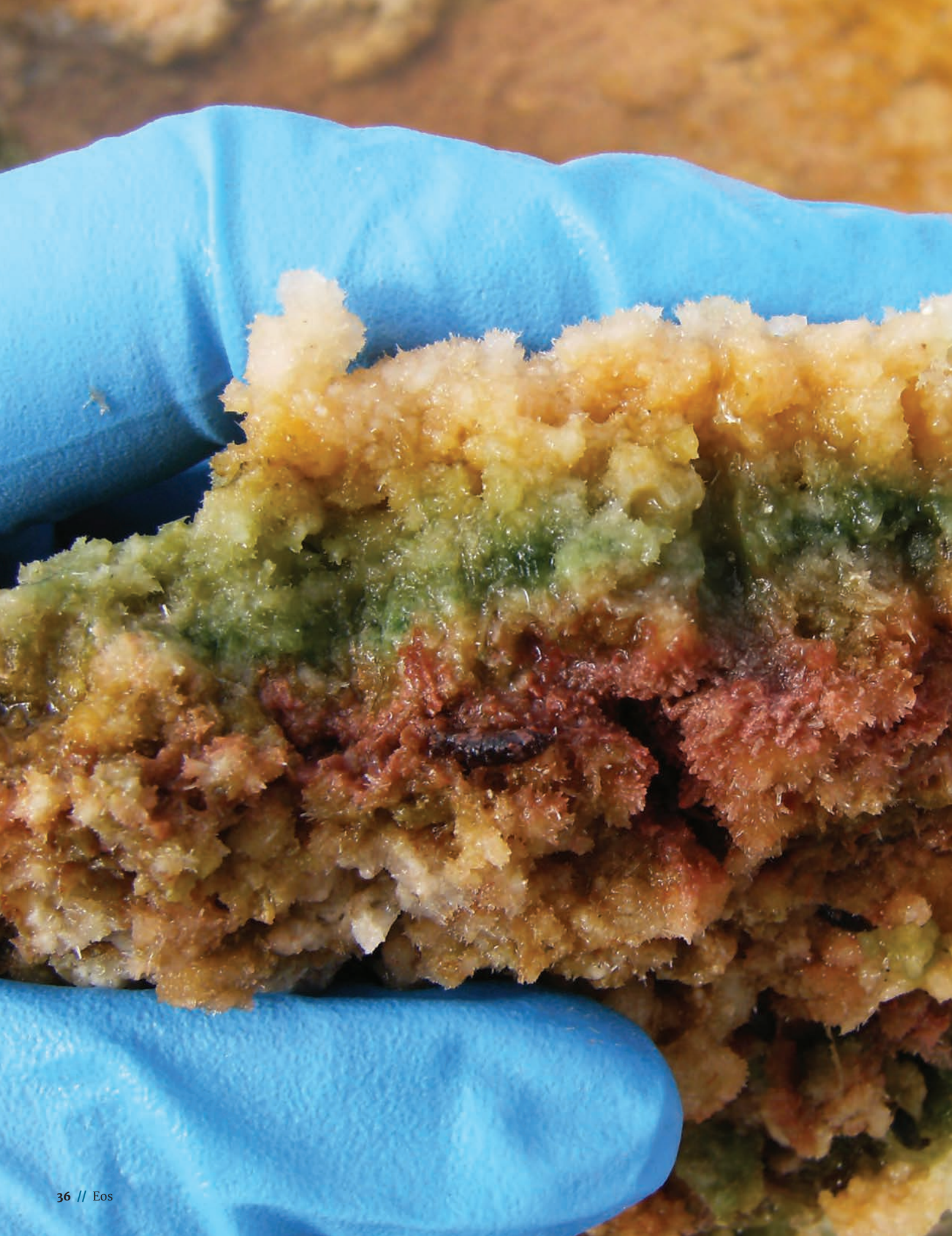
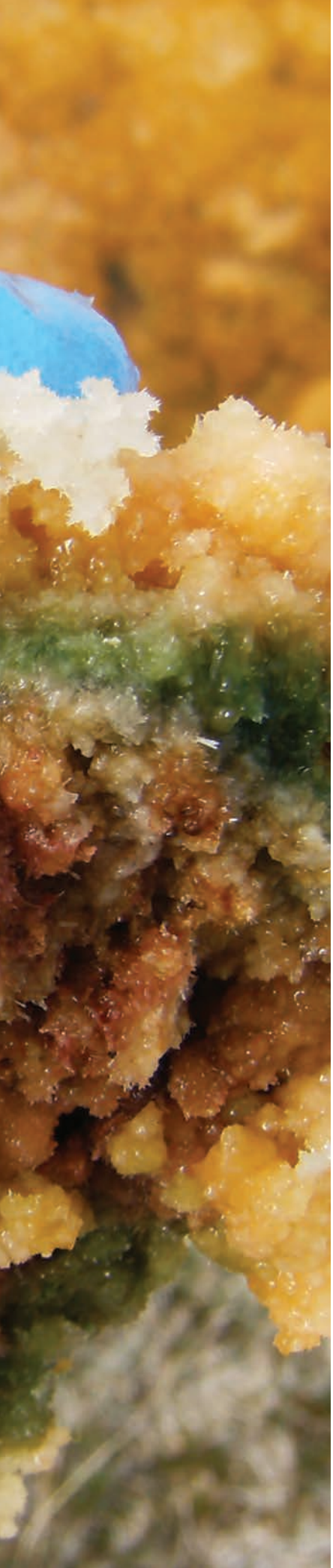
▶Read the full story at bit.ly/Eos-Kerala-landslides





EOS CENTENNIAL COLLECTION

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Cleaning the Air ~~of~~ With Asbestos

By Laura Poppick

Once the source of a notoriously toxic substance, asbestos mines could be climate healers—with a little scientific innovation.

Once celebrated for its heat resistance and durability, asbestos has now become synonymous with "hazardous" due to the health threats it poses when its tiny fibrils become airborne. As a result, the material has been phased out of most consumer products. But the legacy of asbestos mining in Canada and elsewhere around the world has left piles of hazardous material stranded at abandoned mines, with ongoing health threats to those living in close proximity.

Now researchers are looking for ways to clean up and repurpose that waste, all while trying to slow climate change. Jenine McCutcheon, a geomicrobiologist at the University of Leeds in the United Kingdom, has worked with colleagues to develop techniques that could turn abandoned asbestos tailings into deposits of magnesium carbonate, a group of minerals that includes the white powder that gymnasts and rock climbers use to improve their grip. Expanded on a large enough scale, this mine waste remediation could also help slow global warming by pulling carbon dioxide out of the atmosphere and storing it in stable carbonate rock form.

This carbon sequestration process occurs naturally as rocks break down over the course of millions of years. But McCutcheon and colleagues are devising a method to dramatically expedite that natural occurrence with the help of bacterial mats.

"We are looking to accelerate this process and transition it from a pile of asbestos waste to a deposit of carbonate mineral which is completely harmless," said McCutcheon.

McCutcheon is the lead author of a recent study in *Environmental Science and Technology* (bit.ly/mg-carbonate-minerals) documenting the methods that could prove useful not only at abandoned mines but also at active mines that are extracting rocks with similarly magnesium rich compositions, including copper,

A layered mat of cyanobacteria consolidated by carbonate minerals. The researchers found this mat growing naturally in a wetland and used it as an analogue as they developed their new technique. Credit: Jenine McCutcheon

A handful of hydromagnesite, one of the carbonate minerals the researchers aim to produce with their technique. Credit: Jenine McCutcheon

nickel, and platinum. Not only would the methods help clean up toxic waste; they also could offer a way for these mines to offset their carbon emissions—an asset that has become increasingly appealing as taxes on such emissions have emerged in places like Canada and elsewhere around the world.

"I think we are approaching the tipping point," said McCutcheon, "of people having to more actively think about how the carbon tax will influence their finances."

Once one of the world's leading producers of asbestos, Canada is now a hot spot of abandoned asbestos mines. With the Canadian federal carbon tax of C$20 per metric ton slated to increase to C$50 per metric ton by 2022, these methods could offer companies the opportunity to balance their budgets and do their part to slow climate change at the same time.

A Dangerous Substance Turned Harmless

Asbestos includes a group of silicate minerals composed of tiny fibrous crystals packed tightly together. The material doesn't pose much of a hazard when fully intact, but as these crystals break down and become airborne, they can enter the body and cause major health problems, including lung cancer.

But the very quality that makes asbestos so hazardous to inhale also makes it especially well equipped to pull carbon dioxide out of the atmosphere, said McCutcheon. The thin fibrils have a very high surface area, which contributes to their high reactivity and tendency transform into carbonates.

"This is a process we do see naturally occurring at mine sites," McCutcheon said. "You can go to mine tailing storage facilities and climb these carbonate crusts."

That's in part because the mining process further increases the rock's reactivity by pulverizing it into a fine powder, allowing a mineralization process that may take 1 million years to occur in a solid boulder to occur within just 1 year at a mine site, said Sasha Wilson, a biogeochemist at the University of Alberta and previous adviser to McCutcheon during her Ph.D. Those are "incredibly fast weathering rates," Wilson added.

These methods could offer companies the opportunity to balance their budgets and do their part to slow climate change at the same time.

Still, naturally occurring crusts tend to stop forming at a certain depth in tailings piles, so the carbon storage potential of these abandoned piles has been limited, Wilson noted. One problem researchers have found is that the crusts clog the pore space within piles, preventing fluids from seeping to deeper depths. "The reaction itself relies on carbon dioxide reacting with rainwater," said Wilson.

If carbon dioxide–infused water can't trickle down into the clogged pore space, the carbonation reaction will stop. So Wilson, McCutcheon, and their colleagues devised a plan to see whether cyanobacteria could help pick up the slack by providing a source of carbon in the system.

Cyanobacteria "are really good at concentrating carbon from the atmosphere," said Wilson, because unlike most

Carbonate crusts form naturally on mine tailings with the help of naturally occurring cyanobacteria. Credit: Jenine McCutcheon

bacteria, they photosynthesize and absorb carbon dioxide during that process. "They collect it, they concentrate it, and when they die, they are decomposed by other bacteria, and that replenishes the supply of dissolved carbon in solution."

Aside from tweaking the chemistry of the tailings in favor of carbonate mineralization, cyanobacteria can also provide a point of nucleation from which carbonate crystals can begin to grow, McCutcheon said. They also naturally tend to colonize many different types of environments, including mine sites, so inoculating tailings with cyanobacteria would not drastically change the surrounding environment. "We would help their growth and increase cell populations to a scale that would be suitable for this carbon storage," said McCutcheon.

The next task becomes devising a method to propagate these larger colonies of bacteria. "You really need to keep the bacteria happy," Wilson said.

Scaling Up

To stay "happy," cyanobacteria require the same three ingredients all photosynthesizing organisms need: water, sunlight, and nutrients.

McCutcheon noted that many abandoned mines have open pits that are already full of water, so those could be good sources of wetlands for the bacteria. To help the bacteria grow, scientists would need to add nutrients (a solution of phosphorus and nitrogen). Leached mine waste could then pass through these bacterial mats, generating carbonate deposits.

As a proof of concept, McCutcheon's team designed a lab-based experiment using a 10-meter-long series of tubes inoculated with cyanobacteria. They then introduced synthetic mine waste similar to what would be left behind at a mine site and fed the bacteria with a nutrient solution. They found that over the course of about 2 months, the process did, indeed, produce substantial quantities of carbonate minerals.

Researchers estimate that scaled up, the reactions could store up to 238 metric tons of carbon dioxide per hectare of wetland per year. Scaled up to a square mile, that's about 62,000 metric tons, or the equivalent of the annual emissions of about 13,500 cars. These findings set the stage to implement these techniques at the mine scale, said McCutcheon. "We have all the tools in place."

As the carbon market has grown, other research groups have investigated the carbon storage potential of other types of mine tailings; (e.g., bit.ly/CO2-mine-tailings). But whereas some of those processes require the addition of heat, magnesium carbonates can form under relatively low temperatures, without the addition of an external heat source—and that's a real asset for remote locations without the infrastructure to build high-temperature reactors, McCutcheon said.

Still, implementing the new process at abandoned sites may prove relatively complicated, noted Wilson, because many in Canada remain under the supervision of local governments and may not have associated funds to set up carbon storage facilities.

Companies are increasingly looking to revisit these abandoned sites, however, to remine them for other mate-

Open pits left behind at abandoned asbestos mines could provide the foundation of the wetlands required to promote cyanobacteria growth. Credit: Jenine McCutcheon

It will take a suite of solutions to slow climate warming, and this is just one of many that could be implemented in those efforts.

rials, such as jade. This technique could be a good option for those groups already planning to bring new infrastructure to these sites, Wilson said.

A Promising Future

Alissa Park, a chemical engineer at Columbia University who studies other methods of carbon capture and storage in mined materials, thinks that these new methods could prove helpful as one promising form of carbon sequestration in the global carbon market. "I think there is a good future for this technology," she said.

McCutcheon noted that there could be unforeseen risks associated with the method, but these bacteria already naturally exist in these environments, so their impacts should be minimal. Groups would need to be mindful to inoculate sites with the species local to that particular mine to not throw off the natural balance, she said.

Louis-César Pasquier, a researcher at the Institut National de la Recherche Scientifique in Quebec City who studies mine waste recovery, agreed that these methods could prove promising if implemented at the mine scale.

Pasquier also noted that the new methodology would be even more appealing to companies if they were able to repurpose the carbonate minerals as value-added products. He sees potential for magnesium carbonates in products including pharmaceuticals and wastewater treatment, as well as building materials.

But the cost of production would need to be relatively low compared to the market value of those products. "You need to find the efficient and low-cost way to produce your by-products," Pasquier said.

A Suite of Solutions

Despite these challenges, Pasquier thinks that the new method could work in tandem with other carbon sequestration methods to move society forward in pulling greenhouse gases out of the atmosphere. "It will take all of the solutions to solve the large problem of greenhouse gas emissions," he said.

Wilson agreed that it will take a suite of solutions to slow climate warming and that this is just one of many that could be implemented in those efforts. "For a long time people were looking for a silver bullet," Wilson said. But in recent years, industries have mobilized to create more diverse, smaller-scale carbon sequestration solutions. "I think there is going to be a lot of industry-by-industry problem solving when the crunch time comes."

And with carbon taxes rising in Canada, that crunch time might be fast approaching.

"Necessity is the mother of invention," Wilson said.

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▶Read the full story at bit.ly/Eos-asbestos-carbon

EOS CENTENNIAL COLLECTION

Extreme Precipitation Expected to Increase with Warming Planet

Heavy rain will likely be a more common occurrence on a warming planet. Credit: Santosh Kumar, CC BY 2.0 (bit.ly/ccby2-0)

The simplest thermodynamic equations make it clear that warmer air can hold more moisture than colder air: The Clausius–Clapeyron equation shows that for every 1°C temperature increase, Earth's atmosphere can hold 7% more water.

The reality of global climate science, however, is often more complicated than the simplest thermodynamic equations.

Earth's atmosphere is not uniform. Its composition is constantly changing, and it's certainly not heating evenly everywhere—some places are even getting colder. Forecasting the likelihood of extreme precipitation events is therefore more challenging than adding numbers to a model. Still, the historical record, especially since anthropogenic warming took off in the 1900s, can provide insight into how Earth's atmosphere responds to rapid warming.

In a new study, *Papalexiou and Montanari* use a novel technique to analyze historical data and investigate the likelihood that global warming was driving the frequency and magnitude of extreme precipitation events. The scientists collected their data from the Global Historical Climatology Network–Daily database. This data set includes measurements from approximately 100,000 precipitation stations across the world.

For their analysis, the researchers focused on the 1964–2013 period, when global warming accelerated. They looked at how many complete years of data were recorded for a given station; then they chose to analyze that number of extreme precipitation events. So if a station provided 45 complete years of data, they analyzed the top 45 most extreme events. The authors argue that this analysis technique represents extreme rainfall events more accurately than simply looking at a series of annual maximum precipitation numbers, because in the absence of some external force (such as rising temperatures) it should result in an even distribution. Stations with fewer than 5 complete years of data in each one of the 5 decades studied were excluded from the analysis, and after screening for a variety of other criteria, the researchers were left with a record from 8,730 stations from around the world, mostly clustered in North America, Europe, Russia, China, and Australia.

The researchers then constructed a time series for both annual frequency and average magnitude of the extreme rain events for each weather station. For the frequency data, the results were especially pronounced, with the occurrence of extreme precipitation events increasing significantly as time went on. In the last decade of data (2004–2013), the scientists found 7% more extreme precipitation events than they'd expect if no external force were skewing the distribution. The data related to magnitude were less pronounced but also indicated a slight uptick. In addition, the researchers report that they found no strong correlation between increasing frequency and increasing magnitude.

Finally, because each weather station is also tied to a geographical location, the researchers were able to analyze where the extra rain was falling, with Eurasia, northern Australia, and the midwestern United States absorbing the bulk of the new moisture.

The study suggests that as the planet continues to warm, extreme rainfall events will continue to become an increasingly common part of life for many heavily populated parts of the world. As land managers and policy makers fight to stay ahead of climate change, this type of data will become ever more informative and necessary. (*Water Resources Research*, https://doi.org/10.1029/2018WR024067, 2019)

—David Shultz, Freelance Writer

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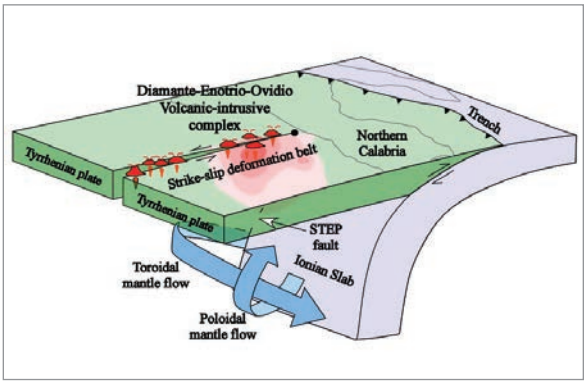
New Volcanic Complex Found Below the Southern Tyrrhenian Sea

Subduction and retreat of the Adriatic–Ionian microplate—a sliver of oceanic crust that separated from Africa during the Cretaceous—beneath Eurasia have controlled much of the tectonic and stratigraphic evolution of the western Mediterranean Sea. The subduction forged Mount Vesuvius and other southern Italian volcanoes and their concomitant geohazards, and episodes of rapid rollback of the subducting slab have led to the opening of basins including the Tyrrhenian Sea between Sardinia, Sicily, and mainland Italy.

Tearing and faulting of downgoing oceanic plates are common in subduction systems, sometimes producing faults called Subduction-Transform Edge Propagator (STEP) faults at slab edges that propagate perpendicularly to the subduction strike. This process can allow magma upwellings caused by subduction-induced mantle flow to rise to the surface and has been suggested to explain the presence of volcanic seamounts beneath the southern Tyrrhenian Sea. To date, however, this magmatism has been poorly documented.

Now *De Ritis et al.* report a detailed investigation of a large volcanic-intrusive complex located about 15 kilometers off the Tyrrhenian coast of Calabria in southwestern Italy. Using a suite of geophysical data, including multibeam sonar bathymetry, as well as seismic reflection, magnetometric, and seismological data, the authors characterized the complex, which formed within the past 780,000 years and had not yet been identified or studied in detail.

The team's data indicated the presence of numerous magmatic intrusions that reached the seafloor in several locations to form seamounts and other volcanic features like chimneys and lava flows. The researchers divided the complex into two distinct realms: an eastern domain (the Ovidio seamounts), characterized by a series of flat-topped volcanic edifices, and a western domain (the Diamante and Enotrio seamounts), where strike-slip faults deform the volcanic edifices.



Researchers have identified the previously unknown Diamante–Enotrio–Ovidio volcanic-intrusive complex on the floor of the southern Tyrrhenian Sea off the coast of Calabria, Italy, which they suggest formed because of a Subduction-Transform Edge Propagator (STEP) fault in the subducting Ionian slab that directed the ascent of magma rising from the mantle. Credit: Fabrizio Pepe

Collectively, the results affirm that the newly identified volcanic-intrusive complex originates from decompression melting of mantle material at the northern edge of the Ionian slab. The authors hypothesize that a strike-slip belt associated with the formation of a STEP fault controlled the magma's ascent and the location of this complex. These findings shed light on magmatic processes occurring along the edges of subducting slabs as well as on the potential geohazard risk in a densely populated region whose volcanic activity was previously believed to be one of the best characterized in the world. (*Tectonics*, https://doi.org/10.1029/2019TC005533, 2019)

—Terri Cook, Freelance Writer

Detecting Carbonates on the Surface of Mars

Was Mars warm and wet enough to support life during the planet's first few hundred million years? Scars of ancient lakes and rivers, as well as minerals that form only when water is present, have convinced many researchers that Mars was once conducive to life. But one type of alteration mineral, carbonate, has been conspicuously scarce in some studies, raising doubts about whether there was enough carbon dioxide vapor to warm Mars's early atmosphere.

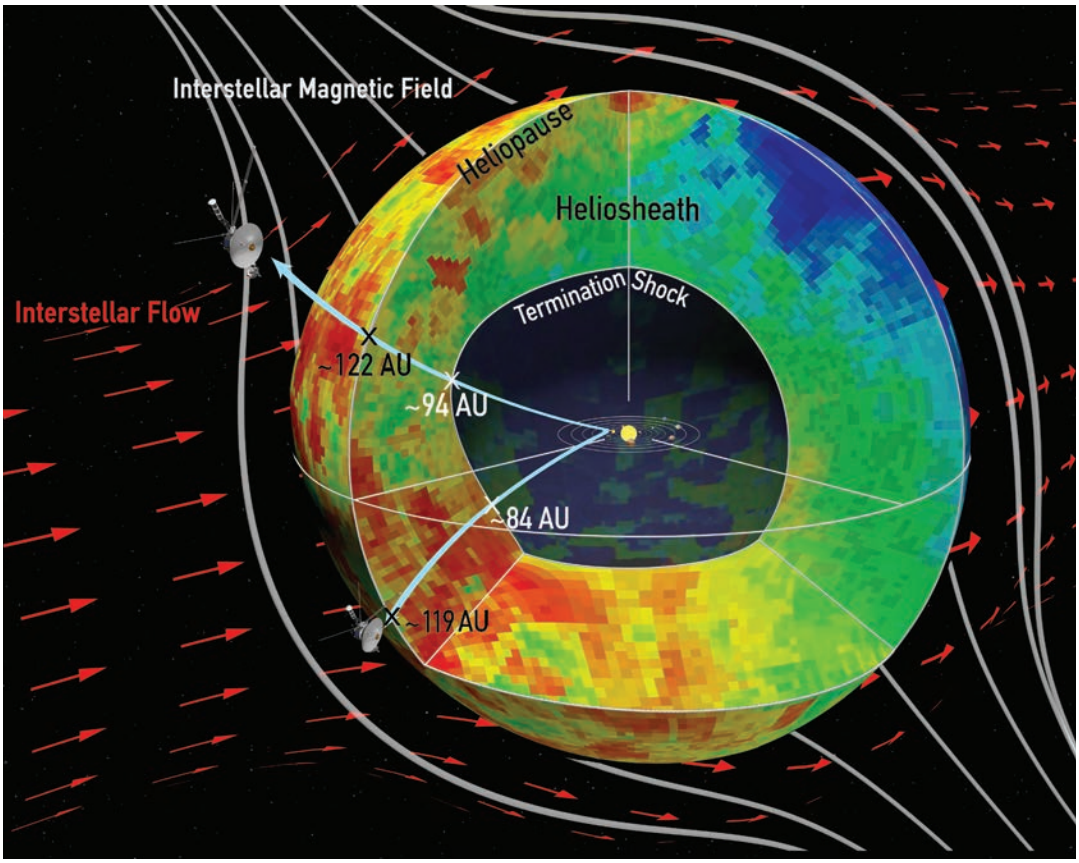
Carbonate minerals such as calcite, the key ingredient of marble, limestone, and seashells, are formed when water traps atmospheric carbon dioxide. The pale, translucent minerals have a distinct spectral signature, which remote sensing instruments located aboard the Mars Reconnaissance Orbiter can detect. The orbiter had spotted carbonates before, but in 2017, the Curiosity rover found no evidence of carbonate minerals on Mars's surface, confounding scientists.

A study based on the orbiter's remote sensing data presents fresh evidence of carbonates mixed among hydrated minerals across Mars's surface. *Bultel et al.* searched for carbonates all over Mars in weathering profiles, vertical arrays of rock that span from a few centimeters to 100 meters thick. These profiles hold clues to what the climate was like on Mars in the past because they show how rocks have lost and gained soluble elements over time. On Mars, the profiles often resemble a layer cake, with clay minerals rich in aluminum on top, iron-rich clay in the middle, and magnesium-rich clay on the bottom.

Confirming previous remote sensing data, the team found widespread evidence of carbonates across Mars's surface. The new study bolsters the hypothesis that there was liquid water on Mars's surface until around 3.7 billion years ago and that fluids containing carbonic acid (carbon dioxide dissolved in water) weathered the planet's surface. Although there are still many mysteries about Mars's early environment, the study sheds new light on the period of the planet's history when it is most likely that life could have emerged. (*Journal of Geophysical Research: Planets*, https://doi.org/10.1029/2018JE005845, 2019)

—Emily Underwood, Freelance Writer

Sampling the Space Between the Stars



In this schematic, the basic shape and properties of the heliosphere, the protective magnetic bubble created by the solar wind, are based on measurements of heliosheath proton distributions from Voyager 1 and 2 (illustrated in the diagram) and of energetic neutral atoms by Cassini. The location of the inner edge of the heliosheath, called the termination shock, is roughly 10 astronomical units (1 astronomical unit is equivalent to the mean Sun–Earth distance of about 150 million kilometers) farther from the Sun where Voyager 1 crossed it compared with Voyager 2, but the location of the outer edge, the heliopause, is at about the same distance along both Voyager trajectories. Red arrows represent the interstellar plasma flow deflected around the heliosphere bubble. Credit: K. Dialynas, S. M. Krimigis, D. G. Mitchell, R. B. Decker and E. C. Roelof

Charged particles that spew into space as part of the solar wind create a protective magnetic bubble tens of billions of kilometers wide around the solar system. This bubble, called the heliosphere, plows through the harsh cosmic radiation of interstellar space.

Understanding the physics at the bubble's edge, called the heliosheath, is not easy. The boundary is in constant flux and pushes out against the broader interstellar magnetic field that permeates our corner of the Milky Way. Only two spacecraft—Voyager 1 and 2, launched by NASA in 1977—have ever traversed the frontiers of our local bubble.

Now *Dialynas et al.* have combined Voyager data with observations from NASA's Cassini mission, which orbited Saturn from 2004 to 2017, to gain more insight into this region of space. The researchers recognized that the missions, although launched 20 years apart, had collected complementary data. Voyager 1 and 2 had instruments that measured energetic ions as the craft crossed the heliosheath and exited the solar system. Cassini, meanwhile, was able to remotely observe energetic neutral atoms (ENAs) arriving in all directions from the heliosheath.

These two phenomena are related: ENAs come from the heliosheath, where fast solar wind protons collide with neutral hydrogen atoms from interstellar space and "steal" an electron from the interlopers. The Voyager probes took in situ measurements of the parent heliosheath proton distributions as they passed through this region. Meanwhile, the protons with newly added electrons become ENAs and zip off in all directions.

The synergy among the spacecrafts' observations allowed the researchers to use Voyager data from the heliosheath to ground truth and calibrate ENA data from Cassini, which was more sensitive to lower-energy particles than Voyager was. Together, the spacecraft extended data on the intensity of both ENAs and ions to include a broader range of energies, which gave the team a window into the physics of the heliosheath as the solar wind and interstellar medium press against each other.

The researchers found that in the energy range considered in their study (>5 kiloelectron volts), lower-energy ions with energies between about 5 and 24 kiloelectron volts played the largest role in maintaining the pressure balance inside the heliosheath. This allowed the team to calculate the strength of the magnetic field and the density of neutral hydrogen atoms in interstellar space: about 0.5 nanotesla and 0.12 per cubic centimeter, respectively.

On the basis of calculations from Voyager 2 data, the researchers predict that the heliopause, the outer boundary of the heliosheath, is located roughly 18 billion kilometers from the Sun, or 119 times the distance from the Sun to the Earth—right where Voyager 2 found it in November 2018.

Furthermore, the finding that the lower-energy ions dominate the pressure balance in the heliosheath means that space physicists will have to rethink their assumptions about the energy distribution of such particles in the heliosheath. (*Geophysical Research Letters*, https://doi.org/10.1029/2019GL083924, 2019)

—Mark Zastrow, Freelance Writer

How Land Use Affects Nutrient Pollution in a Changing Climate

In Japan's mountains, torrents of water cascade down steep ridges, flow beneath cedar boughs in unmanaged forests, stream through farms maintained by an aging rural population, and, finally, course past the urban areas to which many younger citizens have flocked. By the time this water reaches the rivers that feed local drinking supplies, it has picked up a lot of evidence of the land it has traversed, including nutrient pollution.

Nutrient pollution, or an excess of nutrients such as nitrogen and phosphorus in the water, can lead to a host of health and environmental problems. Many nutrients enter rivers as runoff from farms and residential areas. Scientists have also suggested that forest soils may generate nutrient runoff, especially in coniferous forests, where soil surfaces are often bare and prone to erosion.

As global climate warms and strong rainstorms become more frequent throughout the world, researchers are wondering how the increase in heavy precipitation might affect nutrient pollution. *Ide et al.* studied the Hii River basin in western Japan to understand how nitrogen and phosphorus levels there fluctuate with rainfall.

Over an 18-year period, the researchers collected water samples from subbasins within the larger river basin and from the area where the entire basin drains into a single river. They measured concentrations of nitrate, phosphate, total nitrogen, and total phosphorus and then analyzed their data with a model designed to evaluate many possible factors, including land cover, and relationships that could explain patterns seen in their results.

The researchers found that the relationship between nutrient concentrations and surrounding land types was strongest during times of heavy rain and high river flow. Agricultural land always leached phosphorus and nitrogen but did so even more during heavy rains. In contrast, forests of all types helped dilute excess nutrients, reducing nutrient concentrations even more during periods of heavy rain.

On farms, nutrients from fertilizers accumulate over time and are flushed out in high doses with rainfall, an issue that may be exacerbated in Japan. Proper fertilizer use tends to require a lot of work, and the aging farming population of Japan often opts instead for fewer, heavier fertilizer applications, the researchers noted. The team found that even a small stretch of agricultural or residential land had a disproportionately large effect on nutrient levels in the rivers studied.

The scientists predict that as heavy rainstorms occur more frequently and as young people continue migrating from rural to urban areas, nitrogen and phosphorus levels in Japan's rivers will go on rising, affecting the drinking water and lakes downstream. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2018JG004513, 2019)

—Elizabeth Thompson, Freelance Writer

A New Look at Winter Air Quality in the Northeastern United States

What's the haze hanging over the northeastern United States in winter? Traditionally, scientists thought that organic particles in wintertime haze came directly from wood smoke and burning fossil fuels. But more than half the region's wintertime pollution is actually the product of atmospheric chemistry—secondary particles produced by mingling of airborne chemicals—a new study finds. The more accurate assessment could help air quality managers curb pollution in the region.

Air pollution shifts from season to season. In summer, gases called volatile organic compounds (VOCs) arise from car exhaust, paint thinners, trees, and many other sources. Some of them react with oxidizing chemicals in the atmosphere to form particles called secondary organic aerosols (SOAs), which can enter the lungs and bloodstream, causing premature death.

Because sunlight plays a role in the chemical reactions that form SOAs and trees emit more VOCs in summertime, SOAs were thought to be less important in wintertime pollution in the northeastern United States than primary pollutants, such as smoke from wood stoves. A new study by *Shah et al.* challenges that notion on the basis of data from 13 research flights funded by the National Science Foundation.

Haze over eastern Pennsylvania photographed during a research flight. Credit: Lyatt Jaeglé, University of Washington

Flying at an altitude of 1 kilometer, the team collected samples of air pollution across the northeastern United States and analyzed them with an aerosol mass spectrometer. Most of the organic aerosols collected were not produced directly by burning wood or another fuel, such as gasoline, but were instead SOAs. Past atmospheric chemistry models for the region have underestimated SOAs by a factor of 10, the team found.

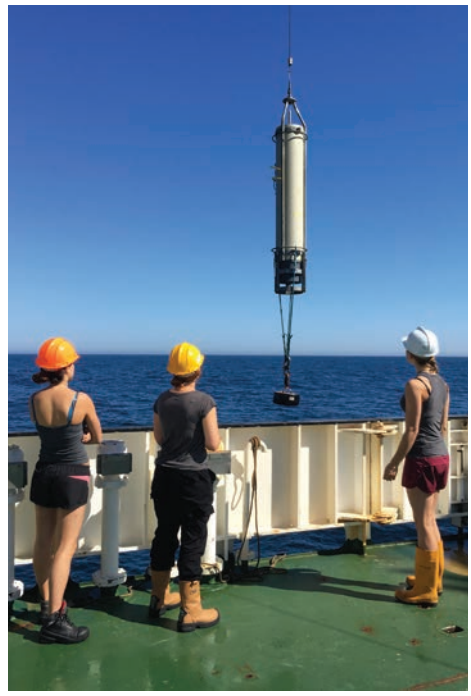
Although past studies have suggested that SOA pollution is concentrated in urban areas of the Northeast, the researchers found that the SOAs were present all over the region, including in rural areas. Getting a more detailed picture of where the region's smog comes from will help pinpoint sources of pollution, information that could be used to improve air quality, they say. (*Geophysical Research Letters*, https://doi.org/10.1029/2018GL081530, 2019) **—Emily Underwood, Freelance Writer**

Revealing the Ocean's Rare but Prolific Carbon Export Events

Photosynthesizing phytoplankton serve as primary producers in the upper ocean, where they take up atmospheric carbon dioxide and incorporate it into their biomass. In a process known as carbon export, some of this biomass is ultimately transported to the deep sea. New research by *Henson et al.* examines the factors that drive variations in export efficiency, the fraction of organic carbon produced by primary productivity that is eventually exported.

To conduct their investigation, the researchers combined and analyzed relationships among several global data sets collected since the mid-1980s. These included measurements or estimates of carbon export, phytoplankton community structure and primary productivity, zooplankton and bacterial abundance, and water column structure and nutrient availability.

Previous research has shown that typically, only a small fraction of organic carbon from primary production is exported to deeper waters. However, the new analysis revealed the existence of rare, high carbon export efficiency events. These events appear to occur mainly when macrozooplankton and bacterial populations are low. For instance, at the beginning of a springtime phytoplankton bloom, growth of zooplankton may lag behind growth of the phytoplankton they feed on. Instead of being eaten, a larger proportion of phytoplankton cells and the carbon they contain may sink, boosting export efficiency.



Devices such as this marine snow catcher are used to catch sinking particles of organic carbon in the ocean to help quantify carbon export from the surface to the deep sea. Credit: Stephanie Henson

These rare occurrences of high carbon export efficiency result in a global inverse relationship between primary productivity and export efficiency. This relationship poses a potential problem for empirical models of carbon export that rely on satellite data and that typically assume a positive relationship between the two variables. In some cases, these models may be underestimating carbon export.

The new analysis highlights the importance of the entire upper ocean ecosystem, including phytoplankton, zooplankton, and bacteria, in determining export efficiency and suggests that different factors drive export efficiency in different regions of the world. The authors note that incorporating region-specific information into computational models could improve the models' ability to simulate carbon export accurately. (*Global Biogeochemical Cycles,* https://doi.org/10.1029/2018GB006158, 2019) **—Sarah Stanley, Freelance Writer**

Tracking Earth's Shape Reveals Greater Polar Ice Loss

Earth may be called the "Blue Marble," but it is not a perfect sphere. The planet is slightly flattened at the poles because of its rotation, and this flattening has a large effect on Earth's gravity field. The flattening, or oblateness, can change as Earth's crust sinks or rises according to the weight of ice sheets resting on its surface or as water from melting polar ice sheets enters the ocean.

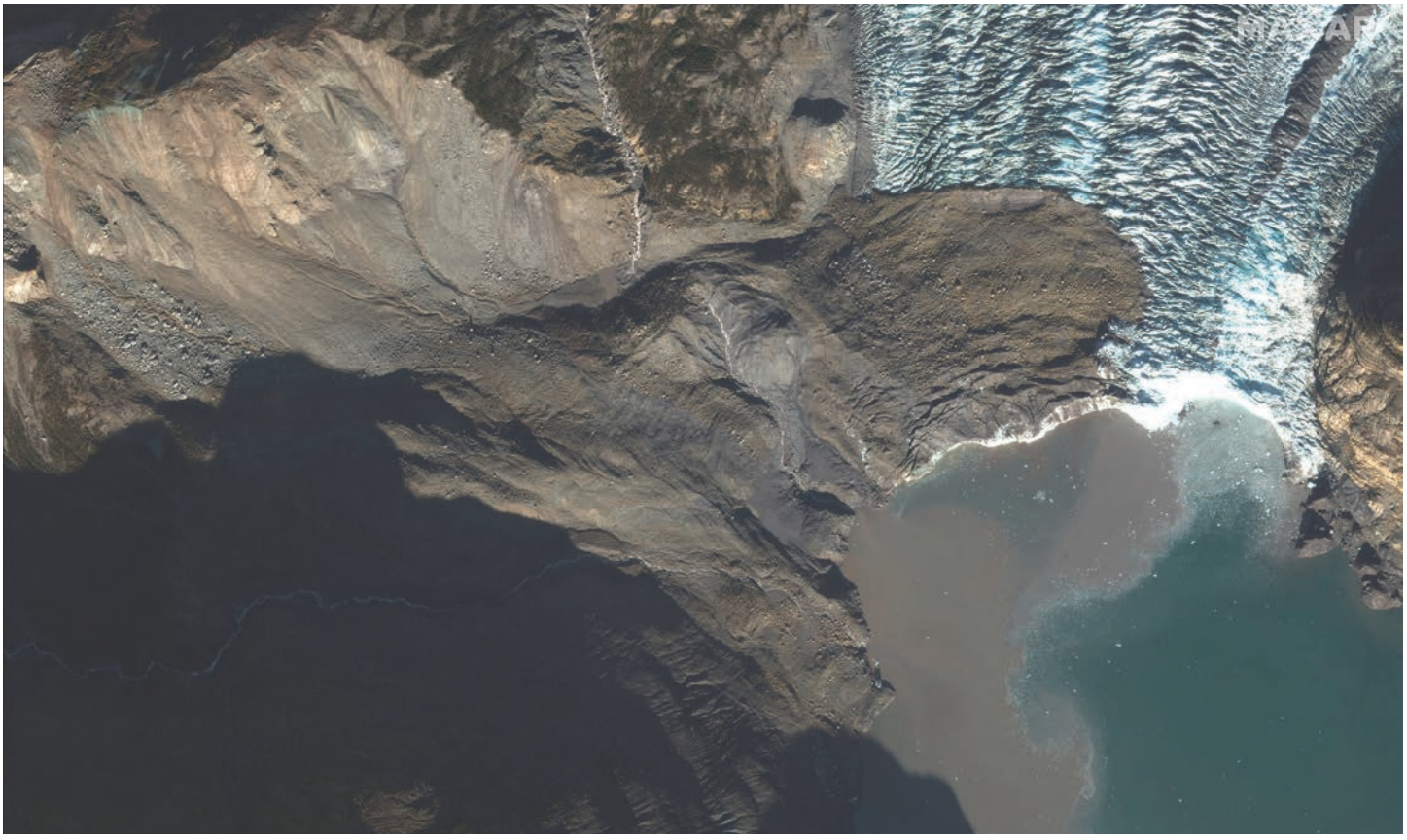
In 2002, NASA and the German Aerospace Center launched the Gravity Recovery and Climate Experiment, or GRACE (and later the follow-on mission GRACE-FO), to track anomalies in Earth's gravitational field and monitor the mass of ice sheets and ocean waters. But one key issue with GRACE was quickly identified: The oblateness measurements were off, leading to errors when calculating mass changes.

Organizations around the world have proposed ways to correct GRACE's measurements. In a new study, *Loomis et al.* analyze existing methods and propose a solution of their own, integrating GRACE's gravity anomaly data with a technique called satellite laser ranging (SLR).

With SLR, scientists send a laser pulse to a satellite, which reflects it back to Earth. By measuring the time the light pulse takes to return, they can precisely calculate the distance it traveled and gain valuable information about how Earth's gravity field affects the motion of orbiting satellites. Other solutions have also integrated SLR, but this study explored various SLR data processing techniques to obtain the most accurate oblateness measurements and therefore the most accurate mass calculations.

More accurate estimates mean that ice melt at the poles lines up with observed sea level rise—every part of the global sea level budget is accounted for. The researchers discovered that there has been greater ice mass loss at both poles than was previously thought. Improving the accuracy of our mass change observations is critical for improving our models and advancing our understanding of our changing planet. (*Geophysical Research Letters,* https://doi.org/10.1029/2019GL082929, 2019) **—Elizabeth Thompson, Freelance Writer**

Study of Alaskan Landslide Could Improve Tsunami Modeling



The Tyndall Glacier landslide as seen on 17 October 2015 from satellite. Credit: Satellite image ©2019 Maxar Technologies

In 2015, a massive landslide plunged more than 50 million cubic meters of debris into Alaska's remote Taan Fiord, a finger of Icy Bay in front of the tidewater Tyndall Glacier. The rockfall sent water almost 200 meters up the other side of the inlet, more than triple the height of Japan's devastating 2011 tsunami. No one was hurt, but the Taan Fiord landslide and tsunami provided an ideal opportunity for scientists to study such events, which are likely to grow more frequent as glaciers retreat. Glacial retreat removes the support for the base of fjord walls, which makes them more likely to landslide.

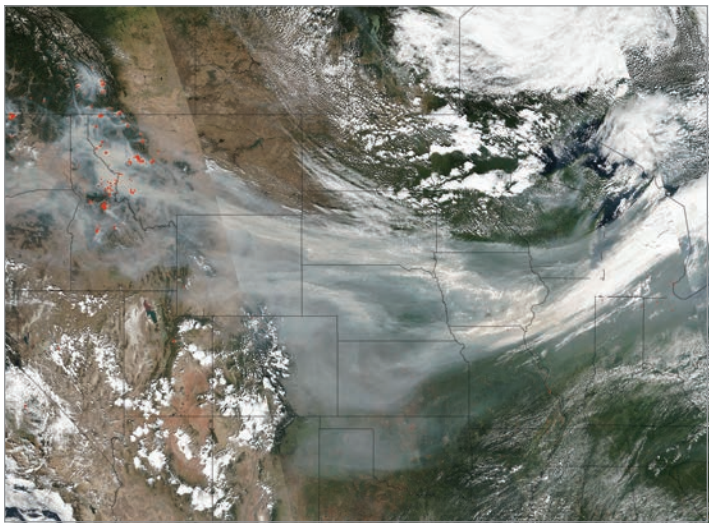
Historically, landslides that begin on land and fall into oceans or fjords—also known as subaerial-to-submarine landslides—are rare. Big waves result when they do occur: Subaerial-to-submarine landslides were responsible for all 10 of the highest tsunami run-ups on record. In 1958, for example, a magnitude 7.8 earthquake in Lituya Bay in Alaska triggered a rockfall into a fjord. The resulting splash caused the world's highest tsunami run-up, reaching more than 500 meters above sea level—higher than many skyscrapers.

Most of the big landslide-triggered tsunamis occurred more than 60 years ago, before scientists were systematically tracking them. So when the 2015 Taan Fiord landslide occurred, scientists flocked to study its impacts. In their new study, *Haeussler et al.* used sonar and seismic data to make underwater 3-D maps of the fjord and compared them with similar maps produced before the slide.

The team was able to account for the different parts of the landslide deposit. The initial landslide was about 76 million cubic meters. About 50 million cubic meters entered the water, but that amount had the energy to dislodge an additional 100 million cubic meters of underwater debris. Large, angular, blocklike deposits up to 45 meters thick marked where the slide had occurred, including one large chunk that the team dubbed "Edgar," which was transported 1.5 kilometers underwater all the way across the fjord and then deposited on land. Thick layers of deposited sediment called megaturbidites settled on the fjord floor minutes to days after the landslide, and underwater signs of the slide could be found as far as 6 kilometers away, the researchers report.

Such signatures could help researchers identify where other subaerial-to-submarine landslides have occurred in the past, the authors say. They also provide a valuable reference point for scientists modeling how landslides loosened by melting glaciers will cause tsunamis in the future. (*Journal of Geophysical Research: Earth Surface*, https://doi.org/10.1029/2018JF004608, 2018) **—Emily Underwood, Freelance Writer**

How Will Future Warming Affect the Jet Stream?



Smoke from West Coast fires accentuates the jet stream across the United States. Determining how jet streams and storm tracks will respond to future warming is considered a grand challenge in climate science. Credit: Jeff Schmaltz, LANCE/EOSDIS MODIS Rapid Response Team, GSFC

Midlatitude jet streams, narrow bands of strong upper atmospheric winds, steer high- and low-pressure weather systems and help maintain our planet's habitable climate. They are closely related to the preferred track of midlatitude low-pressure storm systems known as storm tracks.

The position and intensity of jet streams typically vary in response to processes that affect surface temperature gradients between the equator and the poles. Although many comprehensive climate models predict that Earth's jet streams will shift poleward as the planet warms, the projected magnitudes of these shifts appear to vary widely depending on the planet's response to changes in radiative energy.

Tan et al. have developed a series of simulations to test how different approaches to modeling radiation can affect the response of jet streams to global warming. The results indicate that when using a gray radiation scheme, which has been used in many simplified modeling studies, the midlatitude jet stream responds by shifting toward the equator rather than the pole.

The authors conclude that despite the prevalence of the gray radiation scheme, this approach does not adequately capture the circulation response to global warming. Instead, they showed that using a simple four-band longwave radiation scheme that incorporates the effects of water vapor more effectively replicates circulation responses in full general circulation models.

The results suggest that the authors' model captures the fundamental processes that influence the response of midlatitude circulation to increasing temperatures and demonstrate that this approach can boost our understanding of how jet streams and storm tracks will respond to future warming. (*Journal of Advances in Modeling Earth Systems* (*JAMES*), https://doi.org/10.1029/2018MS001492, 2019) **—Terri Cook, Freelance Writer**

Geochemistry

Robert Nathan Ginsburg Chair in Marine Geosciences

The Rosenstiel School of Marine and Atmospheric Sciences requests applications for the Robert Nathan Ginsburg Endowed Chair in Marine Geology. Although applicants are encouraged in all fields of the Marine Geology, we are particularly interested in scientists in the field of sedimentology, conducting research in the modern to unravel processes in forming or distributing carbonate sediments. Candidates for this position are expected to develop a vigorous, externally funded field and laboratory research program, supervise graduate students, and participate in the teaching mission of the Department and the School at both the graduate and undergraduate levels and interact with current faculty. In particular, the candidate will play a major role in the Comparative Sedimentology Laboratory – Center for Carbonate Research established by Robert Ginsburg. The appointment is expected to be made at the Professor level, but we will consider applications from motivated and energetic younger scientists for appointment at the rank of Associate Professor.

The University of Miami offers a unique tropical location adjacent to major modern carbonate environments and the opportunity to integrate biological and physical oceanographic expertise into process-oriented sedimentological research through collaboration with faculty in the Departments of Marine Biology and Ecology and Ocean Sciences. More details of the faculty and opportunities within the Department of Marine Geosciences can be found at https://marine-geosciences.rsmas.miami.edu/index.html.

Interested applicants should contact Professor Peter K. Swart, Department of Marine Geosciences, RSMAS/University of Miami, 4600 Rickenbacker Causeway, Miami Fl, 33149 (pswart@rsmas.miami.edu).

Applications will only be accepted electronically to www.miami.edu/careers Requisition #R100035651. The position will remain open until filled. Ideally, we would like the successful candidate to be in place by September 2020.

The University of Miami is an equal opportunity employer.

Geodesy

Assistant Professor – Remote Sensing Geoscience

The Department of Geology in the School of Earth, Society, and Environment (https://earth.illinois.edu/) at the University of Illinois at Urbana-Champaign, the flagship campus of the University of Illinois System, seeks an outstanding scholar with expertise in Remote Sensing. Applications are invited from candidates whose research falls within the broad scope of Earth sciences—including, but not limited to: surface and groundwater, landscape change, tectonics, environmental and climate science, earthquakes, glaciology, and volcanology. The full-time, 9-month (academic year) tenure-track faculty appointment is at the Assistant Professor level with a target start date of August 16, 2020.

The Department of Geology resides within the College of Liberal Arts and Sciences, a world leader in research, teaching, and public engagement. Faculty in the College create knowledge, address critical societal needs through the transfer and application of knowledge, and prepare students for lives of impact in the state, nation, and globally. To meet these objectives, the College embraces and values diversity and difference through hiring faculty candidates who can contribute through their research, teaching, and service to the diversity and excellence of the Illinois community.

The University of Illinois is an Equal Opportunity, Affirmative Action employer. Minorities, women, veterans and individuals with disabilities are encouraged to apply. For more information, visit http://go.illinois.edu/EEO.

The University of Illinois is committed to the family needs of our faculty members, including dual career partners. The Dual Career Academic Couples program, Provost Initiative #8, facilitates the placement of tenure-system faculty partners in positions on campus (including tenure track). More information may be found at: https://provost.illinois.edu/policies/provosts-communications/communication-8-dual-career-academic-couples-program/

The Geology Department is committed to building and maintaining an excellent and diverse academic environment. We are dedicated to advancing inclusion and diversity through our teaching, research, and service. Qualified applications will be considered regardless of age, race, religion, color, sex, gender identity, sexual orientation, national origin, disability, or protected veteran status.

Responsibilities in Research and Teaching: The successful candidate will establish and maintain an externally funded and independent research program in the area of remote sensing. The successful candidate will be expected to teach at least two courses within the Geology curriculum at the undergraduate and graduate levels.

Synergy with Campus Excellence Themes and Strengths: The successful candidate will benefit from existing strengths within the Department of Geology: surface environments and landscape research, tectonics, geophysics, geodynamics; within SESE: CyberGIS & geography, and Atmospheric Remote Sensing; and across campus: the National Center for Supercomputing Applications, data science programs in Computer Science and Electrical & Computer Engineer-

ing, and fluid dynamic, surface environments and earthquake hazards research in Civil and Environmental Engineering, and Mechanical Science and Engineering. Excellent opportunities also exists for collaborations with the United States Geological Survey and Illinois State Geological Survey.

Qualifications: Ph.D. or equivalent international degree in Geology or a related field by mid-June 2020 for a preferred start date of August 16, 2020. Applicants must have a promising research agenda and a strong commitment to undergraduate and graduate teaching.

Candidates with superior qualifications who will complete all the Ph.D. requirements within the first appointment year may be appointed at the rank of Instructor. After the Ph.D. requirement is met, the appointment will be changed to Assistant Professor.

Salary and Benefits: Salary is competitive, commensurate with skills and experience. Information on benefits may be found at: https://www.hr.uillinois.edu/benefits/.

Application: To apply, create your candidate profile through https://go.illinois.edu/GEOLOGYfaculty and submit application materials by November 15, 2019. Required documents:

- Cover letter that details suitability for and interest in the position
- Curriculum Vitae
- Up to three representative publications
- Statement of Research Interests
- Statement of Teaching Experience and Goals
- Statement on Advancing Diversity and Inclusion
- Contact information for three professional references. Letters of recommendation may be requested electronically from referees at a later date.

Only applications submitted through the University of Illinois Job Board will be considered. Questions can be directed to search committee chair Prof. Lijun Liu, ljliu@illinois.edu, phone: (217) 333-3540.

The University of Illinois conducts criminal background checks on all job candidates upon acceptance of a contingent offer.

Interdisciplinary

Assistant Professor of Earth and Environmental Sciences

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

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

Faculty Position–Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

The Department of Atmospheric Sciences at National Taiwan University seeks two to four faculty members in the areas of weather, climate and earth system, or atmospheric physics and chemistry, at the Assistant, Associate or Full Professor levels. Applicants

should have a Ph.D. degree, preferably with postdoctoral experience, cross-discipline research capability, and teaching experience. The position will begin in August 2020. Application should be submitted through the Academic Jobs Online by including (1) curriculum vitae including publication list, (2) statement of research interests, and (3) statement of teaching experience and interests. The applicant should also arrange three letters of reference that sent directly from the recommenders. All application material should be submitted by December 31st, 2019.

Related website: https://academicjobsonline.org/ajo/jobs/14121

Faculty Search Committee
Department of Atmospheric Sciences,
National Taiwan University,
No.1, Section 4, Roosevelt Road,
Taipei 106, Taiwan
E-mail: minhuilo@ntu.edu.tw

Full-Time Tenure-Track in Environmental Geoscience, California State University, East Bay

The Department of Earth and Environmental Sciences seeks an environmental geoscientist with experience in geostatistics, geospatial analysis, and/or large data sets. Preference will be given to applicants with a focus area such as geologic hazards, including nearshore marine hazards (for example, landslides or flooding); physical hydrology and fully-coupled hydrologic modeling; air quality modeling or atmospheric transport modeling. The successful applicant will teach a variety of introductory undergraduate courses, as well as courses in their area of specialty for undergraduate majors in Environmental Science and Geology, and graduate students in Environmental Geosciences. Of particular importance to our student body is the ability to teach quantitative skills within the context of the discipline, so candidates with a successful record of teaching quantitative skills will be viewed favorably.

Faculty in the Department of Earth and Environmental Sciences typically teach 3-4 courses per semester at either the undergraduate or graduate level. Teaching loads are typically smaller for new faculty members, in order to enable new faculty to build a program of research and scholarship. Faculty in the Department of Earth and Environmental Sciences are active researchers, with research partners and collaborators at the local, regional, national, and international levels. Professional achievement, such as publication and dissemination of research and scholarship, is expected and highly encouraged. In addition to teaching and scholarship, all faculty have advising responsibilities, assist the department with administrative and/or committee work, and are expected to assume campus-wide committee responsibilities.

Apply at https://apply.interfolio.com/61672

Tenure-track Assistant Professor in Earth System Science

The Department of Atmospheric and Environmental Sciences (DAES) of the University at Albany, State University of New York, invites applicants at the Assistant (tenure track) Professor level, effective Fall 2020. We are seeking individuals with expertise in Earth System Science, broadly defined as those working on the understanding of fundamental processes and dynamics within individual components of the earth system or the coupling between different components, such as the ocean, water cycle, land surface, cryosphere or biosphere. Such processes could reflect physical aspects or biogeochemical cycles, which are fundamental to understanding how substances cycle through our environment. Areas of research could be related to cycling of carbon, nitrogen, water, or other key substances; stable isotope geochemistry; toxic substances in the air, soil or water; or intersections of any of these areas with climate change on a range of spatial and temporal scales. However, candidates whose research specialization complements existing research programs in the department are also encouraged to apply.

The successful candidate will be expected to carry out the responsibilities of a full-time faculty member in the DAES, which includes:

- Teaching at the graduate and/or undergraduate level
- Maintaining a strong externally funded research program
- Mentoring and supervising graduate students
- Participating as necessary in all programmatic activities of the Department, College and University

DAES maintain collaborations across several UAlbany departments and via a number of facilities, including

- DAES Facilities
- ASRC
- Biology
- Environmental Health Sciences
- NYS Mesonet
- Albany Pine Bush Preserve
- White Face Mountain
- Pinnacle State Park Field Site
- NYS DEC

The new home of DAES as of summer 2021 will be the Emerging Technology and Entrepreneurship Complex (ETEC). This state-of-the-art facility will provide excellent laboratory and teaching facilities for DAES faculty, and rich new opportunities for collaboration and innovation.

DAES values inclusion and diversity. We work to support the recruitment and retention of a diverse population of staff, students, and faculty within the

FACULTY POSITION IN MARINE ENVIRONMENTAL SCIENCE

The University of Texas at Austin invites applications for a **faculty position in the Department of Marine Science**. We seek an accomplished marine biologist or marine chemist that uses experimental approaches to investigate regional and/or global environmental processes. This faculty position is open at all ranks, including Assistant Professor. The Associate Professor or Professor ranks will be eligible for the **Mary Anderson Abell and Joseph Miles Abell, Jr., M.D. Endowed Chair in Marine Science**, as a Chair Fellow or Holder, respectively. Candidates are sought with areas of interest in any discipline in environmental biology and chemistry including, but not limited to, chemical ecology, toxicology, physiology and biochemistry. The successful applicant will be expected to establish a nationally recognized research program at the University of Texas, mentor graduate students and postdoctoral scientists, and teach at the graduate and undergraduate levels.

FACULTY POSITION IN PHYSICAL OCEANOGRAPHY

The University of Texas at Austin invites applications for a faculty position in the Department of Marine Science. We seek an accomplished physical oceanographer at the Assistant or Associate Professor rank that will use field, remote sensing, and/or computational methods to study estuaries and coastal oceans. Interdisciplinary researchers that couple physical, biogeochemical and/or biotic processes in estuarine and coastal environments are encouraged to apply. Areas of research interest include, but are not limited to: circulation and connectivity of watersheds and the open ocean, ocean-atmosphere interactions, mixing processes, and sediment transport including quantitative geomorphology. The successful applicant will be expected to establish a nationally recognized research program at the University of Texas, mentor graduate students and postdoctoral scientists, and teach at the graduate and undergraduate levels.

The positions are located at the University of Texas Marine Science Institute in Port Aransas, Texas. The institute offers close proximity to estuarine, inshore and offshore habitats of the Gulf of Mexico, as well as excellent shoreside facilities for experimental work. Our infrastructure includes state-of-the-art research laboratories, offices and meeting spaces; the Estuarine Research Center housing the Mission-Aransas National Estuarine Research Reserve in partnership with NOAA, a Marine Science Library, and full-service core analytical facilities. New facility renovations completed or underway include the Fisheries and Mariculture Laboratory Complex, marina, research pier, public Marine Science Education Center and the new Center for Coastal Ocean Science that will house marine environmental science research in chemical ecology, toxicology, physiology and biochemistry. Successful applicants will have the freedom to follow independent and collaborative research, and will be provided with 9 months of state-funded salary support for research and teaching.

The University of Texas Marine Science Institute is interested in candidates who will contribute to diversity and equal opportunity in higher education through their teaching, research, and service. UT Austin is committed to addressing the family needs of faculty, including dual-career couples and single parents. Applications should include a letter of interest, curriculum vitae, teaching statement, a research statement, a statement of contributions to diversity, and three reference letters sent electronically to Interfolio: **https://home.interfolio.com/15714**. Review of applications will begin **January 2020**.

The University of Texas at Austin is an Equal Opportunity Employer. Background check conducted on applicant selected.

CLUSTER HIRING IN DOSE, SUSTECH

1. OVERVIEW OF SUSTECH

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

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

2. OVERVIEW OF DOSE

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

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

3. OCEAN SCIENCE & FACULTY OPENINGS

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

All positions remain open until filled.

4. OCEAN ENGINEERING & FACULTY OPENINGS

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

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

All positions remain open until filled.

5. REMUNERATION & START-UP PACKAGES

I. Income and Benefits

1. Globally competitive (including US & HK) salary

2. Apartment inside campus (depending on remaining apartment quantity) or housing allowance of leasing outside;

3. Social Insurance Retirement insurance, medical insurance, unemployment insurance, industrial injury insurance, maternity insurance and housing accumulation funds. Special health insurance negotiable.

4. Shenzhen living subsides of CNY 1.6~3 million and other living subsidies according to your talent level.

II. Lab space no less than 150 square meters.

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

6. CONTACT INFORMATION

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

department. We work to share our science with diverse audiences locally, nationally, and globally. We strive to foster a departmental climate that is inclusive, welcoming, and respectful to all. Applicants must address in their application their ability to work with and instruct a culturally diverse population.

Qualified candidates should submit a cover letter, a detailed curriculum vitae, a statement of research, a statement of teaching goals, a statement on diversity, and the names and contact information of three references through Interview exchange at https://albany.interviewexchange.com/candapply.jsp?JOBID=115581 by December 1, 2019.

For more information about this announcement, including deadlines and required documents, please refer to the Human Resources website at https://albany.interviewexchange.com/jobofferdetails.jsp?JOBID=115581 or contact Mathias Vuille (mvuille@albany.edu, 518-442-4472).

Position contingent on final budget approval.

The University at Albany is an EO/AA/IRCA/ADA Employer.

TENURE TRACK ASSISTANT PROFESSOR IN REMOTE SENSING / GEOSPATIAL TECHNOLOGY

The Geological Sciences Department at California State Polytechnic University, Pomona, invites applications for a tenure-track, ASSISTANT PROFESSOR position, beginning in the 2020-2021 academic year. We invite applications from geoscientists whose research incorporates data from ground-based remote sensing or observations from unmanned aerial vehicles or satellites. The position is open to a broad range of research specializations, such as natural hazards, active tectonics, environmental geoscience, and/or climate change. A Ph.D. in geology, geophysics, environmental geoscience or a directly related science or engineering discipline is required. The successful candidate will have the potential for excellence in teaching, and for developing an externally-funded research program that will involve undergraduate and Master's students. Teaching responsibilities will include a mix of geoscience courses at the lower division, upper division, and graduate levels, and incorporate classes in Geographic Information Systems, Remote Sensing or other specialty courses in the candidate's area of expertise. Demonstrated experience with data collection and analysis using modern instrumentation is expected. Preferred qualifications include demonstrated success with external funding, established ties to research institutions, industry or government agencies and interest in developing intradepartmental and cross-campus collaborations. At Cal Poly Pomona we cultivate success through a diverse culture of experiential learning, discovery, and innovation. Cal Poly Pomona is committed to being the model for an inclusive polytechnic university. The position is open until filled. First consideration will be given to completed applications received no later than December 30, 2019. Apply at https://apply.interfolio.com/66998.

Wrigley Institute for Environmental Studies at USC Dornsife: Director and Co-Director Search

USC Dornsife College of Arts, Letters and Sciences seeks two dynamic leaders to serve as the Director and Co-Director of the Wrigley Institute for Environmental Studies. One will serve as the director of natural science, and the other will serve as the director of social science. Both will hold endowed chairs.

For more than five decades, USC Wrigley has been a regional leader in marine science and sustainability research. The USC Wrigley Marine Science Center, a state-of-the-art research center and teaching facility on Catalina Island, 20 miles offshore from Los Angeles, provides a testbed for early-stage sustainability innovations. A staff of more than 30 supports research and educational outreach on Catalina and the main campus.

Recognizing that solutions to our environmental crises will require contributions across many disciplines, the Institute's new mission is to bring together natural and social scientific research to address contemporary environmental problems. The Director and Co-Director will lead this ambitious expansion of Wrigley's mission to become a major national center for frontier research on sustainability and the environment. This is an opportunity to reinvent the Wrigley Institute. The Director and Co-Director will guide a comprehensive approach to tackling sustainability challenges that prioritizes action toward meaningful change.

In addition to setting the intellectual agenda for the Institute, the new leadership will foster new research initiatives, enhance its educational programming, work with foundations and the public to enhance environmental awareness, steer fundraising efforts, and manage the Institute's staff.

We will consider applicants at the full professor level from disciplines in both the natural and social sciences. The Institute's leadership structure will be determined based on scholarly credentials, leadership experience and vision. Both successful candidates will bring a distinguished record of innovative research and publication related to environmental studies. The successful applicants will each have a primary appointment in his / her disciplinary home department within USC Dornsife and must each hold a doctoral degree in appropriate field of study.

A pairing of a natural scientist and a social scientist who have contem-

plated their collaborative vision for the Wrigley Institute in advance would be welcomed (but is not prerequisite for either position).

Applications should include a curriculum vitae, and statement on personal research accomplishments and future research directions, a statement on teaching and educational activities, and three names of individuals familiar with the applicant's work to be contacted for letters of recommendation. Applications should also include a vision statement on how, as a leader in the USC Wrigley Institute, the applicant would advance the Institute's goals. To be considered for this position, applicants are required to submit an electronic USC application through the following link: https://usccareers.usc.edu/job/los-angeles/wrigley-institute-for-environmental-studies-at-usc-dornsife-director-and-co-director/1209/13209724.

Inquiries from social scientists may be directed to William Deverell, Search Committee Chair, deverell@usc.edu and for Natural Sciences to Will Berelson, Search Committee Chair, berelson@usc.edu. These two search committees will work together to select the best leadership team. Review of completed applications will begin November 1, 2019 and will continue until the position is filled.

USC is an equal opportunity, affirmative action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, protected veteran status, disability, or any other characteristic protected by law or USC policy. USC will consider for employment all qualified applicants with criminal histories in a manner consistent with the requirements of the Los Angeles Fair Chance Initiative for Hiring ordinance.

Natural Hazards

Assistant Professor – Geohazards

The Department of Earth and Environmental Sciences at the University of Texas Arlington invites applications for a tenure-track faculty position in broadly construed areas related to geohazards or environmental health at the level of Assistant Professor. Faculty candidates for higher ranks with exceptional track records will also be considered. We seek a broadly-trained geoscientist or environmental scientist who complements the interdisciplinary nature of our earth and environmental science program. While candidates from all sub-disciplines of earth and environmental sciences are encouraged to apply, we are particularly interested in candidates with expertise in one of the following areas: geohazards, processes leading to earthquakes, rock strength change, landform response to disturbances, climate change and its impact, data analytics, dynamical or statistical modeling, the exposome, biomarkers, and metabolics. Opportunities for collaboration exist with departmental research groups in geochemistry, petrology, sedimentary geology, environmental health and toxicology, climate change and paleoclimatology, paleontology, hydrogeology, and other research groups of data science, analytical chemistry, ecology, and genomics in the College of Science, the College of Architecture, Planning, and Public Affairs, and the College of Engineering. Our analytical strengths include the on-campus Shimadzu Institute for Research Technologies (http://www.uta.edu/sirt/), particularly the Shimadzu Center for Environmental, Forensics, and Material Science, an ultraclean laboratory, and a gas isotope ratio mass spectrometer housed within the Earth and Environmental Science and the novel Science & Engineering Innovation & Research buildings.

Applicants should have a doctoral degree in earth and environmental sciences or a related field. Successful candidates are expected to demonstrate a commitment to diversity and equity in education through their scholarship, teaching, and/or service.

To apply online at https://uta.peopleadmin.com/postings/10400. A complete application includes: 1) curriculum vitae, 2) summary of current and proposed research (max. two pages), 3) statement of teaching interests (max. one page), and 4) names and email addresses of three references.

Review of applications will begin immediately and continue until the position is filled. For full consideration, applications should be submitted by November 16th, 2019.

Question regarding this position may be directed via email to Dr. Majie Fan, Search Committee Chair (email: mfan@uta.edu) or the Department of Earth and Environmental Sciences administration (email: lpanther@uta.edu).

UTA is an Equal Opportunity/Affirmative Action institution. Minorities, women, veterans and persons with disabilities are encouraged to apply. Additionally, the University prohibits discrimination in employment on the basis of sexual orientation. A criminal background check will be conducted on finalists. The UTA is a tobacco free campus.

Ocean Sciences

Research Scientist in Mesoscale Eddy Parameterization

The Atmospheric and Oceanic Sciences Program, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral or more senior researcher to work in the area of mesoscale eddy parameterization.

This work is a component of a high profile Climate Process Team (CPT) on Ocean Transport and Eddy Energy involving multiple institutions including New York University (NYU), Woods Hole Oceanographic Inst., University of Colorado, Boulder, the National Center for Atmospheric Research, among others. The role of the Princeton team is to i) implement existing parameterizations in a numerical ocean circulation model (MOM6), ii) evaluate parameterizations in both an idealized ocean and later a global climate model, iii) help develop, implement, and assess, new parameterizations created at the partner institutions. The work will be very collaborative and involve some travel for project workshops, frequent virtual meetings, and regular travel between Princeton and NYU to coordinate with the lead PI, Laure Zanna, and her team. Information about the broader project and related positions can be found at https://ocean-eddy-cpt.github.io/.

The ideal candidate has a strong background in one or more areas among dynamical oceanography, dynamical meteorology, applied mathematics, or numerical methods. Experience with scientific software development will be advantageous in this research.

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

Complete applications, including a CV with a list of publications, a statement of research interests, and contact information of 3 references should be submitted by October 31, 2019, 11:59 p.m. EST for full consideration. Applicants should apply online to

https://www.princeton.edu/acad-positions/position/13701.

For more information about the research project and application process, please contact Alistair Adcroft (aadcroft@princeton.edu), Stephen Griffies (stephen.griffies@noaa.gov), Robert Hallberg (robert.hallberg@noaa.gov).

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

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

Software Engineer, Princeton University

The Atmospheric and Oceanic Sciences Program at Princeton University, in collaboration with the Geophysical Fluid Dynamics Laboratory, is hiring one or more software engineers to support model development funded as part of the Disaster Related Appropriations Supplemental ("Hurricane Supplemental"). This collaborative effort aims to build new functionality within next-generation weather and climate models powered by the Finite-Volume Cubed-Sphere Dynamical Core (FV3) specifically for simulating and predicting tropical cyclone and extreme weather, for eventual use in NOAA operational prediction and community research modeling. This project is part of a larger and highly productive effort at Princeton and GFDL to produce next-generation weather and climate models centered around GFDL's world-leading model components and infrastructure for a variety of applications ranging from basic science to weather and climate prediction to human and ecosystem impact assessment.

This position is a 1 year term position with possibility of renewal.

The selected individual(s) will assist GFDL's participation in the Hurricane Supplemental by working with GFDL scientists to implement new variable-resolution capabilities within models using the Flexible Modeling System (FMS) framework and the Finite-Volume Cubed-Sphere Dynamical Core (FV3), as well as in the pre-and-post-processing tools supporting these systems. The individual(s) will also work with scientists on the implementation of other new capabilities, including improved component coupling between the dynamical core and other model components (physics, land, ocean, ice, chemistry, and so on), improved model diagnostics, and others. This individual will also collaborate with GFDL scientists and engineers to help develop model workflows putting the new innovations to use and to help run and validate these models, and finally to assist with the dissemination and documentation of the new capabilities to Hurricane Supplemental collaborators and other external partners.

The selected candidate(s) must have a strong background in software development and be comfortable with several languages, especially C, C++, and Fortran. The candidate(s) should have some familiarity with parallel processing, especially the message-passing interface (MPI) and OpenMP; candidates with experience programming for multi-core systems (especially GPU) will be particularly welcome.

Applicants should apply online to https://main-princeton.icims.com/jobs/10884/software-engineer/job?hub=15.

A Masters' degree is preferred. Specific experience with weather and climate modeling or computational fluid dynamics codes is appreciated not necessary.

Princeton University is an Equal Opportunity/Affirmative Action Employer and all qualified applicants will receive consideration for employment without regard to age, race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability status, protected veteran status, or any other characteristic protected by law. EEO IS THE LAW

Planetary Sciences

Professor of Earth and Planetary Sciences

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

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

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

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

Volcanology Geochemistry and Petrology

Assistant Professor, Earth Materials

The School of the Environment at Washington State University invites applications for an Assistant Professor in Earth Materials, to begin August 2020, with an emphasis in petrology, mineralogy, volcanology, magmatic processes, or tectonic processes. The candidate will take a leadership role in developing and funding research initiatives that take advantage of WSU's Peter Hooper GeoAnalytical Laboratory and the Radiogenic Isotope and Geochronology Laboratory, which maintain state-of-the art capabilities in whole rock and microscale major and trace element analysis, geochronology, and radiogenic and stable isotope geochemistry. Lab facilities include current generation electron microprobe, X-ray fluorescence, inductively-coupled plasma mass spectrometer, and laser ablation facilities (https://environment.wsu.edu/facilities/geoanalytical-lab/).

The successful candidate will: (i) develop an externally funded research program; (ii) publish research in top quality journals; (iii) teach undergraduate and graduate courses in Earth Materials; (iv) mentor graduate students; (v) take a leadership role in the GeoAnalytical Laboratory; (vi) work with faculty and mentor students from a wide range of backgrounds; and (vii) serve university and professional organizations. To learn more and apply, visit: https://www.wsujobs.com/postings/48041

WSU is an EO/AA Educator and Employer.

Assistant Professor – Environmental Volcanology/Petrology

The Department of Marine, Earth, and Atmospheric Sciences (MEAS) at North Carolina State University intends to fill a tenure-track assistant professor position in environmental volcanology/petrology.

Desirable expertise includes research employing observation, experiments, and modeling to investigate the origin of magmatism in different tectonic settings, the role of volatiles in volcanic eruptions and short and/or long-term climate change, and/or geohazards. The anticipated start date is August 16, 2020.

Applicants must hold a Ph.D. degree in Earth or related sciences. The successful candidate must demonstrate strong potential for outstanding accomplishments in research, research supervision, and teaching. Enthusiastic engagement in NC State's undergraduate and graduate degree programs in Earth, marine and atmospheric sciences is expected. Course offerings may include undergraduate or graduate classes in mineralogy, hard rock petrology, or other classes commensurate with the candidate's interest and expertise. MEAS places a high value on excellent instruction and the use of innovative teaching methods.

Initial review of applications is expected to begin by December 1, 2019, with on campus interviews scheduled for early 2020. Further details are available at https://meas.sciences.ncsu.edu/. Applications must be submitted online at http://jobs.ncsu.edu/postings/121811 or search for position number 00001313. Applications from women, minorities, and persons with disabilities are encouraged.

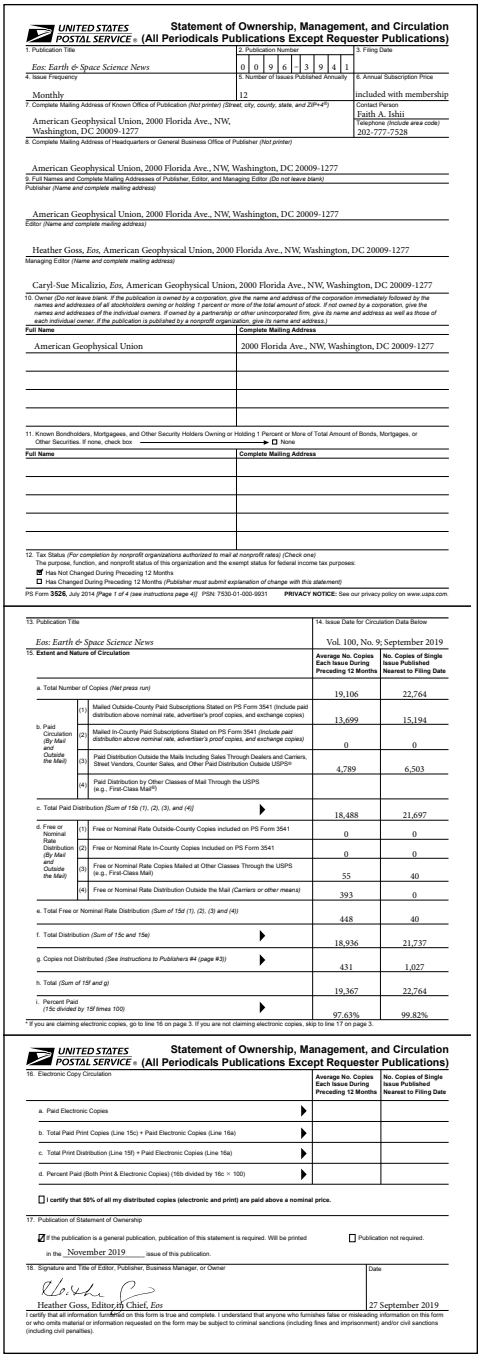
Assistant Professor in Geological Sciences, University of Missouri

The Department of Geological Sciences at the University of Missouri invites applications for a tenure-track position at the rank of Assistant Professor in the fields of mineralogy and petrology. Potential areas of research interest could include igneous and/or metamorphic petrology, volcanology, meteoritics, planetary geology, geochemistry, mineral surface chemistry, and/or other related areas of expertise. This position has an anticipated Fall 2020 start date. As a minimum qualification, a Ph.D. in geological sciences or related field by the time of appointment is required. The successful candidate will be expected to teach across the curriculum, including mineralogy and courses within their expertise, and to build an externally funded research program that complements the existing strengths in paleobiology, geochemistry, structural geology, and geophysics. Applicants will be evaluated on their ability to conduct independent research and effectively teach students across the curriculum at the graduate and undergraduate levels. Information about our department and our undergraduate and graduate curricula can be found at our department website [geology.missouri.edu].

Our department occupies a building dedicated to Geological Sciences, and houses numerous analytical facilities [geology.missouri.edu/research-facilities] including a new X-ray Tomographic and Scanning Electron Microscopy laboratory [xray.missouri.edu] as one of the MU Research Core Facilities, and a high-performance computing cluster. Elsewhere on campus is a wide variety of geochemical instrumentation at the MU Research Reactor [murr.missouri.edu] and at other research core facilities [research.missouri.edu/about/cores].

To apply: Please apply on line at: http://hrs.missouri.edu/find-a-job/academic (Job Opening ID 31617). Use the online application to upload (i) a letter of application that describes your teaching and research experience; (ii) a CV; (iii) a statement describing research and teaching interests and a plan for attracting students, including students from demographic groups who traditionally have been underrepresented in the geological sciences; and (iv) a statement of inclusion and diversity. Three reference letters are required and should be sent (electronically or hard copy) to Dr. James Schiffbauer (schiffbauerj@missouri.edu), Chair of the Search Committee. Applicants may contact the Chair of the Search Committee with questions about the job duties. Please contact Human Resource Services (muhrs@missouri.edu) with any questions about the application process. Review of application materials will begin on Tuesday, December 17th, 2019. To ensure full consideration, applications should be complete (including reference letters) on or before this date. The position will remain open until filled.

The University of Missouri and the Department of Geological Sciences are fully committed to achieving the goal of a diverse and inclusive academic community of faculty, staff, and students. The University of Missouri is an Equal Opportunity/Access/Affirmative Action/Pro Disabled & Veteran Employer. To request ADA accommodations, please contact the Office of Accessibility & ADA Education at 573-884-7278 or CheekA@missouri.edu.



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Full Name	Complete Mailing Address
American Geophysical Union	2000 Florida Ave., NW, Washington, DC 20009-1277

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Full Name	Complete Mailing Address

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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)			19,106	22,764
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)	13,699	15,194
	(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®	4,789	6,503
	(4)	Paid Distribution by Other Classes of Mail Through the USPS (e.g., First-Class Mail®)		
c. Total Paid Distribution (Sum of 15b (1), (2), (3), and (4))			18,488	21,697
d. Free or Nominal Rate Distribution (By Mail and Outside the Mail)	(1)	Free or Nominal Rate Outside-County Copies included on PS Form 3541	0	0
	(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)	55	40
	(4)	Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)	393	0
e. Total Free or Nominal Rate Distribution (Sum of 15d (1), (2), (3) and (4))			448	40
f. Total Distribution (Sum of 15c and 15e)			18,936	21,737
g. Copies not Distributed (See Instructions to Publishers #4 (page #3))			431	1,027
h. Total (Sum of 15f and g)			19,367	22,764
i. Percent Paid (15c divided by 15f times 100)			97.63%	99.82%

* If you are claiming electronic copies, go to line 16 on page 3. If you are not claiming electronic copies, skip to line 17 on page 3.

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b. Total Paid Print Copies (Line 15c) + Paid Electronic Copies (Line 16a)		
c. Total Print Distribution (Line 15f) + Paid Electronic Copies (Line 16a)		
d. Percent Paid (Both Print & Electronic Copies) (16b divided by 16c × 100)		

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17. Publication of Statement of Ownership
☑ If the publication is a general publication, publication of this statement is required. Will be printed in the November 2019 issue of this publication. ☐ Publication not required.

18. Signature and Title of Editor, Publisher, Business Manager, or Owner: Heather Goss, Editor in Chief, *Eos*. Date: 27 September 2019

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Good morning!

I am Alia Khan, Ph.D., and I'm a polar field and research scientist with the National Snow and Ice Data Center (NSIDC) and an assistant professor at Western Washington University. I've traveled the global cryosphere studying snow and ice biogeochemistry.

In this photo, I am sampling snow in Nepal for the Contribution to High Asia Runoff from Ice and Snow (CHARIS) project, which was developed to learn more about the role that glaciers and snow play in contributing to the freshwater resources of High Asia.

Anyone recognize the big mountain in the background? That's Mount Everest!

—Alia Khan, Huxley College of the Environment, Western Washington University, Bellingham; and National Snow and Ice Data Center, Boulder, Colo.

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