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SCIENCE NEWS BY AGU

Flash Droughts Are Getting Flashier

Saturn's Shiny Rings May Be Pretty Young

Mexico City Is Sinking

The Career Issue

How scientists navigate the rivers and roads to success.

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Inspiring Others to Braid Their Own Paths

When I was in high school, I had to take a career test—the kind that predicted what your future profession should be on the basis of your answers to a series of seemingly unrelated questions. My result? A journalist. My teenage self said "nope," and I walked as far away from journalism as I thought possible. I wanted to be a scientist. Experiments, the great unknown, big discoveries—I loved it all. A few degrees later, I realized that talking about my work and learning about the various ways people do science brought me a joy I didn't find in the lab or field. After graduate school, I leapt head first into science journalism. My high school vocational test was shockingly accurate.

Some career paths are straight. Others take sharp turns. Some take you in a direction you didn't expect. Each is unique and valid: There is no wrong way to navigate the journey.

By popular demand, we're publishing our annual Career Issue. This year, we highlight 14 scientists who have fashioned their own courses through formal (or not so formal) education, trial and error, and sometimes random chance. They are researchers, entrepreneurs, curators, and wanderers. Some have followed straight(ish) journeys; many have pivoted. Some have gone back to their roots to find purpose and inspiration. Others have found themselves in careers they didn't know existed.

Boldly go and read about how astrophysicist Erin Macdonald advises one of science fiction's most iconic space franchises. Back on Earth, find out why storm chaser Jen Walton founded an organization that encourages women like her to seek adventure. Discover how, after learning about the devastating effects of air pollution in his home country of Ghana, Collins Gameli Hodoli sought a Ph.D. abroad, then returned home to pepper communities with air quality monitors. Meet paleontologist Aline Ghilardi, who has spoken out against colonialism in the geosciences, advocating for the repatriation of fossils to their country of origin.

This year, we here at *Eos* are reflecting on mentorship—relationships that inspire, guide, and nudge us along our paths. Mentors show us what it can mean to be a scientist and introduce us to paths unknown. Mentees offer perspective and opportunities to develop leadership and communication skills. We find mentorship in both predictable and unexpected places when we form meaningful bonds with people who are like us or very much not like us. If you reach beyond your circle, you may just learn something new.

Jennifer Schmidt, Managing Editor

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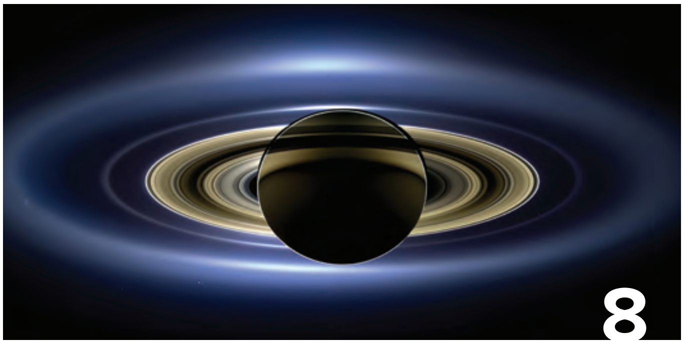
Janice Lachance, Interim Executive Director/CEO

Features

On the Cover

Aerial view of a braided river from glacial runoff in New Zealand. Credit: iStock.com/Philip Thurston



Columns

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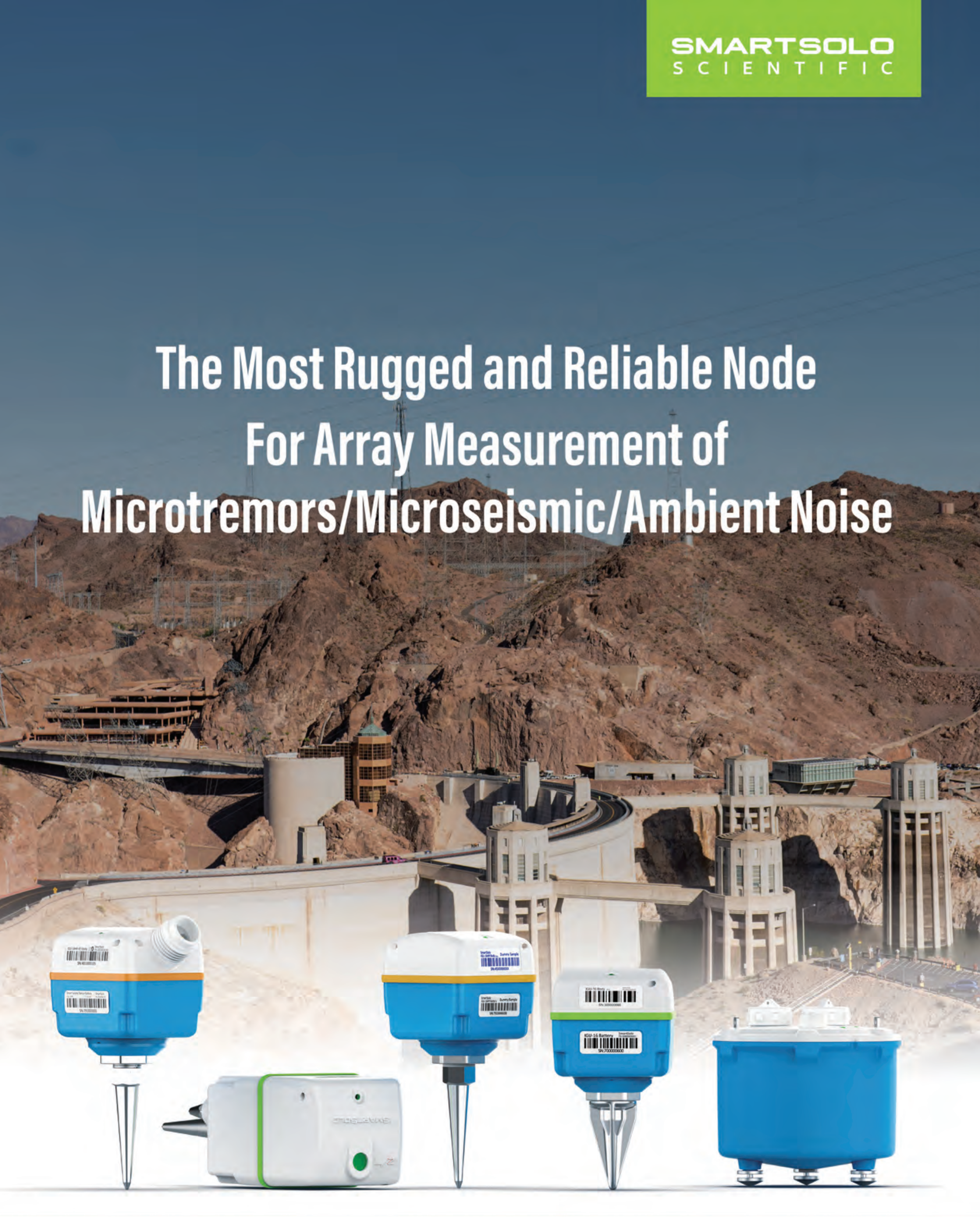

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Forecasting Earthquake-Induced Floods

Surface-rupturing earthquakes can reroute rivers, including New Zealand's Waiau Toa (Clarence) River, shown here. Credit: Schwede66/Wikimedia, CC-BY-SA-4.0 (bit.ly/ccbysa4-0)

Today, Reelfoot Lake in northwestern Tennessee is a tranquil place and a haven for migratory birds. But the 15,000-acre body of water was birthed violently and abruptly: After a series of earthquakes in 1811 and 1812 temporarily diverted the flow of the Mississippi River, water inundated the landscape and pooled, forming the lake.

Historical examples abound of rivers suddenly changing course in response to surface-rupturing earthquakes, and now a team of researchers has modeled these events to better assess the hazards they pose. Their results were published in *Science Advances* (bit.ly/flood-hazard).

A Sudden Lurch

Rivers change course all the time. Erosion and sediment deposition drive those course corrections—known as avulsions—gradually, over decades or even centuries. But the river avulsions that Erin McEwan, a tectonic geomorphologist at the University of Canterbury in Christchurch, New Zealand, and her colleagues recently studied were set in motion much, much faster.

When a fault lurches and displaces Earth's surface either horizontally or vertically, the resulting fault scarp can divert a river that happens to crosscut the region. "The fault scarp presents an immediate obstacle," said Timothy Stahl, a geologist also at the University of Canterbury and a member of the research team.

A river's water obviously still has to go somewhere. "It may pool up against the fault scarp and then flow outside of its channel," McEwan said.

Tens of fault rupture–induced river avulsions have been recorded over the past few hundred years. And the potential for future events is significant. Worldwide, rivers flow over active faults in more than 25,000 places. Adding people to the mix makes for a risky situation, according to McEwan. "Anywhere [there are] highly active faults, large populations, and rivers overlying those faults, there's going to be an issue," she said.

A Lake in Farmland

With the goal of forecasting the characteristics of fault rupture–induced river avulsions, McEwan and her colleagues conducted a case study of an event that occurred in New Zealand just after midnight on 14 November 2016.

When a magnitude 7.8 earthquake struck the country's South Island, the Papatea fault suddenly moved roughly 7 meters vertically and 4 meters horizontally where it intersected the Waiau Toa (Clarence) River. As the river's water—flowing at nearly 200 cubic meters per second—encountered that fault scarp, it was forced to change direction by about 45°. It spilled out of its existing channel and coursed for more than a kilometer across farmland.

Those floodwaters went on to form Lake Murray, which inundated more than 32 hectares (80 acres) for several months. Even today, more than 6 years later, parts of the Waiau Toa (Clarence) River are flowing hundreds of meters from their old channels. "There's been a real change in the landscape," McEwan said.

McEwan and her colleagues modeled the Waiau Toa (Clarence) River event. First, they tested whether they could accurately reproduce the extent of the river avulsion using river discharge data obtained just an hour before the event and a digital elevation model of the post-earthquake landscape assembled from lidar imagery. The researchers found that their 2D simulation was 94% accurate compared with real-world observations of the river avulsion.

But a more useful test was whether the river avulsion could be accurately reproduced using only pre-event data. To that end, the researchers created a digital elevation model of the landscape based on lidar data collected in 2012 and modified it using a synthetic fault scarp informed by the real fault's movement. When they fed those inputs into their simulation, they reproduced the avulsion with 89% accuracy.

Finally, the researchers simulated a range of possible flooding scenarios by considering five different fault scarp displacements and five different water discharge rates. That approach made sense, said Kélian Dascher-Cousineau, an Earth scientist at the University of California, Berkeley who was not involved in the research, explaining that it's impossible to prognosticate the exact parameters of an earthquake or how a river will be flowing at any instant. "You need to approach this from a probabilistic process," he said.

An Avulsion in the Future

Of the 25 modeled scenarios the researchers produced, in seven cases the Waiau Toa (Clarence) River completely abandoned its parent channel and carved a new path through the landscape. Larger fault displacements and higher discharge rates tended to produce more inundation, the team found, a result that was not surprising.

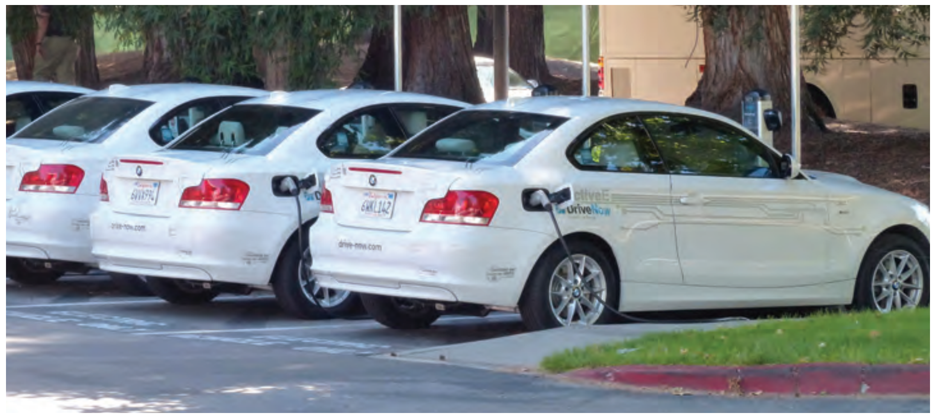
The researchers also found that in some instances, fault displacement merely primed the landscape for a future avulsion when the river's flow rate increased. An avulsion doesn't necessarily follow in lockstep with an earthquake—"It could be instantaneous or delayed," Stahl said.

Similar modeling could be used to assess the potential vulnerabilities of other rivers that are more prone to earthquakes, McEwan said: "That's what we'd do in places where this hasn't occurred yet and we're trying to assess the risk."

The results could inform hazard planning and legislation around mandatory building setbacks from fault lines, McEwan explained.

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

The Unequal Benefits of California's Electric Vehicle Transition



A row of electric BMWs charge at the Google campus in Mountain View, Calif. Credit: R Boed/Flickr, CC BY 2.0 (bit.ly/ccby2-0)

California has some of the most aggressive climate laws in the country, including its Clean Vehicle Rebate Project, which incentivizes the purchase of electric vehicles (EVs), fuel-cell vehicles, and plug-in hybrids. The state has issued more than half a million clean vehicle rebates since 2010. A new study shows that the program is having a mixed effect on air quality.

"I want to emphasize that the California Clean Vehicle Rebate Project has had many successes," said environmental sociologist Jaye Mejía-Duwan, a doctoral candidate at the University of California, Berkeley. The program supports decarbonizing transportation, a sector that emits nearly 40% of the state's carbon dioxide emissions. Individuals who purchase one of the vehicles on the program's approved list receive a $1,000–$7,500 check, depending on income.

Air quality improved in well-off communities as more clean cars hit the pavement between 2010 and 2021.

But in marginalized neighborhoods? Not so much. These communities saw fewer reductions in nitrous oxide, sulfur dioxide, and sootlike particles called $PM_{2.5}$ from car exhaust than well-off neighborhoods did.

The study, published in *PLOS Climate*, is the first to compare pollution in more granular census tracts than broader countywide swaths—a more accurate way to tease out air quality differences among neighborhoods (bit.ly/clean-vehicles). The researchers considered air pollution between 2010 and 2021 on the basis of public listings of rebates and emission models.

Collecting the Pieces

"One of the great things about California is that it reports such high-quality and publicly available data," Mejía-Duwan said. The Clean Vehicle Rebate Project posts the make and model, vehicle type, and census tract of every rebate granted.

Mejía-Duwan and their colleagues determined the change in local vehicle emissions using the state's Emission Factor (EMFAC) model, which estimates the rate of air pollution different types of vehicles emit. They applied those emission rates to vehicles tallied by the rebate project in each census tract. The researchers accounted for car movement by adjusting the emissions of surrounding census tracts within a 15-kilometer radius (the typical length of a California metro commute).

Plug-in vehicles are "only as clean as the underlying electric grid from which their electricity is sourced.

In the second half of the analysis, the researchers turned to U.S. EPA's electricity dispatch model AVERT (avoided emissions and generation tool) to calculate the change in emissions from power plants due to EV charging.

Plug-in vehicles are "only as clean as the underlying electric grid from which their electricity is sourced," said Mejía-Duwan.

The researchers calculated the change in annual pollutants at each of the state's 231 electrical generating units as more plug-ins came online. They assumed that people living within 5–20 kilometers (3–12 miles) of power plants were exposed to emissions.

The study showed that carbon dioxide, nitrous oxide, and sulfur dioxide emissions decreased statewide between 2010 and 2021. But the drop was uneven.

Annual nitrous oxide and sulfur dioxide emissions in marginalized communities fell by a third of those that well-off communities experienced. In a surprising result, statewide primary $PM_{2.5}$ emissions increased even as more cars went electric. (Heavier EVs causing more tire and road wear contribute to $PM_{2.5}$.) Still, wealthy neighborhoods were more likely to see decreases or stagnation of $PM_{2.5}$ rather than increases.

Sociologist Manuel Pastor of the University of Southern California in Los Angeles, who did not participate in the research, called the work "well done." He praised the mixture of modeling and varied energy sources.

"The authors make the important contribution of considering air pollutant emissions from the power plants that generate the electricity to power electric vehicles," said Lara Cushing of the University of California, Los Angeles, who was not involved in the study.

The Sources of Inequalities

Addressing historical inequalities and ensuring an equitable transition to low-emission technologies have been key priorities for California, said Dave Clegern of the California Air Resources Board, the state agency funding the rebate program. Clegern said that the focus of the rebate program has evolved from kick-starting an emerging technology in 2010 to actively addressing accessibility for the technology.

Although California seeks to lift the state's disadvantaged communities rather than leaving them behind, "so far, the incentive program has not achieved that," said sustainable transportation researcher Dana Rowangould of the University of Vermont, who was not involved in the study.

Mejía-Duwan pointed out structural challenges that exclude marginalized communities from benefiting from EVs. The ability to purchase electric vehicles is highly dependent on income, and marginalized communities "receive substantially fewer rebates than their undisadvantaged counterparts," they said. Though a few models, such as the compact Nissan Leaf, start at or around \$30,000, the average electric car price was \$61,000 in 2023, according to Kelly Blue Book.

Furthermore, EVs increase the load on power plants, which are disproportionately located in marginalized communities.

Downtowngal/Wikimedia Commons, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

Marginalized communities "receive substantially fewer rebates than their undisadvantaged counterparts.

Environmental injustice, defined as the disproportionate exposure of racial and ethnic minorities and low-income groups to pollutants, hazardous waste, and other environmental hazards, is a "severe problem in both the state of California and the nation," Pastor said. "These results will doubtlessly cause the state to take an extra look and make sure that it is addressing climate and equity goals most effectively."

Starting in 2016, the state adjusted the rebate program to shift resources toward low- and moderate-income groups, Clegern said. California now offers higher rebates to people with incomes less than or equal to 400% of the federal poverty level and excludes high-earning residents from receiving rebates. He also pointed to a new \$2,000 rebate benefit that began last month for charging support in disadvantaged neighborhoods.

The data show that past payment structure adjustments did improve the inequitable distribution of rebates, "but not substantially," Mejía-Duwan said. Before the changes, 5.9% of rebates went to disadvantaged communities, compared with 8.25% afterward.

"Vehicle electrification is helpful in some important ways," Mejía-Duwan said, but "it's not a silver bullet, a magical technological fix to all of our environmental inequities."

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

Saturn's Shiny Rings May Be Pretty Young

Saturn's rings gild the jewel of our solar system, and their shininess has helped astronomers pin down their age. Data from NASA's Cassini mission show how fast dust has been pelting the Saturnian system, revealing that for the rings to have remained as shiny and dust-free as they are, they can be no more than 400 million years old, much younger than the planet itself.

The age of Saturn's rings "is an old question," said Sascha Kempf, lead author of the research and a physicist at the University of Colorado Boulder who studies cosmic dust. Astronomers' fascination with this problem "is not so much about the age itself, even not so much about Saturn," he said. "It's that this provides us with another puzzle piece about planet formation."

The Age of the Ring

The Sun and its planets formed around 4.5 billion years ago, and many of the planets' moons, including ours, followed not long afterward.

Astronomers initially thought that Saturn's rings formed during that early dynamical period, when large collisions were common. That would seem to be a natural outcome, Kempf said. The rings' orbits and compositions support the idea that they are old.

"But there was an uneasy feeling about all of that," Kempf added. For almost 200 years, scientists have understood that rings don't stick around for long. Collisions between the icy particles that make up Saturn's rings generate a "ring rain" that pours down into the planet's atmosphere.

Measurements of the rainfall rate and the total mass of the rings from NASA's Cassini spacecraft, which orbited Saturn for 13 years, suggested that the rings must be far younger than the planet; otherwise, they would have disappeared already.

It was a real needle in a haystack problem.

Cassini also revealed that the rings are fairly shiny, having accumulated only a small amount of cosmic dust—tiny silicate particles that come from the far reaches of the solar system or beyond.

Dust particles are constantly flowing. "You can't shut them off," Kempf said. Most Saturnian dust comes from within—Enceladus produces a lot, as do the rings themselves. But that "dust" is mostly water ice, whereas dust that comes from beyond Saturn contains more silicates, which darken the rings over time like dirt on fresh snow.

Because the rings don't have a lot of silicate dust on them, they likely haven't had a lot of time to collect it. Knowing the speed at which dust streams into the Saturnian system is therefore key to determining just how long the rings have been around.

Cassini's Cosmic Dust Analyzer did just that. Over 13 years, it detected more than 2 million dust particles. The research team analyzed the trajectory of each particle and found only 163 dust particles that likely came from beyond Saturn.

"It was a real needle in a haystack problem," Kempf said.

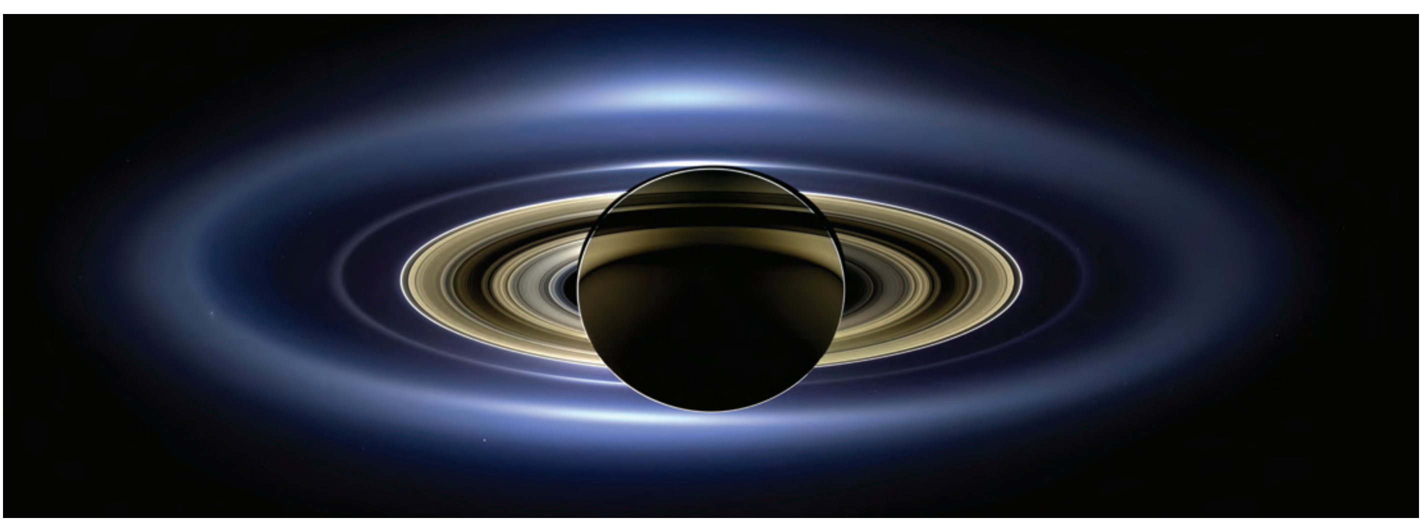
Considering how small an area of the rings Cassini sampled, 163 dust particles over 13 years extrapolates to a lot of dust moving through the rings. The team found that at that rate, the barely dusty rings have likely been around for just 100–400 million years. These results were published in *Science Advances* (bit.ly/Saturn-rings-age).

Shiny Snapshots

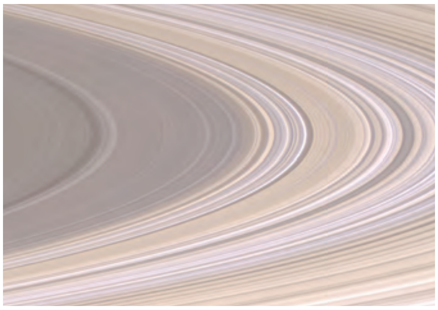
Even before the new finding, planetary scientist Philip Nicholson of Cornell University, who was not involved with the research, had been in the "young rings" camp. The new result built on some of his previous Cassini research on the mass and dustiness of the rings.

"Although the age of Saturn's rings has been hotly debated for many years, we have only really had good data bearing on this question since the Cassini mission," Nicholson said.

He added that the new age estimate is also consistent with past research that pins the



This mosaic of the Saturnian system was constructed from images taken by NASA's Cassini spacecraft while the Sun was hidden behind the planet. Credit: NASA/JPL-Caltech/Space Science Institute, Public Domain



Saturn's rings are dominated by water ice and naturally vary in color. Dust pollution creates more color variation. Credit: NASA/JPL/Space Science Institute, Public Domain

age of some of Saturn's small moons at 10–100 million years.

Despite the agreement with past results, forming a ring system "would require breaking up an icy body the size of the satellite Mimas—about 200 kilometers [125 miles] in radius—which is not easy to arrange so late in the history of the solar system," Nicholson cautioned.

The recent revelations about Saturn have certainly opened our eyes to the possibility that all of these ring systems may be relatively young.

"A prudent person would probably say that the case is still open, despite many groups' strenuous efforts to provide the key data with which to resolve it," he said.

Saturn isn't the only object in the solar system with rings. Jupiter, Uranus, Neptune, and several dwarf planets all sport them. Scientists lack the detailed information on those systems that Cassini provided for Saturn. Nevertheless, "the recent revelations about Saturn have certainly opened our eyes to the possibility that all of these ring systems may be relatively young," Nicholson said.

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

Supersized Potholes Discovered off South African Coast

South Africa's coast is renowned for mighty waves and world-class surfing. Those same breaks might have carved the world's largest marine potholes.

Researchers recently discovered a cluster of large depressions on the seafloor 90 meters (300 feet) below the ocean surface off the coast of Eastern Cape Province. That's far deeper than similar features elsewhere, said Andrew Green, a marine geologist at the University of KwaZulu-Natal in South Africa and lead author of a new study published in *Geomorphology* (bit.ly/marine-potholes).

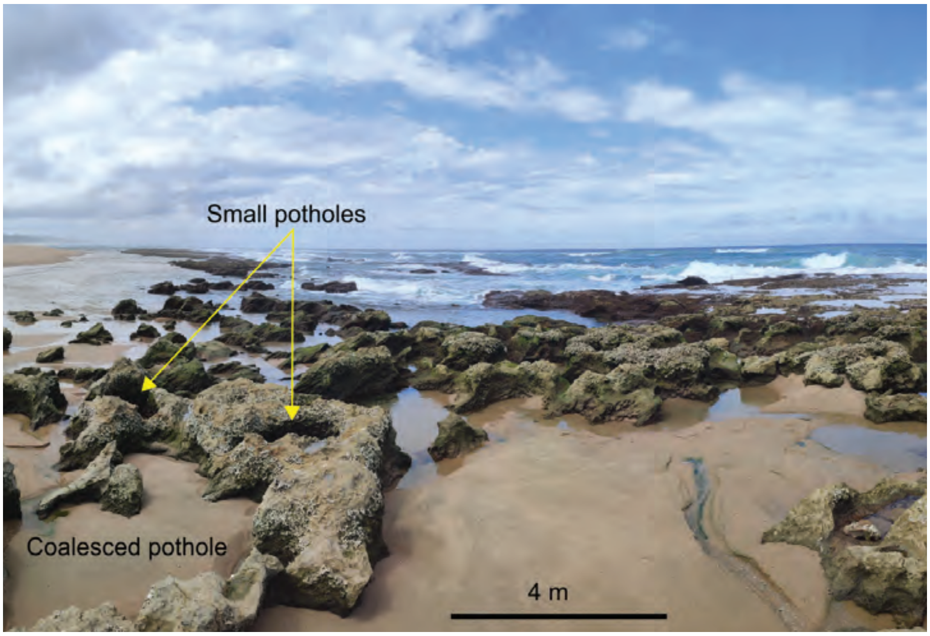
Green and his colleagues believe the formations are marine potholes, circular depressions drilled into bedrock by grinding sediments. Potholes can form anywhere water swirls stones against bedrock, from river eddies to rainy hillsides.

In intertidal zones, constant waves send sediments corkscrewing. That phenomenon can result in a landscape pocked by small, grooved bowls. Most observed marine potholes are found no deeper than 50 meters below the surface—shallow enough for a scuba diver to visit, Green said. The Eastern Cape potholes sit on a seafloor almost twice as deep.

Once a site of crashing waves, the location would have been submerged as rising sea levels shifted the intertidal zone inland. The potholes may therefore reveal the location of an ancient seashore.

That is, if the pits are even potholes at all. Their depth is just one of the cluster's curiosities. Marine potholes rarely exceed 2 meters in diameter, but these depressions stretch up to 60 meters (200 feet) across. Compared with marine potholes in China, Hawaii, and Japan, Green said, "these things are orders of magnitude bigger." They are also unusually shallow: Their diameter-to-depth ratio is

Waves near Durban, South Africa, are known for surfing. They also may have created the largest marine potholes on Earth. Credit: Lynn Greyling/Pixabay



Aeolianite formations at Cape Vidal in northern KwaZulu-Natal, South Africa, show evidence of modern-day potholing along the shoreline. Credit: Andrew Green, University of KwaZulu-Natal

50:1, whereas most potholes have a ratio of around 2:1.

Stumbling on the Scene

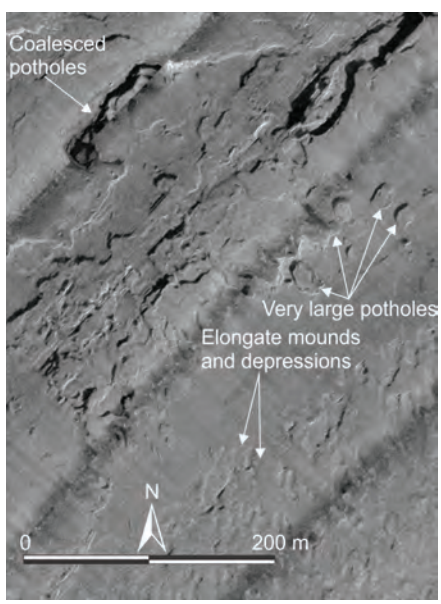
Green first found the holes while working with developers looking to anchor an underwater energy farm within the shelf's fast moving current. An initial survey of the seafloor turned up a string of depressions. Instead of being buried under a thick layer of sediment, as expected at the ocean bottom, the bedrock features were completely uncovered.

The holes were generally symmetrical, leading Green to suspect that they might be supersized potholes. He returned with a research vessel equipped with bathymetry and sonar devices to paint a 3D portrait of the seafloor and identify the bedrock material beneath the pits. To verify their maps, the researchers sent submersibles to collect photographs and seafloor samples. In total, the mapping revealed 238 holes on the Eastern Cape shelf.

Examining the Clues

Green and his colleagues estimated that the potholes formed about 14,500 years ago, as Earth transitioned from an ice age to a period called the Bølling-Allerød warming. The ice age was the last time sea levels were low enough for long enough to expose the location to waves.

The holes tend to form in bands that align with natural layers in the bedrock, which is made of aeolianite, a rock formed from hardened sand dunes. The researchers suggested that when the area was above sea level, sea spray may have pooled on the aeolianite and chemically dissolved weaker layers of the rock, similar to the way rainwater dissolves limestone to create sinkholes. Later, as sea level climbed, waves swirled small rocks into the shallow striations and eventually carved out massive circles.



Sonar revealed that the aeolianite shelf off South Africa's Eastern Cape is pockmarked with what may be potholes. Credit: Andrew Green, University of KwaZulu-Natal

Pothole size is limited by time and climate, Green said. The larger the pothole is, the longer the bedrock was exposed to waves and weathering. The Bølling-Allerød warming period was wet and warm—prime conditions for chemical weathering—and lasted long enough to satisfy the sea spray hypothesis.

But many details are missing. Stones that carve potholes typically end up stuck inside the hole they created. Nearby potholes on the KwaZulu-Natal shelf closer to the shore are full of grinding stones, the researchers noted. None of the 238 Eastern Cape potholes has grinding stones.

The theory proposed in the paper is questionable, said Balai Chandra Das, a geomorphologist at Krishnagar Government College in India. Depressions need a critical depth-to-diameter ratio to trap grinding stones, he said. The Eastern Cape potholes are too shallow and too large to trap much, or even sustain the vortex needed to spin sediments. Any grinding stones likely would have washed away, rather than getting caught in an abrasive spiral.

I think that is the most important mechanism that created that kind of irregularity.

"Obviously, there is some chemical weathering," Das said. "I think that is the most important mechanism that created that kind of irregularity."

Green and his colleagues recognize that these anomalies need further study. The survey was a first attempt to explain the unique formations by mapping the seafloor. Green said that he hopes to collect more seafloor samples to date when the formation submerged. For now, the mystery remains.

By **J. Besl** (@J_Besl), Science Writer

Tornadoes' Fastest Winds Howl Close to the Ground

A set of radar instruments mounted on a truck, called a Doppler on Wheels, prepares to take measurements of an approaching tornado. Credit: Joshua Wurman

As if tornadoes weren't fearsome enough, new research suggests that they may be stronger near the ground than previously thought. The actual speeds of destructive winds are therefore probably being underestimated by weather forecasts meant to help people brace for impending storms.

"One surprising thing about tornadoes is, for such a well-known phenomenon, the fundamental details are poorly known," said Joshua Wurman, a meteorologist at the University of Illinois at Urbana-Champaign.

Until recently, most of what was known about these low-altitude wind speeds was inferred from the destruction wrought when they blustered through a town. "The information that we can infer from that damage is crude and has known biases," Wurman said, due to the relative rareness of tornadoes crossing through populated areas and the fact that they damage weak structures.

In the United States, tornadoes are typically observed by the National Weather Service's network of stationary radars. But the height at which the radar beam measures increases with distance from the twister, said Jana Houser, a meteorologist at the Ohio State University who wasn't part of the new work. Unless the tornado is very close, the beam doesn't collect data near the surface.

When radar observations are available, they're typically from far above the ground—higher than 100 meters (330 feet). They don't reveal the nature of winds near the surface, where damage happens, said Karen Kosiba, a meteorologist also at the University of Illinois at Urbana-Champaign. Early mathematical and computer models suggested that the strongest blasts occurred above the heights of buildings, she said.

To get the lowdown on wind speeds near where people live, Kosiba and Wurman observed hundreds of tornadoes using weather radars on trucks—a system they call Doppler on Wheels. When a supercell thunderstorm spins up a tornado, the pair and their colleagues race to get their instruments in front of it to collect radar data from about 2–3 kilometers (1–2 miles) away.

"Basically, we do what storm chasers do but with a very different goal," Wurman said.

Wurman and Kosiba manage the Flexible Array of Radars and Mesonets facility, which maintains, among other equipment, several Doppler on Wheels vehicles available to the research community. (The researchers are continuing their work after a 2021 settlement with the U.S. government over alleged misspending of grants under a prior project.)

In the latest study, published in *Communications Earth & Environment,* Kosiba and Wurman dug through radar data from 73 tornadoes that occurred between 1999 and 2009 in the Great Plains of the United States (bit.ly/tornado-winds). For each storm, they constructed a vertical profile of wind speeds using measurements at heights of 15–100 meters (50–330 feet) aboveground. These profiles revealed that the tornadoes spin 30% faster at 15 meters (50 feet) than radars taking measurements higher up had indicated.

The finding suggests that "the true average intensity of tornadoes may be even stronger than we thought," Wurman said.

The Business End of the Tornado

The swirling dust a tornado kicks up makes quite an impression, "but the business end of the tornado really is very close to the ground," said Richard Rotunno, an atmospheric scientist at the National Center for Atmospheric Research in Boulder, Colo., who was not involved with the research. That the strongest gusts often occur close to the ground isn't surprising, Rotunno said, as it is consistent with current theory and modeling of tornadoes.

Friction is important near the ground, Houser said. Though friction does slow winds to a degree, it also causes the air swirling on the outside of the twister to turn toward the upward moving column in the center. This makes the tornado's radius smaller and causes it to rotate faster.

"It's like the ice skater effect," Houser said, referring to how the twirling of ice skaters speeds up when they draw their arms or legs nearer their body.

There are still many questions around how tornadoes form, Houser said, and real-world observations like those in this study help to untangle the physics of what's happening inside storms. Kosiba and Wurman are continuing to collect data on tornadoes to investigate the factors—such as the roughness of a landscape—that might affect a tornado's longevity or wind speeds.

Knowing how wind speeds vary with height is crucial for designing buildings and structures to withstand storms. Risk from tornadoes is increasing, said Wurman, especially as suburbs sprawl in tornado-prone areas. "Understanding the true intensity of tornadoes is the only way to really quantify that risk in a meaningful way," he said.

By **Carolyn Wilke** (@CarolynMWilke), Science Writer

Tiny Martian Moon May Be a Chip Off the Old Block

The origin of Mars's moons, Phobos and Deimos, has puzzled scientists since their discovery in the 1870s. On the basis of the objects' small, irregular shapes and shade (among the darkest in the solar system), scientists have thought they could be asteroids captured by chance into Martian orbit.

Since the captured-asteroid theory took hold, however, new ideas have emerged to explain the origin of Phobos and Deimos—mostly variations of a giant impact scenario that launched enough Martian material into orbit to form the moons. One variation posits that the moons could have coalesced directly from material lifted by the impact. Another suggests that a single larger moon formed first but got too close to Mars and disintegrated, leaving Phobos and Deimos to form from its scraps.

New close-up images of the outer moon, Deimos, seem to support the impact theory. The images, obtained by the Emirates Mars Mission, show that Deimos lacks the expected signs of an asteroidal origin. Instead, chemical clues point to a makeup similar to that of Mars itself, suggesting that the moon could have been born of the Red Planet.

Deimos is seen by the Hope probe, with Mars in the background. Credit: Emirates Mars Mission

Long Time No See

Deimos is a hard target for space missions. It averages just 12 kilometers in diameter and orbits more than 20,000 kilometers from the surface of Mars—much farther away than most spacecraft around the planet. The Viking 2 lander achieved the last close-up in 1977 while en route to Mars.

The Hope probe, as the Emirati spacecraft is called, arrived at Mars in February 2021 to observe variations in the Martian atmosphere over the seasons. To get a full view of the outer atmosphere, the satellite has a high elliptical orbit at 20,000–43,000 kilometers from the planet.

After a full Martian year of watching the planet, mission scientists took a unique opportunity to approach Deimos. Flight engineers maneuvered the spacecraft to synchronize its orbit with the moon, enabling a series of flybys. The nearest approach occurred on 10 March 2023, when it got to within 103 kilometers of the moon's surface.

During the flyby, Hope mapped almost the entire surface of Deimos, capturing the first view of its farside. The craft's visible-light camera took photos of the surface with a resolution of 10 meters per pixel. Two other instruments recorded the infrared and ultraviolet light radiating off the moon's surface, revealing details about its composition and temperature. The findings were reported at the European Geosciences Union General Assembly in April (bit.ly/Deimos-flybys).

Hope mapped almost the entire surface of Deimos, capturing the first view of its farside.

Visually, Deimos doesn't look like asteroids Ryugu or Bennu, visited by the Hayabusa2 and OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) spacecraft, respectively. Those asteroids have a very coarse surface filled with loose boulders and rocks. Deimos, on the other hand, is covered by a fine powder called regolith, lending it a smooth look, similar to those of our own Moon and neighboring Phobos.

In the ultraviolet, the researchers didn't find signs of organic compounds or carbon-rich minerals, which are expected in D-type asteroids—those that look most like Deimos. These asteroids formed beyond Jupiter's orbit and are thought to be rich in water and other volatiles.

This is the first time either Martian moon has been successfully observed in the ultraviolet. "Previous missions had tried to look at Phobos at similar wavelengths and just failed to get any signal at all," explained Justin Deighan, a planetary scientist at the University of Colorado Boulder. The Emirates Mars Ultraviolet Spectrometer (EMUS) on board Hope is the most sensitive spectrometer that has ever orbited Mars, a capability that proved crucial to observing the dark Martian moon, he said.

In the infrared, the tiny moon doesn't match what scientists expect from an asteroid, either. Researchers compared Deimos's infrared signature with those of the carbon-rich Tagish Lake meteorite (which landed in British Columbia in 2000), the closest match to the expected composition of a D-type asteroid. Instead of seeing similarities with the meteorite, however, they found that Deimos's infrared spectral signature more closely resembled that of basalt, a volcanic rock that covers most of the Martian surface.

No More Asteroid Talk?

Given the new observations, the captured asteroid scenario looks less likely than the giant impact theory.

"This raises interesting questions, like, Why do some of the rocky bodies in our solar system have different moons?" said Christopher Edwards, a planetary scientist at Northern Arizona University and an instrument scientist for the Emirates Mars Infrared Spectrometer (EMIRS) on board Hope. Scientists question why Venus and Mercury don't have moons at all, he said, while Earth has one big moon and Mars has two small moons. "[A giant impact origin] tells us about the diversity of early planetary processes that may be going on in our solar system," he explained.

The new data don't entirely rule out Phobos and Deimos as captured asteroids—in part because researchers don't know for sure what a D-type asteroid looks like up close. "If we were to somehow magically take Deimos out of its orbit and put it on its own in the asteroid belt, we would call it a D-class asteroid based on its visible and near-infrared spectrum," said Andrew Rivkin, a planetary scientist at the Johns Hopkins University Applied Physics Laboratory who isn't involved with the Emirates Mars Mission. Still, "it's great to get [these] data for the first time ever," Rivkin said.

Rivkin said he thinks that a definitive answer about the origin of Mars's moons will likely have to wait for the Japan Aerospace Exploration Agency's Martian Moons Exploration (MMX) mission—scheduled to launch in 2024—which will orbit Phobos and return a piece of it to Earth.

"I think the impact hypothesis is putting itself in a good position here," Rivkin said, "but MMX will absolutely clinch it."

By **Javier Barbuzano** (@javibarbuzano), Science Writer

Groundwater Pumping Is Causing Mexico City to Sink

In the Ampliación Santa Martha neighborhood of Mexico City, land subsidence has contributed to hundreds of leaning fences, fractured walls, and cracked streets. Credit: Rodrigo Botello

Gerardo Medina's plumbing has never worked well. Most of the time, water arrives at his home on the outskirts of Mexico City dirty...or it doesn't come at all. And although the Mexico City Water System (SACMEX) repeatedly sends people to fix the pipes, the lines always fail again, Medina said. "It's a never-ending story."

In Medina's neighborhood, Ampliación Santa Martha, broken pipes, cracked streets, and curved windows warn of a (not so) hidden problem: Mexico City is sinking.

Scientists have agreed that groundwater extraction is a contributing factor to this subsidence, although estimates of the extraction rate vary. Authors of a new study published in *Geophysical Research Letters* used satellite data to narrow these estimates (bit.ly/Mexico-City-groundwater). They found that 1–13 cubic kilometers (0.2–3 cubic miles) of groundwater have been pumped each year since 2014 to serve the 22 million residents of the Mexico City Basin. (For reference, that's enough water to fill nearly 5 million Olympic-sized swimming pools.)

Perfectly Disastrous

The Mexico City Basin is like a wet sponge. It is composed of lava flows, ashes, clays, and sands. Water flows in the pore spaces between these sediments. Though pumping has caused the surface to sink by about 35 centimeters (14 inches) per year, subsidence is not uniform, according to the study's authors.

When water is removed, the sediment compacts, causing subsidence in some areas and cracks in others, explained Dora Carreón Freyre, a geological engineer at the National Autonomous University of Mexico (UNAM) and a member of the United Nations Educational, Scientific and Cultural Organization's Land Subsidence International Initiative (LASII) who was not involved in the new research.

Mexico City's growth also blocks precipitation from reaching the spongy sediments by increasing the amount of land covered by impervious surfaces like roads and parking lots. These impervious surfaces prevent increasingly scarce rains from recharging underground aquifers. "It's a perfectly disastrous formula," Carreón Freyre said.

Although previous studies did consider pumping to be a factor causing subsidence in Mexico City, some researchers have argued that the main trigger is long-term compaction of an ancient lake bed. The city was built on Lake Texcoco, which filled with silt in the

17th century after Spanish conquistadores began draining the lake. Since then, the weight of the city's development has caused the silt to steadily pack more tightly, making the ground shrink and sink. Authors of a 2021 study pointed to steady subsidence that did not fluctuate with groundwater pumping rates as evidence of the lake bed's compaction as the dominant influence on the phenomenon (bit.ly/Eos-sinking-ground).

Seeking to further explore the mechanisms responsible for Mexico City's subsidence, Mohammad Khorrami, a geotechnical engineer at the Virginia Polytechnic Institute and State University (Virginia Tech), and his colleagues took to the skies to calculate how much water had been pumped from the basin below.

With satellite data from the Gravity Recovery and Climate Experiment (GRACE), the researchers measured a slight decrease in the basin's gravity since 2014 due to changes in the mass of water near the surface. Modeling groundwater storage changes along with interferometric synthetic aperture radar (InSAR) data—which record slight changes in surface elevation—captured between 2014 and 2021 indicate that groundwater pumping is the main driver of subsidence, Khorrami said.

The satellite data indicate that because of groundwater loss, Earth's surface is sinking in some areas and rebounding in others, Khorrami explained. In some places surrounding Mexico City, the ground is rising 2 centimeters (0.7 inch) per year. The research offers "one of the first InSAR observations of rebounding of the ground as a result of the huge amount of groundwater mass loss or extraction," Khorrami said.

Enrique Cabral, a geological engineer at UNAM, is skeptical about the interpretation of these results. Using satellite gravity data is the right thing to do for this type of analysis, Cabral said, but these tools are intended for studying much larger, subcontinent-sized basins. "The margin of uncertainty is large," he said. "Although Mexico City is big, the basin area is not of those dimensions."

All research that… puts the magnifying glass on this process and on the fact that we must do something to address it is very welcome.

Carreón Freyre, too, expressed some skepticism. The new study reflects a good use of remote measurement and modeling techniques, she said, but the volume of withdrawn water and supposed uplift do not make much sense considering the context of Mexico City's water management.

"Groundwater has been extracted little by little over decades," she explained, so a scenario in which the surface rebounds as if all the water were removed at once is far from realistic.

A Long-Standing Problem

One of the great challenges surrounding Mexico City's subsidence is the availability of groundwater-level data, said Manoochehr Shirzaei, a geophysicist at Virginia Tech and a coauthor of the new study.

UNAM geological engineer Darío Solano agreed. Although public authorities such as SACMEX and the National Water Commission (CONAGUA) have a history of opacity in publishing this type of data, he said, the information exists and can be accessed by direct request through online data transparency systems.

Continued research into Mexico City's subsidence is important to keep attention on a problem that often remains neglected, Cabral said. The effects of subsidence, such as a limited water supply and damage to infrastructure, are long-term in scope. As a result, many residents and policymakers do not perceive the current level of pumping as an immediate problem and are less likely to conserve water, he explained.

"All research that…indirectly puts the magnifying glass on this [subsidence] process and on the fact that we must do something to address it is very welcome," Cabral said.

By **Humberto Basilio** (@HumbertoBasilio), Science Writer

Flash Droughts Are Getting Flashier

Matt Palmer, Unsplash

In summer 2012, a severe drought unexpectedly struck the central United States. The event began in May and rapidly intensified until it peaked in mid-July, when precipitation hit record lows throughout the Midwest, affecting approximately 80% of U.S. agricultural land and causing $34.5 billion in losses.

Flash droughts such as this are developing more quickly and happening more frequently because of climate change, according to a recent study published in *Science* (bit.ly/climate-change-flash-droughts).

Unlike slow droughts, which develop over years, flash droughts arise in a matter of weeks and can last for 30–45 days (or even for years). Because these events are abrupt and relatively localized, they are more difficult to forecast.

"People have less time to prepare for them," wrote Xing Yuan, a hydroclimatologist at Nanjing University of Information Science and Technology in Jiangsu, China, and lead author of the study, in an email.

Droughts that come on quickly are especially worrying for regions that are not well adapted, according to climatologist Peili Wu of the Met Office in the United Kingdom, who is a coauthor of the study. "In the U.S., I think people are more aware about flash droughts," he said. "But in other parts of the world—in Europe, for example—people are less familiar with this concept."

The predictability of slow droughts, on the other hand, helps communities and governments adapt.

Flashier Times

To gauge how flash droughts have changed over time, Yuan, Wu, and their colleagues analyzed daily precipitation and evaporation data from different climate reconstructions, as well as soil moisture data, to identify droughts that occurred over a subseasonal timescale (1–2 months) between 1951 and 2014. They classified flash droughts as periods with a rapid drop in soil moisture and dry conditions lasting for at least 20 days. The rest of the droughts were categorized as slow.

The researchers compared regional trends by dividing Earth into polygons and found that the proportion of dry spells considered flash droughts increased in 74% of the regions. Northern and East Asia, Europe, and the west coast of South America experienced the biggest increases in flash droughts, as well as their quickest arrivals.

Less precipitation, greater evaporation, and hotter days are driving the trends, according to the researchers. Warmer air can hold more moisture, so as temperatures rise, more evaporation occurs and plants release more water.

Flash droughts were 2–3 times more common in humid regions than in others. Evaporation is driven in part by the intensity of the Sun. A drop in precipitation and cloud cover speeds up evaporation and, therefore, the onset of drought, explained the researchers.

The results of the study are robust, said Joel Lisonbee, a climatologist at the Cooperative Institute for Research in Environmental Sciences. However, he said he worries that by studying droughts at the subseasonal timescale, the researchers "would have missed out on multiyear droughts that began [as flash droughts]."

Turning Up the Heat

To determine whether the transition to flashier droughts was related to human-caused climate change, the researchers simulated two different histories: one that included both human-induced climate forcings (such as greenhouse gas emissions) and natural climate forcings (solar and volcanic activity) and one that included only natural ones.

The latter simulation failed to capture the trends the researchers observed in the data, whereas the simulation that considered natural and human effects did, leading the researchers to conclude that the shift toward more flash droughts is linked to human influence.

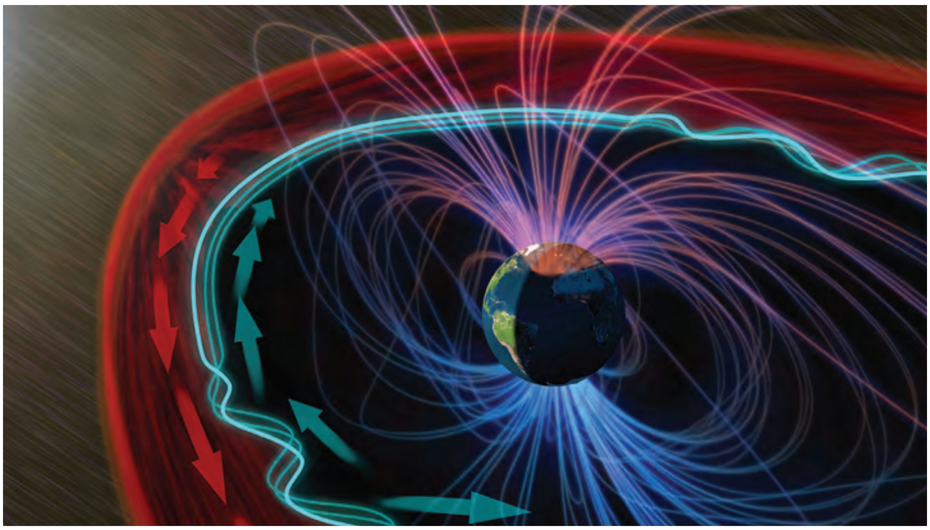
"Traditionally, droughts are thought to be a slow climatic process, but given the increase in temperature due to global warming, [their onset] actually sped up," Wu said.

"Within a couple of weeks, you can go from a very green, healthy-looking ecosystem to something that is withering and sort of dying away," said ecohydrologist Jagdish Krishnaswamy of the Indian Institute for Human Settlements. "That's really alarming." This study lays the groundwork for more fine-scale mapping of climate variables in vulnerable regions, he explained.

"We need to stop thinking of drought as a slowly developing disaster and start thinking about it as something that can happen really quickly," Lisonbee said.

By **Roberto González** (@ggonzalitos), Science Writer

Eavesdropping on the Vibrations of Earth's Magnetic Bubble



A magnetic bubble protects our planet from most of the radiation that streams from the Sun. However, turbulent solar winds can strike the magnetic field, causing it to resonate like a harp string. Credit: Martin Archer/Emmanuel Masongsong/NASA Goddard Space Flight Center

Our solar system is not silent nothingness. It's buzzing with charged particles expelled from the Sun and lofted along by solar winds. Gusty and energetic solar winds can send ultralow-frequency waves quivering along the magnetic field lines that surround our planet—just like a harp string when plucked.

These haunting melody is too low in pitch for us to hear, but researchers have turned the sounds into something audible and are now asking the public to help listen to the din of space (see bit.ly/space-weather-sonification).

"We're hoping that the wisdom of the crowd, combined with our highly tuned human sense of hearing, will help us pick out the features of these waves," said Martin Archer, a space physicist with Imperial College London and one of the scientists behind the project, Heliophysics Audified: Resonances in Plasmas (HARP).

By classifying the different types of vibrations, the researchers hope to get a better picture of how they influence Earth's magnetic field.

Sounding Out the Notes

Stunning aurorae, seen dancing across skies near the poles, provide one illustration of how plasma energy carried by solar winds can interact with Earth's magnetic field, or magnetosphere.

Beyond creating colorful light displays, waves generated when our magnetosphere is struck by solar winds also contribute to disruptive space weather, which can pose a risk to satellites, telecommunications, and astronauts.

Characterizing plasma waves could help improve predictions of space weather hazards. But studying them has proved challenging in the past because even computers struggle to separate out the many simultaneous vibrations among the background noise of space.

"These plasma waves are really complicated," said Wen Li, an astronomer at Boston University who is not involved in the HARP project. "Even after decades of study, we still have a lot of questions about how they work."

One unknown the researchers hope to explore is why some plasma waves interact with their space environment more strongly than others. "Audio analysis could add a new dimension to our understanding of these waves," Li said.

To amplify the sound of plasma waves for human ears, the researchers used a technique called sonification to speed up years of electromagnetic measurements collected by NASA's THEMIS mission (Time History of Events and Macroscale Interactions during Substorms), which deployed five satellites to fly through Earth's magnetosphere in 2007.

Back in 2018, Archer trialed a small-scale version of the project with high school students, who identified a series of solar storms reverberating within Earth's magnetosphere. Each storm sounded like a loud crunch, followed by whistles that steadily lowered in pitch as the magnetic field lines readjusted.

"Space scientists had barely discussed sounds like this before," Archer said. The storms "leapt out at us when we listened to the data but were easy to miss in the plots."

Since that discovery, with the backing of NASA, the HARP team has worked with

We're hoping that the wisdom of the crowd, combined with our highly tuned human sense of hearing, will help us pick out the features of these waves.

Stunning aurorae, or northern and southern lights, are caused by solar winds interacting with Earth's magnetic field. These interactions can also trigger vibrations that with the right tools can be amplified for us to hear. Credit: NASA's Marshall Space Flight Center, CC BY-NC 2.0 (bit.ly/ccbync2-0) sound experts to create an interface that allows people to highlight and comment on the waveforms. The researchers are asking volunteers to listen to the audio and describe what they hear—whether the sound is a formless static noise or pure tone, for instance.

Borrowing techniques used by musicians was fundamental to the project, said Archer, who has a background in radio and as a DJ. "It struck me that these data might be better suited to our ears," he continued.

"Hearing these waves really brings them to life," said David Sibeck, a heliophysicist at NASA Goddard Space Flight Center and a THEMIS mission scientist who is not involved in the HARP project. The huge bank of data gathered by the mission has been a challenge for scientists to analyze by themselves, Sibeck said.

Aside from being a way to engage the public in space science endeavors, asking folks to listen to the data also brings scientific benefits. Humans excel at disentangling competing sounds, even set against background noise, Archer explained, offering an example: "Take our ability to filter out conversations at a cocktail party."

An Ear on Space

One of the team's goals is to identify the properties of each plasma wave. Just like the strings of a harp, each wave resonates and interacts with its surrounding space differently. Certain plasma waves are thought to play a role in forming the giant donut-shaped radiation belts, or Van Allen belts, within Earth's magnetosphere. These belts, which contain highly charged particles, are a major hazard for astronauts and spacecraft because of their high radiation levels.

Current theories suggest that plasma waves can energize the charged particles in these belts, making them more hazardous. Stronger plasma waves with larger amplitudes are thought to be more effective at transferring energy between particles, said Li, "but we are still unsure exactly how this process works."

Observations from HARP could help scientists understand that energy transfer, according to Sibeck. "We really won't know which waves are important until we survey them all," he said.

The public contribution will be crucial to the success of the project, Archer said.

By **Erin Martin-Jones** (@Erin_M_J), Science Writer

Raising Hazard Awareness at the Foot of Nyiragongo

Students in Goma, Democratic Republic of the Congo, play the board game Hazagora to learn about volcanic hazard resilience. Credit: Blaise Mafuko Nyandwi

Memories of the glow emanating from the top of the Democratic Republic of the Congo's Mount Nyiragongo volcano have not been forgotten by those living nearby. At the volcano's summit is a lava lake that lights up the night sky like a beacon. In May 2021, an unexpected lava flow came down Nyiragongo's flank, pouring into the outskirts of the nearby Congolese city of Goma as residents fled in the dark.

Now, researchers are studying ways of educating residents about the hazards of living near one of the world's most dangerous volcanoes. The scientists presented their research at the European Geosciences Union General Assembly 2023 (bit.ly/prepared-community).

As a child in Goma, Blaise Mafuko Nyandwi grew up with towering Nyiragongo as a backdrop and watched the red glow of its lava every night. Now a volcanologist at the University of Goma, he knows from experience that people living in the city still do not know how volcanoes work and may therefore be unprepared to react during future eruptions.

"Volcanic eruptions cannot be prevented, so mitigation strategies are needed to reduce impact," said Mafuko, lead researcher of the new study. Mitigation can mean making the nearby population aware and ready to react, he added.

With the ever present threat in the region, situated in the Virunga Volcanic Province of East Africa, Mafuko and his colleagues worked with 435 sixteen-year-old students from 12 high schools in Goma to test how well two extracurricular activities raised awareness of geological risk: playing the board game Hazagora and visiting the Virunga Volcano Museum.

Gaming and Exploring the Way to Awareness

On the fictional island of Hazagora, players develop a society regularly hit by earthquakes, volcanic eruptions, floods, and landslides. Five to 10 players, representing the island's mayor, a fisherman, a lumberjack, a farmer, and a tour guide, must figure out how to survive disasters by making trade-offs among protective measures. Players use their annual income to provide for their families' basic needs but can also stockpile supplies and reinforce or protect infrastructure, for instance.

The game, originally developed by researchers at Vrije Universiteit Brussel in Belgium, includes information sheets on geo-

The Virunga Volcano Museum houses displays and documentaries about nearby volcanoes and how to build resilience against hazards. Credit: Caroline Michellier

logical hazards that the moderator can use to reinforce the players' knowledge. Through discussions about the events and possible consequences, players learn more about the natural processes at work and how to reduce risk.

"The information on volcanic risk that makes Hazagora valuable is broad," Mafuko explained. The game could symbolize any volcanic region.

On the other hand, the Virunga Volcano Museum, which recently opened next to the Goma Volcano Observatory (GVO), features informative panels and documentaries about volcanic hazards specific to the region, monitoring activities conducted at GVO, historical eruptions of Nyiragongo, and what to do during an eruption. In the center of the room is an animated 3D model of the Virunga volcanic chain.

"At the museum, students learned about Nyiragongo's historic eruptions. The exhibit reinforces knowledge of volcanoes, and Virunga volcanoes specifically," Mafuko said. "The students were introduced to volcanologists and monitoring equipment and read about volcano preparedness and mitigation measures for risks."

Museums are useful because they take the students out of their normal learning environment and provide good samples, tools, and, often, expertise to help the students connect the dots on the topic, said Carina Fearnley, director of University College London's Warning Research Centre, who was not involved in the study.

Through surveys and conversations, the researchers found that both the game and the museum visit reinforced students' knowledge of volcanism, but the museum was a more effective tool to help students learn about how volcanoes work. The Hazagora game, on the other hand, made the students more knowledgeable about how to take protective action.

Volcanic eruptions cannot be prevented, so mitigation strategies are needed to reduce impact.

This study provides valuable insight into the success of a paired approach to learning about volcanoes, using a range of tools and types of engagement, Fearnley added.

Striking Motivation

Mafuko said he was struck by the students' initial low level of understanding about volcanic processes and risk despite their living at the foot of the volcano. He and his colleagues did find, however, that the students were motivated to learn more and were willing to engage in disaster risk reduction activities in their school communities and with their families.

"These students are the future decision-makers and stakeholders in disaster risk reduction," said Joseph Makundi, Goma's civil protection coordinator. "They are powerful in influencing members of their community to adopt protective behavior." Reaching students is therefore key to building a prepared community in Goma.

The work "highlights the importance of teaching hazard and risk management at schools, not just in Goma," Fearnley said. "Goma is a particularly vulnerable population for volcanic hazards, and any work that can be done to build awareness and resilience is vital."

Academics, risk managers, and teachers should work together to design attractive educational actions specific for their context, Mafuko suggested.

These kinds of simple educational activities may be more practical for teaching, especially in the Global South, where advanced technologies such as augmented virtual reality are difficult to implement. Policymakers should integrate disaster resilience into school curriculums and recommend extracurricular activities in which students can be active learners, Mafuko said.

Goma, Democratic Republic of the Congo, sits at the foot of Nyiragongo volcano. Credit: MONUSCO/Abel Kavanagh, Flickr, CC BY-SA 2.0 (bit.ly/ccbysa2-0)

By **Munyaradzi Makoni** (@MunyaWaMakoni), Science Writer

Tracking Marine Heat Waves

Bottom marine heat waves can cause thermal stress for ocean species living near continental shelves. Credit: Jim Beaudoin, Unsplash

Heat waves have spiked in recent years. The United States is now scorched by about six per year, compared with just two annually in the 1960s. At sea, marine heat waves, such as the Blob, which warmed waters off the U.S. West Coast from 2013 to 2016, are becoming hotter over time.

Now, scientists have discovered that more intense, longer-lasting heat waves on continental shelves can strike the ocean bottom independent of the surface. Excess heat disrupts oceanic ecosystems and thwarts the ocean's twin promises of cooling and carbon sequestration.

"These things can happen without any clear surface signature," said Dillon Amaya, a climate scientist at NOAA who led the study published in *Nature Communications* (bit.ly/bottom-marine-heat-waves). Unfortunately, ocean temperatures have historically been measured mainly at the surface, leaving scientists in the dark about what's happening in the deep.

"That's the scary part," Amaya said. "Often, we won't know that these things are happening until after the fact, when the ecosystem impacts are more apparent."

Toastier Times in the Deep

Focusing on continental shelves—the offshore parts of a continent—Amaya and his colleagues combined observations and climate models to evaluate bottom marine heat waves in nine large marine ecosystems off North American coasts from 1993 to 2019. The group combined sparse existing observations with climate modeling to approximate missing data through time.

The researchers tracked average temperatures in the ocean from the surface to the seafloor of each continental shelf (up to 400 meters deep). They defined a bottom marine heat wave as temperatures in the top 10% within the study's 26-year range.

The data reveal bottom marine heat waves that lasted for up to 6 months and were 0.5°C–3°C warmer than average. These spikes are enough to stress or kill species that live on continental shelves: lobsters, Dungeness crab, Pacific cod, oysters, clams, and other bottom dwellers, Amaya said. The hot spells sometimes occurred concurrently at the surface but not always.

The data also show that heat wave intensity varied with ocean bottom depth, an observation that could aid future heat wave predictions.

"To get long-term observations [from] below the surface is tricky," said Amandine Schaeffer, a physical oceanographer at the University of New South Wales in Sydney. She pointed out that this new study is not the first to measure heat waves below the surface; previous studies demonstrated similar phenomena on a smaller scale near Australia and in the tropical western Pacific.

The new study, Amaya said, is the first to do this at a large scale and shows that heat wave observations from past studies can be applied on a broader scale.

Continental shelves are nearshore seafloor environments, so the group's findings don't apply to deep or abyssal ocean ecosystems, which can be up to 4.5 kilometers (2.8 miles) deep.

Amaya said he hopes investigations will detail the physical mechanisms that drive bottom marine heat waves, allowing scientists to build tools to forecast temperature variability. Testing whether those mechanisms hold up across physically diverse regions will be key, he said.

The new study "shows the need for subsurface understanding and subsurface observations to really see what's happening in terms of extremes below the surface," Schaeffer said. She added that it usually takes 3 decades

The absolute water temperature of these [heat waves] is definitely getting hotter.

of data just to establish a baseline of what constitutes an extreme temperature, and it is more difficult to track temperatures below the surface—obstacles to broadening this research.

Whether marine heat waves will be more frequent or intense in the future is still an open question, Amaya said, partially because scientists don't yet agree on the best way to analyze them. "But the absolute water temperature of these [heat waves] is definitely getting hotter," he said.

However they are defined, heat waves at the surface or hundreds of meters below will continue to shape marine ecosystems as climate change intensifies in the coming years.

By **Robin Donovan** (@RobinKD), Science Writer

We Need a Better Way to Share Earth Observations

iStock.com/Nobi_Prizue

Florida's costliest storm ever, massive flooding in Pakistan and South Korea, deadly heat waves across Europe—recent headlines attest to natural hazards that continue to catch us off guard.

Scientists and forecasters often see these events coming but not early enough or in enough detail to provide clear, accurate warnings. To better understand, monitor, and forecast natural hazards, their potential effects on people, and how they will change in a warming climate, scientists need environmental observations from many sources. These data must be not only collected but also available, accessible, timely, and trustworthy.

Maps, graphs, models, and other data products created from satellite observations play critical roles in forecasting because of the wide, often global-scale coverage they provide [*National Academies of Sciences, Engineering, and Medicine*, 2018]. In addition to helping us study natural hazards, satellite data products support other activities in Earth science, including a wide range of basic research; artificial intelligence and machine learning applications; education and outreach endeavors; and decisionmaking by community and government leaders, resource and hazard managers, and others.

Though powerful, these products aren't perfect, and they are always being verified and improved using environmental data collected worldwide from the ground, air, and sea. To advance satellite data products and their benefits for Earth science and society, the use of observations collected by the global scientific community must be maximized. The European Union's planned digital twin of Earth, for example, aims to integrate all available global observations for model development and applications. This type of integration can transcend institutional barriers and be applied to other areas of Earth science as well.

However, despite many international efforts aimed at maximizing the use of satellite observations—by the World Meteorological Organization, the Committee on Earth Observation Satellites (CEOS), and the Open Geospatial Consortium (OGC), for example, significant obstacles to integrating and sharing data from disparate global sources remain [*Hills et al.*, 2022]. An innovative data infrastructure for gathering and sharing data that meets the criteria outlined below could help overcome these obstacles.

The Interplay of Satellite and in Situ Data

Since the dawn of the satellite era in the 1960s, scientists have relied on in situ observations gathered by organizations around the world to develop and improve satellite data products for research and operational use. Observations from weather stations and radar networks, for example, help validate the

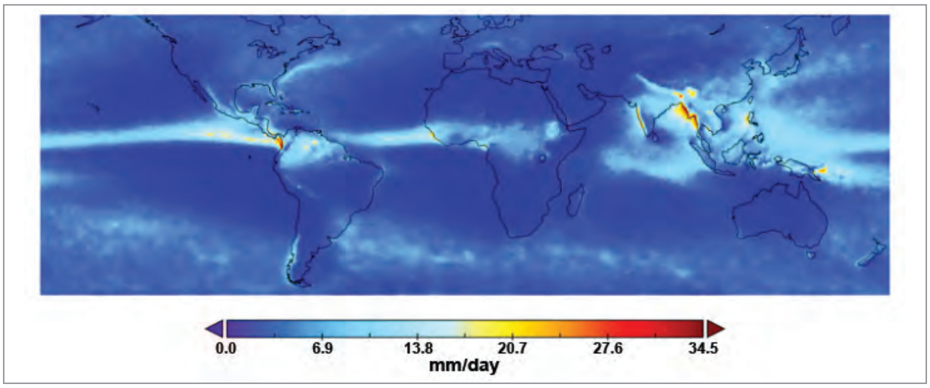


Fig. 1. This map displays average boreal summer precipitation from 2000 to 2021 from the Integrated Multi-satellite Retrievals for Global Precipitation Measurement monthly product with rain gauge calibration. The light-colored band circling the equator indicates the Intertropical Convergence Zone, and the effects of the Indian monsoon are visible around the Indian subcontinent and Southeast Asia.

accuracy of satellite measurements of temperature, precipitation, and soil moisture. However, collecting and providing in situ observations on a global scale are difficult and often costly, especially when it comes to observing vast remote regions on land and at sea.

Satellite-based products, in turn, play an important role in filling gaps where in situ data are sparse or not available and in improving understanding of Earth system processes across the whole planet [*National Academies of Sciences, Engineering, and Medicine*, 2018]. Even with the combined capabilities of satellite and in situ data, though, many data gaps still exist.

Scientists often use observations from multiple satellites as inputs in their product development in conjunction with in situ observations [*Kidd et al.*, 2021]. For example, NASA's Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG) product suite relies on observations from dozens of domestic and international satellites (Figure 1) [*Huffman et al.*, 2019]. These satellites—including the Tropical Rainfall Measuring Mission and the Global Precipitation Measurement mission, which provide core calibration and evaluation data for IMERG [*Huffman et al.*, 2019]—supply observations from several types of onboard sensors (e.g., infrared, passive microwave, and radar) to support global precipitation estimates.

IMERG products also use data from rain gauges on the ground to correct for biases in the satellite data, which can overestimate or underestimate precipitation. These rain gauge data come from the Global Precipitation Climatology Centre (GPCC), which reports precipitation measurements from more than 6,000 gauge stations around the world.

Despite efforts like those of GPCC to collect in situ data, local and regional in situ observations that could extend the use of products like IMERG are not collected in many areas or have not been integrated and made publicly available by other organizations. Attendees at a recent International Precipitation Working Group meeting noted that this lack of data integration and sharing presents a major obstacle to improving satellite-based precipitation products.

Despite many international efforts aimed at maximizing the use of satellite observations, significant obstacles to integrating and sharing data from disparate global sources remain.

Barriers to Data Usability

To address challenges of data sharing, various public and private organizations have previously established Earth science data repositories to provide access to data online. For example, the NASA Earth Observing System Data and Information System (EOSDIS) provides data from NASA satellites (e.g., through the IMERG suite), models, and field campaigns free of charge to the global user community.

Similar data repositories and efforts by other U.S. and international government agencies and organizations exist, such as NOAA's Open Data Dissemination program. And a number of catalog services, such as data.gov and the CEOS database, have been established to provide search capabilities that facilitate data discovery. Also, data availability from nontraditional sources, including commercial sectors and community science activities, has increased rapidly in recent years.

Although these sources have increased data availability, the data in each are collected and curated by the different organizations largely for their own missions or projects, and each repository is unique. Under EOSDIS alone are 12 disciplinary data centers with different portals and designs.

Conducting interdisciplinary work can be challenging because researchers often need multiple data products and services from different data centers. EOSDIS is planning to migrate all its data products to the cloud to simplify the use of its data and facilitate more interdisciplinary activity (e.g., Earthdata Search). Yet in general, existing practices for data collection, sharing, and integration do not transcend organizational barriers, and users are faced with diverse requirements for finding, accessing, and using data and services. Efficient means of data discovery, access, integration, interoperability, reusability, and user-centered services—capabilities laid out in the FAIR (findable, accessible, interoperable, and reusable) data guiding principles [*Wilkinson et al.*, 2016]—have thus not been achieved on a wide scale.

Data Infrastructure That Makes a Difference

Game-changing reforms in data infrastructure are needed to lower barriers and accelerate improvements of data products for Earth science research and applications.

What would such reforms look like?

In short, a successful new data infrastructure would engage the global community to share and use quality-controlled, FAIR-compliant environmental data and services ethically, equitably, and sustainably. It would implement open science practices, which open doors to improve data and information accessibility, efficiency, and quality as well as scientific reproducibility. It would also promote data services supported by open-source software and incentivize data and software sharing by establishing a new mechanism for crediting data providers.

Publicly accessible information-sharing platforms already exist in other areas of society. On YouTube, for example, users can upload videos in any of more than a dozen file formats to share with others around the world without worrying about technical challenges such as data storage and interoperability. Users are responsible for providing services for the content they add, including the descriptive text that appears below each video, responses to comments from viewers, and question-and-answer sections. Such platforms can serve as examples for Earth science data sharing, but there are several challenges.

Open Data You Can Trust

One such challenge involves data integrity. The infrastructure of a new data-sharing platform would provide the convenience of allowing everyone to upload and share their data, but that could open it up to potential misuses, including submissions of incomplete or fake data. Ensuring the veracity and completeness of data would be critical to successfully implementing a new data infrastructure. Certifications for trusted repositories, such as that provided by the International Science Council's World Data System, would help in this effort, as would a user identity vetting process and a user system for reporting abuse.

Ensuring data ethics (e.g., ethical collection, ownership, storage, distribution, and use of data) is another issue for a new infrastructure to address [e.g., *Carroll et al.*, 2021]. Procedures would be needed to prevent users from uploading data without the owner's permission, for example, or in violation of laws or codes of conduct. Ultimately, data submitters would be responsible for their own actions, but a built-in, self-detecting mechanism in the infrastructure could also help minimize violations.

A user-driven data-sharing infrastructure is an ideal place to implement open science principles. Several organizations have developed open science policies, elaborating on how to make data transparent, accessible, and inclusive. Others, such as OGC and the International Organization for Standardization, have issued standards, recommendations, and best practices for Earth science data. Implementing such policies and standards could be challenging because imposing cultural changes (e.g., standard requirements for metadata) on the scientific community is difficult. A new infrastructure should leverage these existing resources without reinventing the wheel.

Heterogeneous data present still another challenge. Earth scientists usually produce data in formats and with structures, units, and vocabularies specific to their domains or specializations. In an environment where all these formats coexist, integrating data and making them interoperable for interdisciplinary activities are difficult. In a new infrastructure, information and tools (e.g., the Integrated Ocean Observing System Compliance Checker) must be available to guide data providers in preparing their data, including metadata, so that they meet community standards before they are submitted to the system.

In addition to addressing the above challenges, it is critical that a new infrastructure meet the following three criteria:

First, it needs an open-source approach to software development to best leverage resources from the entire global community (rather than from only a subset with access to costly or proprietary software) and to avoid repeated development and achieve the goals of open science. Guidelines for software development must be established in accordance with the FAIR principles and open science standards.

Second, it needs to provide a rich collection of data services, which would be a major motivation and incentive for users to submit and share their data. For example, new ground-based radar data products can be generated by merging data submitted by users around the world and used to improve estimates of precipitation. Meanwhile, users can use tools like NASA's Giovanni to explore, visualize, and analyze data without downloading it and accompanying software. Another example is to allow transformation into analysis-ready, cloud-optimized data for analysis in the cloud [*Stern et al.*, 2022].

Third, a new infrastructure needs a mechanism by which credit can be attributed clearly and equitably (e.g., to meet requirements of ethical data practices) to all those involved in generating and providing data, which should further incentivize organizations and individuals to make contributions. With the implementation of open science practices, all work, data, and software should identify credits, and their provenance must be automatically traceable.

Engaging the Global Community

The vast amount of data, scaled-up services, and computing capabilities of the proposed data infrastructure will require a cloud-based platform to host it all, likely making it an expensive endeavor. A big question must be resolved before the global community will see the benefits: Who will cover the costs? We envision the scientific community working together with a consortium of public organizations and private enterprises as the best option for developing and sustaining the infrastructure.

If it is created, we believe the new data infrastructure will engage much more of the global community than is currently represented in existing Earth science data repositories. The increased availability and accessibility of integrated and open data from governments, research institutions, the private sector, and other sources could then accelerate development of satellite and other data products to help address natural hazards and other pressing global challenges.

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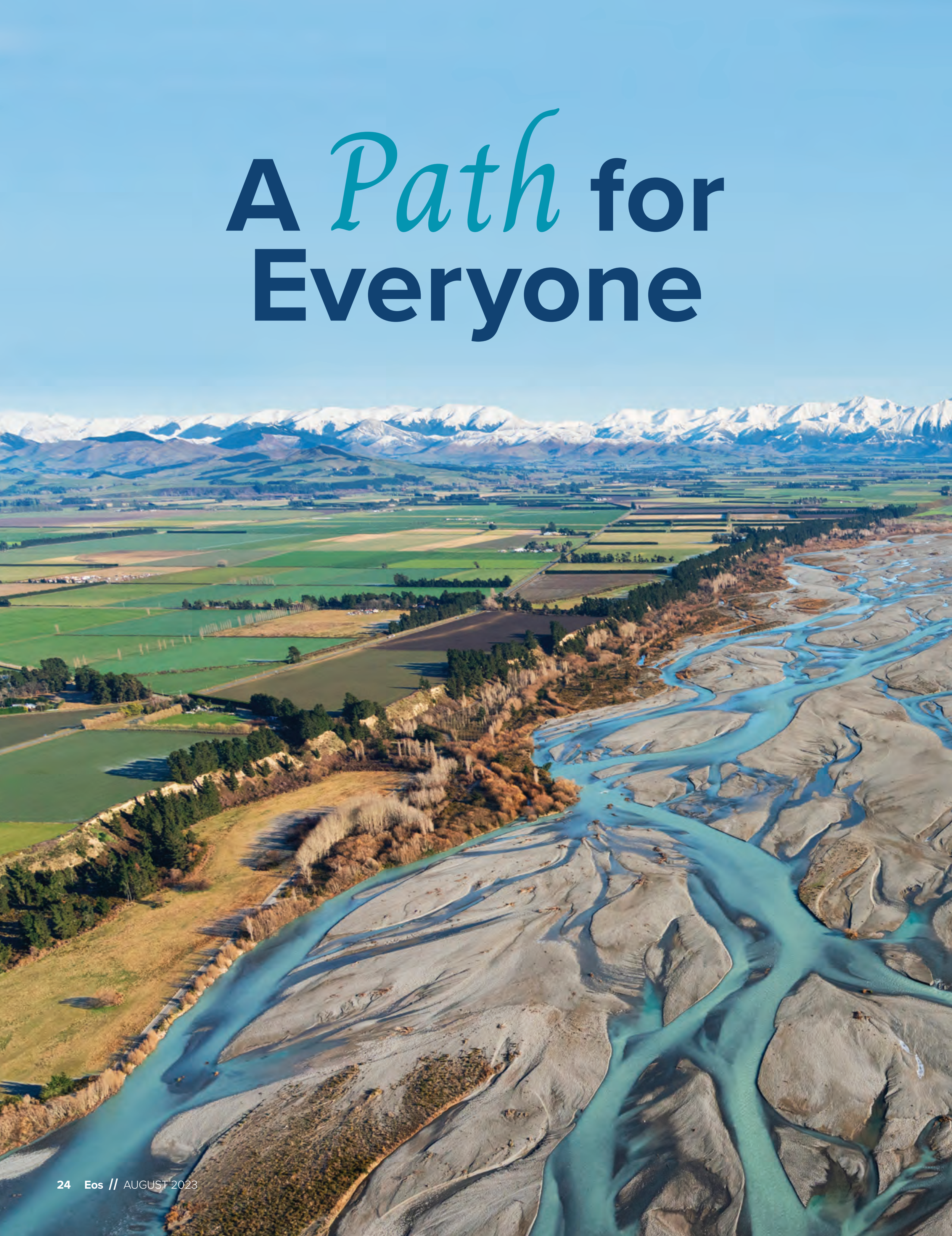
A *Path* for Everyone



What does a geoscientist do?

Yes, Earth and space scientists work at lab benches, but they also design experimental plots, explore exoplanets and ocean depths, and use supercomputers and Secchi disks. Options are plenty, and adventures abound.

Here find the stories of 14 individuals who found their niche in the geosciences. Like the waters of a braided river, these professionals made leaps and pivots but steered a course to success. They travel the streets of New York City, the *Star Trek* universe, and the virtual stacks at the U.S. Geological Survey, among other places.

Read about an environmental scientist who scales structures in the name of air quality, an expert in high stakes project management, and a lab manager whose lively interest in geology was spurred by a trip to Death Valley. Learn how people make data beautiful, approachable, and lasting. Find out how determination (and a bit of luck in the buffet line) can change a scientist's life.

This group shows us that science is about taking chances, getting creative, and venturing into the unknown, and we are thrilled that they are sharing their stories with us. We hope that their journeys encourage you to keep exploring.

—The Editors

ALINE GHILARDI

Fighting Against Colonialism and Sexism in Paleontology

The Brazilian scientist is one of the leading voices in the movement to bring a rare fossil back to Brazil.

Aline Ghilardi, shown here in 2015 at the Museum of Paleontology Plácido Cidade Nuvens in Santana do Cariri, Brazil, is working to repatriate a fossil of a feathered dinosaur to Brazil. Credit: Aline Ghilardi

Aline Ghilardi doesn't remember when she decided to become a paleontologist. "I also don't remember a time in my life [when] I didn't like dinosaurs," she said.

Born in the mid-1980s, the researcher said her passion for the deep past took root even before *Jurassic Park* was released in 1993. "I found out what I wanted to be when I first heard about a dinosaur museum that was going to open in Peirópolis, Minas Gerais State, Brazil," Ghilardi said. "I insisted so much on going that my father took me there—only to find out that construction had just started and there was nothing to see. I broke out in tears," she recalled.

Ghilardi was about 5 years old at the time, and her father had driven her about 200 kilometers (120 miles) from their home in Ribeirão Preto. But the trip was not totally for nothing, as Langerton Cunha, an associate of the groundbreaking Brazilian paleontologist Llewellyn Ivor Price, had a cottage in front of what is Peirópolis's Dinosaur Museum today. Ghilardi's father knew Cunha and decided to stop for a chat. Cunha was moved by the child's disappointment. "He showed me a dinosaur egg, and that changed my life forever," Ghilardi said.

With Brazil lacking any specific university curricula in paleontology in the 2000s, Ghilardi took an undergraduate course in biology at the Federal University of São Carlos. She stayed for a master's degree and studied megafauna fossils found inside caves in the Ribeira Valley in southeastern São Paulo State.

"My father used to say this was a career for men, and I just saw male paleontologists on TV," she recalled. "So as a kid I thought only men could get there."

A 1990s *Paleoworld* episode with Anusuya Chinsamy-Turan, a woman paleontologist from South Africa, showed her otherwise.

At one point while working toward her doctorate at the Federal University of Rio de Janeiro, Ghilardi almost gave up her scientific career following episodes of harassment. It took time and a move away from Rio to heal from the depression in which she found herself. "Harassment takes an immense toll on our mental health. And the hardest part is that this is normalized in academia—the people who harassed me are still there," she said.

"He showed me a dinosaur egg, and that changed my life forever."

Ghilardi is currently a professor in the geology department of the Federal University of Rio Grande do Norte in northeastern Brazil, where she studies vertebrate paleoecology and paleobiology. She was one of the leading figures behind efforts to return the fossil of a feathered dinosaur—*Ubirajara jubatus*—to Brazil. The specimen was collected from the Araripe Basin in northeastern Brazil and allegedly smuggled to Germany in the 1990s. The state of Baden-Württemberg, where the museum holding the fossil is located, ruled that *Ubirajara* be returned to Brazil after public outcry.

Ghilardi is an active voice against science colonialism in Brazil and throughout the Global South. "Our fight now is to develop paleontology in the Brazilian northeast and train researchers in the Araripe Basin so we can value the fossiliferous heritage in the region," she declared.

By **Meghie Rodrigues** (@meghier), Science Writer

ED HAWKINS

Communicating a Changing Climate

The British scientist is the creator of climate stripes, the now-ubiquitous visual representation of climate change.

The Reading Football Club jersey sports climate stripes, which resulted from a collaboration between climate scientist Ed Hawkins and author Nicola Davies. Credit: Reading Football Club and University of Reading

A set of vertical stripes progressing from shades of blue to red and purple has become a symbol of Earth's changing climate.

Emblazoned on items ranging from the sleeves of soccer jerseys in England and beer cans in Arizona to a climate handbook and knitted scarves, climate stripes are a widespread phenomenon that has engaged people in conversations about the warming world. The stripes' creator, Ed Hawkins, is a climate scientist at the University of Reading in the United Kingdom.

An astrophysicist turned climate expert, Hawkins realized he wanted to become a scientist in his teenage years. "I used to read lots of popular science books and magazines and became fascinated by the stories of people and the discoveries they were making," he said.

In the mid-1990s, Hawkins earned a master's degree in astrophysics and then moved on to a Ph.D. at the University of Nottingham.

"I loved astrophysics, and I still do," Hawkins said. "But at the same time, I felt I needed something that could be more directly useful to people."

"I felt I needed something that could be more directly useful to people."

Hawkins isn't sure what made him realize that studying climate was a viable option, but he decided to pursue another master's degree, this time in climate science at the University of Reading.

It wasn't hard to find common ground between astrophysics and climate change. "They are both observational sciences, as you can't do controlled experiments," he said. "Just like we have models for the weather and climate, there are models for the universe in astrophysics." These similarities, he recalled, smoothed what could otherwise have been a bumpy transition.

"I think it is very helpful to bring people from outside the [climate] field to provide fresh perspectives and bring in new techniques and insights," he said.

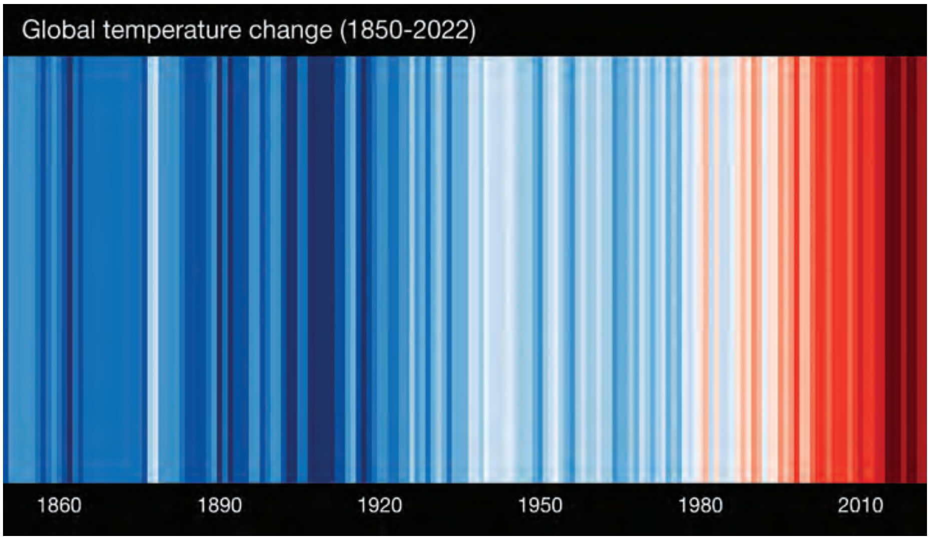
One of Hawkins's fresh perspectives translated into a success story in climate communication. Climate stripes sprang from a collaboration with children's author and poet Nicola Davies at the 2018 Hay Festival of Literature & Arts in Wales. The stripes evolved from a spiral representation that Hawkins had already been using since 2016 to convey the climate urgency message and had already gone big; the visual had been displayed at the opening of the 2016 Summer Olympics in Rio de Janeiro.

Being a visual learner helped Hawkins think about how to communicate climate data. "When I started, I had to learn very fast about climate science [to advance] in my new role, so making visuals was always something interesting to me," he shared.

"I'm really glad about the stripes' power to start conversations about climate change."

Hawkins's work has given him wide recognition, including the Royal Meteorological Society's Climate Science Communication Award in 2017 and a Member of the Order of the British Empire appointment in 2020.

"I'm really glad about the stripes' power to start conversations about climate change," Hawkins said.



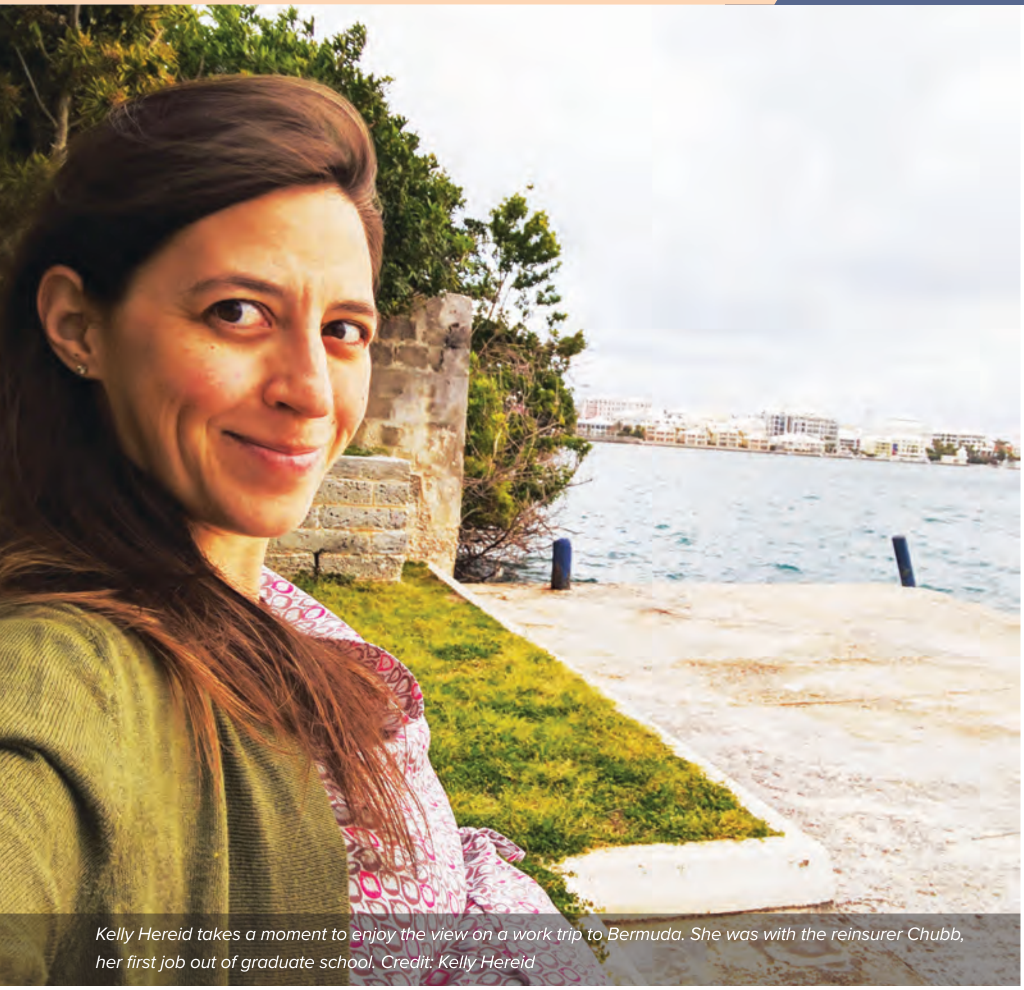
These stripes, representing average global temperatures for the period 1850–2022, change from mainly blue to mainly red in recent years, illustrating the rise in average temperatures. Credit: Ed Hawkins, University of Reading, CC BY 4.0 (bit.ly/ccby4-0)

By **Meghie Rodrigues** (@meghier), Science Write

KELLY HEREID

Modeling Catastrophes for Insurers

A geoscientist helps homeowners and businesses adapt to worsening wildfires, storms, and floods.



Kelly Hereid takes a moment to enjoy the view on a work trip to Bermuda. She was with the reinsurer Chubb, her first job out of graduate school. Credit: Kelly Hereid

Six months before finishing her doctorate in coral paleoclimatology, Kelly Hereid was about to make a career pivot. She'd just been contacted by a reinsurance company—a firm that sells insurance to other insurance companies—about a job opening. Surprised, she googled reinsurance and liked what she saw: an industry at the front lines of climate change adaptation. Now, 10 years later, Hereid serves as the director of catastrophe research and development at Liberty Mutual Insurance.

She googled reinsurance and liked what she saw.

Hereid remembered writing in her first-grade journal that she wanted to be an entomologist. "I couldn't spell it," she said. She drew bugs, birds, and plants in homemade field guides and volunteered at a butterfly house. She majored in both biology and geology at Carleton College in Minnesota but didn't know what a career in science entailed.

With encouragement from professors at Carleton, Hereid headed to the University of Texas at Austin for a Ph.D. in coral paleoclimatology. Nearing the end of her degree, she posted her resume to a career portal for the AGU Fall Meeting, which ultimately led her to reinsurance.

On a typical day at Liberty Mutual, Hereid might work on many natural hazards, including earthquakes in Colombia, hailstorms in Texas, and wildfires in California. She uses catastrophe models, which are statistical models that simulate hypothetical disasters and their impact on the built environment. For instance, her model might simulate how a single-family two-story wood frame house located a mile from a coast would fare in a storm.

On a typical day at Liberty Mutual, Hereid might work on earthquakes in Colombia, hailstorms in Texas, and wildfires in California.

Hereid had dreamed of teaching science at a liberal arts school after her time at Carleton, but she does her own type of teaching now. "I probably give 40 climate talks a year," said Hereid, who speaks to audiences in government, industry, policy, and media.

Hereid frequently advises academics shopping for private-sector jobs. For instance, she studied El Niño and La Niña events in corals. El Niño and La Niña suppress or encourage hurricanes, influencing an insurance company's bottom line. Outlining these connections helped propel her into the private sector.

More private-sector opportunities for geoscientists are on the horizon. "The demand for climate-related expertise has absolutely skyrocketed in the last 2–3 years across the entire financial sector," Hereid said.

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

HIG HIGMAN

Trekking Across the Last Frontier on the Hunt for Geohazards

Higman specializes in human-powered research expeditions in Alaska's epic landscape.

Bretwood "Hig" Higman lives with his wife, Erin McKittrick, and two kids in a converted yurt in Seldovia, a community of 235 people on Alaska's Kachemak Bay. It's an unlikely place for an academic, seeing as there are no roads into or out of town. But then again, Higman has an unlikely career.

"I've spent my life wandering around in circles, bumping into things," he joked.

"I've spent my life wandering around in circles, bumping into things."

Higman primarily works with his nonprofit, Ground Truth Alaska, which specializes in human-powered research expeditions. On these treks, he and others refuse the convenience of helicopters and bush planes, instead reaching study sites by sledding, skiing, bushwhacking, and packrafting over the landscape.

It's a unique specialty he's developed since earning a Ph.D. in geology at the University of Washington. Less than 24 hours after signing his dissertation, he and McKittrick started a trek from their Seattle front door to the easternmost outpost of the Aleutian Islands.

Since that 1-year pack-and-paddle adventure, Higman has completed dozens more human-powered research expeditions for his clients and collaborators. Experiencing the landscape and meeting with its residents provide a narrative backbone for advocacy and research, he said.

His main research interest is geohazards.

In Alaska, thawing permafrost and retreating glaciers are destabilizing mountain slopes. He places dozens of sites in the "terrifying" category, including Barry Arm, a fjord near the town of Whittier whose hillside periodically moves centimeters per day.

"That could potentially be the next tragic story of the geohazards world," he said.

"I try to wear that community member hat just as prominently as the scientist hat."

In his career, Higman has learned the necessity of community engagement. Some Whittier residents first heard about the Barry Arm threat from the *New York Times*, not from the experts researching nearby. That lack of communication breaks public trust, Higman said, and it's why he prioritizes collaboration with communities.

"I try to wear that community member hat just as prominently as the scientist hat," he said. With a lifestyle rooted in small-town Alaska, it's possible to do both.

By **J. Besl** (@J_Besl), Science Writer

Bretwood "Hig" Higman stands on a landslide hummock on the shore of Taan Fjord. In 2015, the landslide visible in the background triggered a 193-meter (633-foot) tsunami in the area. Higman works to research and respond to geohazards in Alaska. Credit: Bjorn Olson, Ground Truth Alaska

COLLINS GAMELI HODOLI

Air Quality Is Data Driven

The environmental scientist is making pollution levels public to draw nonscientists into the fight for clean air.

Collins Gameli Hodoli installs an air sensor on a stage used for public events in Westfield, Serekunda, Gambia. Credit: Buba Manjang

Back in 2016, a local news article on air quality grabbed Collins Gameli Hodoli's attention. Hodoli is from Ghana, where thousands of people die each year from the effects of air pollution, he learned. "Why is nobody doing anything about this?" he wondered.

The problem pervaded his own upbringing in the coastal town of Vodza-Keta. Lacking electricity, his family used kerosene lamps for light and charcoal to cook, both of which release particulate matter. And with no waste management system, residents burned trash, further polluting the air.

Neglecting to act would be almost criminal.

Neglecting to act would be almost criminal, Hodoli thought, so he obtained funding from the Ghanaian government to earn a Ph.D. in environment and agrifood from Cranfield University in the United Kingdom, with the goal of finding ways to curtail air pollution.

Ghanaians were unaware of the health hazards they faced, Hodoli realized during his graduate work. While he was still studying, he founded an organization called Clean Air One Atmosphere, aimed at increasing public awareness of air pollution.

The clean air revolution "should be data driven."

Today Hodoli is a lecturer at the University of Environment and Sustainable Development in Somanya, Ghana, as he continues his work with Clean Air One Atmosphere. In collaboration with researchers from Columbia University in New York, he places air quality monitors in public buildings such as schools and hospitals throughout Ghana and nearby countries. Readings appear in a publicly available app called Yakokae, which means "clean air" in Ewe, the native language of Hodoli's mother.

The work is slow. Internet and electricity are intermittent in West Africa, and the sensors need both. Equipment fails, and there's not always someone around to fix it. Despite setbacks, Clean Air One Atmosphere is having an impact. Results from a sensor in the Methodist Girls' High School in Mamfe, Ghana, for example, convinced administrators to plant trees and grass to limit dust and to stop burning trash.

Hard numbers tend to spur action, Hodoli said. That's why the clean air revolution "should be data driven."

By **Saima May Sidik** (@saimamaysidik), Science Writer

EIKO KITAO

Fossil Hunter and Passionate Educator

From uncovering giant ground sloths to helping build a fossil database, Kitao goes above and beyond as a laboratory technician at Santa Barbara City College.

Eiko Kitao visits her field site at Vandenberg Space Force Base along the central coast of California. Credit: Eiko Kitao

When Eiko Kitao brings students to her field site within Vandenberg Space Force Base, she knows the day will be magical. There, on the rugged central coast of California, the group digs up the bones of Pleistocene mammals, including giant ground sloths, mammoths, and saber-toothed cats.

Kitao's journey to unearthing these fossils has been far from conventional. "I did everything backward in life," she said.

A laboratory technician at Santa Barbara City College (SBCC) in California today, Kitao struggled with math and science in her youth. "I used to count on my fingers," she said. "There were so many times I wanted to quit."

"I did everything backward in life."

After high school, Kitao attended Lake Tahoe Community College as a single mom, eventually moving back to her hometown of Santa Barbara, where she enrolled at SBCC.

During a class field trip to Death Valley, everything changed. The fascinating landscape and hands-on experience ignited a passion for geology that would shape her future. "On that trip, something in my mind clicked where nothing ever had before," Kitao said.

Since then, she has pursued her passion with unwavering determination, earning a bachelor's degree in geological sciences from the University of California, Santa Barbara in 2011. Shortly thereafter, she became a full-time lab technician at SBCC, where she continues to use her expertise to help undergraduates learn about geology through field experiences.

After a 2-year pause to earn a master's degree in geography from California State University, Northridge, Kitao has been at SBCC since 2018.

Her passion for teaching is palpable, and her dedication to her students is evident. In addition to working with students, Kitao creates content for courses, hosts community outreach programs, and helps to develop a national database of the college's fossil samples. Her greatest joy is watching her students grow and develop their love of geology, just as she did during her field trip to Death Valley.

By **Mackenzie White** (@MackenzieMtn), Science Writer

CHRISTOPHER KYBA

Luck in Light Pollution

A series of serendipitous encounters shaped Kyba's path from particle physicist to dark sky defender.

Christopher Kyba studies light pollution and sustainable lighting solutions. Credit: Christopher Kyba, © Phil Dera

The first lucky turn in Christopher Kyba's career path happened at the dinner buffet at a particle physics conference. A University of Alberta undergrad, he had presented his research at the conference and spent the week trying—and failing—to arrange a meeting with the head of the Sudbury Neutrino Observatory (SNO) at Queen's University in Ontario. He wanted to ask about a summer internship.

At the end of the conference, he started chatting enthusiastically about his research with a professor standing behind him in the buffet line. Kyba was lamenting that he had never crossed paths with the head of SNO when the professor introduced himself as the exact person Kyba had been trying to meet!

That conversation led Kyba to a summer internship at SNO and to completing his Ph.D. in experimental particle physics at the University of Pennsylvania.

"It turned out that I had exactly the skills that they needed."

Kyba stayed in Pennsylvania for a few more years as a postdoctoral fellow in radiology at the Hospital of the University of Pennsylvania—he had thought he might pursue more medical-focused work with his particle physics skills. But after his postdoc, he and his family decided to relocate to his wife's home country: Germany.

The move coincided with the 2008 global financial crisis, complicating his job search. He took several years of parental leave to raise their daughter while applying for engineering-focused jobs and was eventually asked to interview for a postdoc at Freie Universität Berlin.

When he arrived for the meeting, he and the interviewer realized there had been a mistake: Kyba had been invited to the wrong job interview. The interviewer was embarrassed about the mix-up but asked Kyba anyway, "Well, what do you know about light pollution?" Kyba explained the basic physics of atmospheric light scattering, and the two of them chatted about his background and experience.

Kyba's goal is to become an environmental consultant specializing in sustainable light planning."

"I hadn't come across the job application before because it was written to search for a geographer," Kyba said. "If I had seen the job ad, I wouldn't have applied for it, but it turned out that I had exactly the skills that they needed."

He started working on remote sensing data measuring light pollution in 2009, and it has been his focus ever since. He currently researches light pollution and sustainable lighting solutions at Ruhr-Universität Bochum and the GFZ Helmholtz Centre in Potsdam. He has helped develop several global crowdsourced science projects to study the spread of light pollution from the ground.

Kyba currently is applying for a professorship in Germany and is submitting a new grant proposal to continue his research. He also is looking forward to an internship with a German company that does commercial and municipal light planning.

Kyba's goal is to become an environmental consultant specializing in sustainable light planning. He said the internship is a good way to see whether it is something he enjoys and to gain experience as a consultant.

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

FRANCES LIGHTSOM

Pivoting to Information Management

Frances Lightsom started her career as an oceanographer. Then she found delight in data.

Many perceive publishing as the end of a scientific project, but for Frances Lightsom, the work is just beginning. Lightsom is an information manager for the U.S. Geological Survey (USGS): She helps scientists publish and release their data, then makes sure the data are easy for citizens and other scientists to find.

Information was not Lightsom's first love, however. Instead, she was fascinated by how water moves. Growing up in Tennessee, she could often be found canoeing, wading in streams, and moving rocks to see how the current would circumnavigate them.

"I got to enjoy thinking about the data without having to write all the papers!"

This fascination led her to earn a bachelor's degree in geology and physics from Oberlin College, then a Ph.D. in physical oceanography from the Massachusetts Institute of Technologyand the Woods Hole Oceanographic Institution. Lightsom's research varied widely during graduate school and subsequent university teaching positions, from asking how water moves deep in the submarine Hudson Canyon, which lies off the coast of New Jersey, to how hurricanes affect sewage outflow.

Often the schedule was intense. Lightsom worked many 60-hour weeks and went on research cruises with little notice. When she became a mother, she knew it was time to pivot.

Information management brought Lightsom a new type of delight: "I got to enjoy thinking about the data without having to write all the papers!" Over the years, she has ensured that USGS data are accompanied by the appropriate metadata, maintained a library of nondigital data, and devised systems that allow USGS scientists to standardize data management.

Her career has been "an opportunity to make sure that science is relevant."

As Lightsom contemplates retirement, information management is taking off. FAIR (findable, accessible, interoperable, and reusable) and open research practices are gaining momentum, creating demand for computer-savvy people who can design, build, and manage databases. At the same time, the field needs people focused on preserving data produced before the digital age.

These positions bring meaning to the scientific method, Lightsom said. Because she ensures that others can find the data scientists have produced, her career has been "an opportunity to make sure that science is relevant."

By **Saima May Sidik** (@saimamaysidik), Science Writer

Frances Lightsom speaks to the United States Geological Survey Community for Data Integration after receiving the 2015 Leadership and Innovation Award. Credit: Keith Kirk

ERIN MACDONALD

Putting the Science in Science Fiction

The "Julia Child of science" makes science accessible through pop culture.

Astrophysicist Erin Macdonald is the science adviser for Star Trek *and runs her own production company, Spacetime Productions. Credit: Erin Macdonald*

"A lot of people would literally assassinate me for what's on my laptop," said Erin Macdonald, only mostly joking.

Macdonald is an astrophysicist, screenwriter, producer, and, thanks to her work as *Star Trek*'s science adviser, guardian of a laptop full of *Star Trek* secrets fans would, figuratively, kill to know. It's her job to handle all things science for the beloved sci-fi franchise, from writing on-screen equations fit for inspection by science-savvy fans to maintaining the internal consistency of "*Star Trek* science," or how fictional technologies like transporters and warp drives work in the *Star Trek* universe.

Macdonald earned her Ph.D. in astrophysics at the University of Glasgow in 2012, working on gravitational waves with the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration and continued this work as a postdoc at Cardiff University. But she ultimately decided that academia wasn't for her and left in 2014, though it wasn't an easy choice.

"I wish someone had told me…outside of academia, you can still inspire people."

"Feeling that I was letting down women probably put my decision to leave academia off by at least a year," she said. Representation matters to Macdonald, who credits her astrophysical aspirations to characters like Dr. Dana Scully of *The X-Files* and Captain Kathryn Janeway of *Star Trek: Voyager*. "I wish someone had told me…outside of academia, you can still inspire people," she said.

While working as an engineer, Macdonald found an outlet for her drive to educate and inspire by giving science talks at sci-fi conventions. And when life brought her to Los Angeles in 2017, word of mouth eventually landed her onstage giving physics talks at official *Star Trek* events. Those talks opened the path to her current position as *Star Trek*'s science adviser.

"I realized I'm not meant to *become* Captain Janeway, I'm meant to *write* Captain Janeway—to inspire," said Macdonald. Going forward, she wants to transition into screenwriting.

Macdonald recently founded a production company, Spacetime Productions, that aims to lift up marginalized people both on screen and behind the camera.

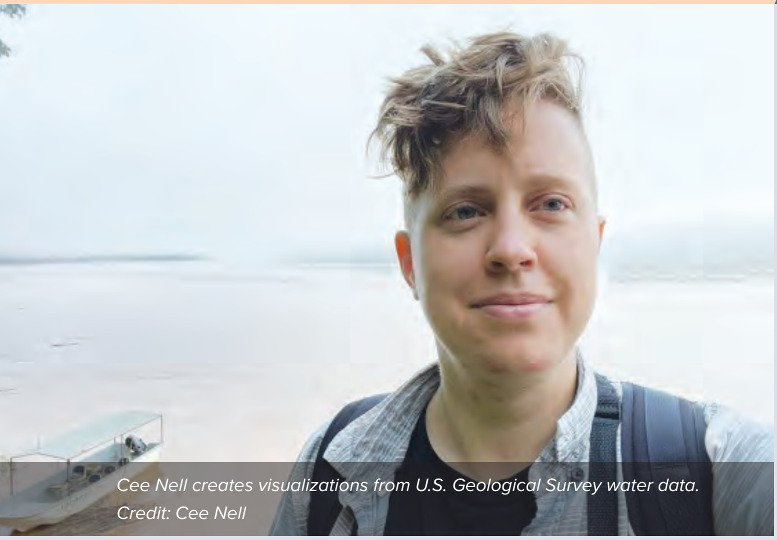
"Being able to integrate science into science fiction, I think, makes science more accessible to a lot of people," she said. "That's really a big mission of mine."

By **Elise Cutts** (@elisecutts), Science Writer

CEE NELL

Making Data Visual

Nell turns vast columns of data into beautiful and understandable graphics.



Cee Nell creates visualizations from U.S. Geological Survey water data. Credit: Cee Nell

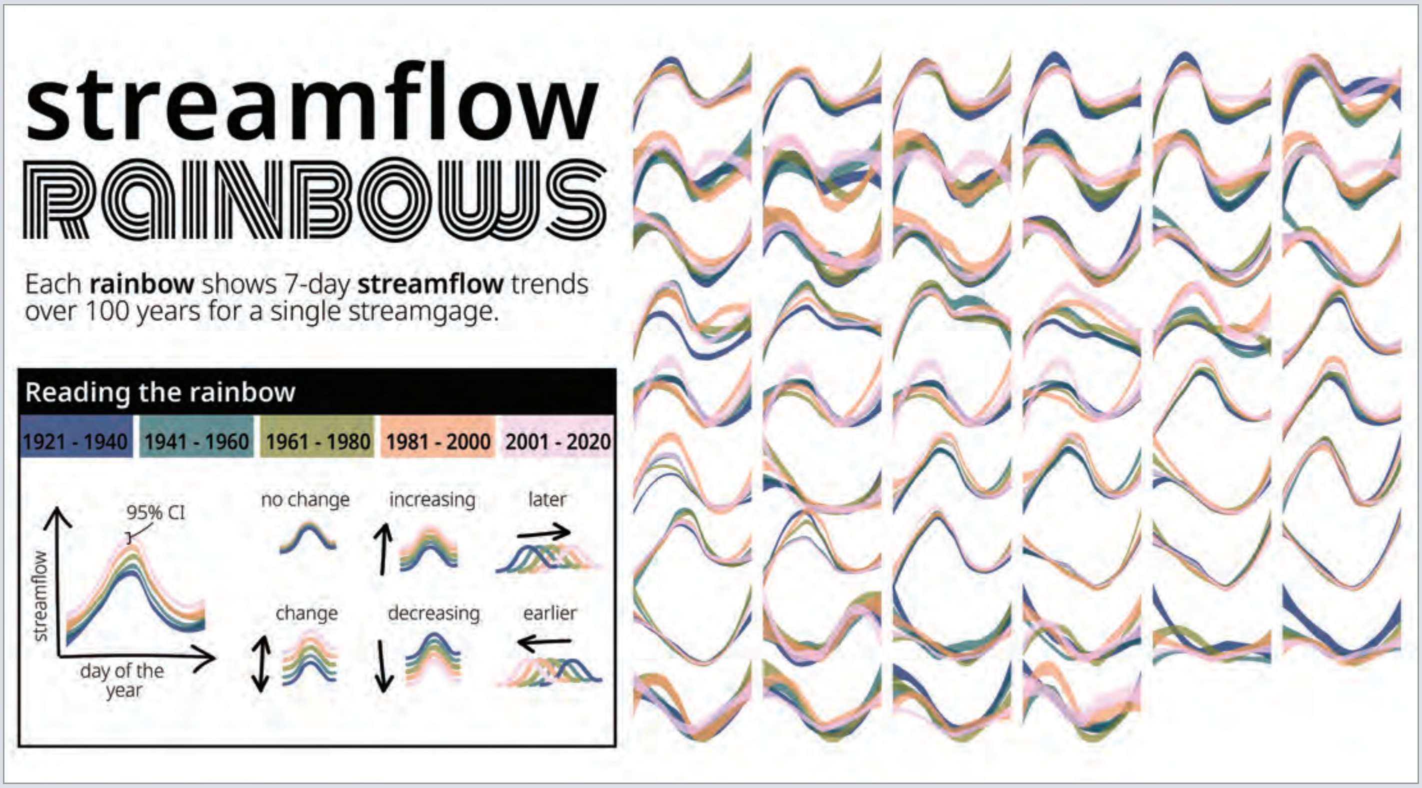
Cee Nell entered graduate school to study tropical birds but emerged entranced by the power of data visualizations. The catalyst was a programming language called R that's used to help parse and visualize large, complex data sets.

R's ability to manage different sources of data and spatial layers and return a compelling graphical representation of what were once just numbers "felt like this very powerful thing to me," Nell said.

"There's this huge need for data visualization at all levels."

While taking data science courses as a Ph.D. student at the University of California, Irvine, Nell used R to make interactive web apps for community groups.

The work reinforced for Nell the transformative power of data visualizations. "That was everything for me. I loved it so much," they said.



Nell created this graphic, which shows 100 years of U.S. hydrologic data as a series of rainbowlike curves.

Now, as the leader of the U.S. Geological Survey's water data visualization team, Nell works with a group of programmers and data scientists to turn data on U.S. waters into beautiful, insightful graphics that communicate complex topics to the public. Collectively, the team has expertise in programming, hydrology, ecology, cartography, illustration, graphic design, and science communication.

"We see ourselves as this visual graphics reporting team, or data journalists, for water science and water data," Nell said.

Nell's portfolio includes a century of hydrological data from streams around the country imagined as a series of rainbowlike curves and a nationwide map showing streamflow changes over the course of a month. In both projects, Nell turned massive data sets into something that can be digested in a few seconds.

"We see ourselves as this visual graphics reporting team, or data journalists, for water science and water data,"

Nell often starts a project by simply plotting every data point and stepping back to see what stands out. Playing with color and layout can help them tease out patterns, and a good visualization proceeds from there, they said.

With its balance of coding and artistic interpretation, a data visualization role may seem like an intimidating mash-up. But the job of making creative, informative representations is more accessible than many imagine, Nell said. And with more data available than ever before, it's a valuable skill.

Today tools such as Excel and Tableau allow even those who don't know R or JavaScript to translate complex data sets into meaningful visualizations.

"There's this huge need for data visualization at all levels," they said. "You don't need to be this really advanced programmer."

By **Nathaniel Scharping** (@nathanielscharp), Science Writer

YAMINA PRESSLER

Slowing Down, Appreciating Complexity, Embracing Soil

Pressler uses art as a way to connect with her science.

Yamina Pressler is a soil scientist and artist. Credit: Yamina Pressler

The ground we tread often gets overlooked or is recognized simply as a place to grow food. But Yamina Pressler sees more. A soil scientist at California Polytechnic State University, San Luis Obispo, Pressler draws inspiration from the soils at her feet.

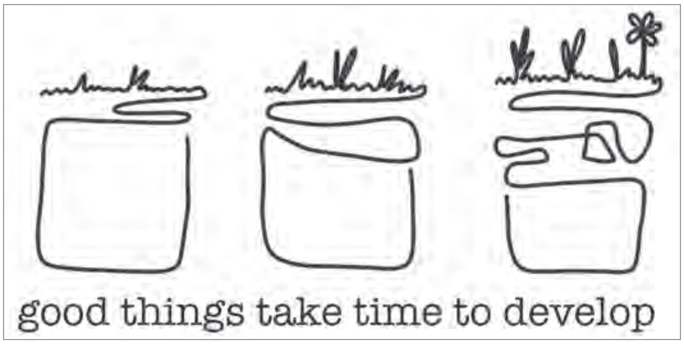
"It's also important for us to view them as a natural wonder," Pressler said.

Pressler's love of soils was planted when she was an undergraduate at the same university where she now works. As an undergraduate studying environmental management and protection, Pressler took a required soil science class and was struck by soils' color and complexity. The child of an abstract painter, Pressler found herself drawn to the pinks, oranges, and yellows she saw in the ground: "all of these bright whimsical colors."

Pressler followed her curiosity about soils, doing a senior research project on soil microbes and venturing on to graduate school. Though she didn't have scientists in her family, Pressler found encouragement from mentors who helped her navigate a career in science that she hadn't anticipated.

Even though Pressler grew up surrounded by color and creativity, she didn't start calling herself an artist until 2019. That year, she tried watercolor painting to calm her nerves during air travel. As she splashed colors across the page, scenes of soils emerged. The trip kicked off a passion for creating and sharing art grounded in soils, some even painted with soil-based watercolors.

Her works celebrate the diversity of soils and encourage people to look at them in a new way. They often capture musings on what soils can teach us.



Pressler's art is inspired by soils. Credit: Yamina Pressler

One of Pressler's digital line drawings evokes the chemical and biological transformations that create layers called horizons, which can be charismatic and colorful. Soils grow in complexity over time. It's a reminder that like all good things, soils take time to develop, Pressler said.

To conserve and protect soils, people first need to care about them, she said. So looking to soils for instruction is a way to rebuild a relationship with this crucial part of the natural world. "Soil has so much to teach us—as soon as we kind of slow down and listen," she said.

By **Carolyn Wilke** (@CarolynMWilke), Science Writer

JOSE ROLON

READY FOR ANY EMERGENCY

An emergency manager for New York City Emergency Management, Jose Rolon deals with the controlled chaos that follows a disaster.

"I would say that there is no typical day," said Jose Rolon, sitting in a car parked somewhere in the Bronx, the borough of New York City to which he'd been assigned that morning. He needed to be in position, ready to go if a call came in. "I might be responding at any moment," he said.

A citywide interagency coordinator at New York City Emergency Management, Rolon describes his work as something like being a project manager for emergencies. Whether facing a fire, a blizzard, a terror attack, or a blackout, he is responsible for coordinating the different agencies—such as the fire department and city utilities—that might need to react to a crisis.

On any given day, Rolon might be organizing or participating in trainings, flying drones to collect vital information for emergency response, meeting with agency officials, or sitting ready to respond quickly when disaster strikes.

Rolon traces his career in emergency management back to 11 September 2001, when he watched smoke rise from the World Trade Center from a window of his Brooklyn high school. He joined the U.S. Army shortly after graduating and served in the Civil Affairs and Psychological Operations Command, coordinating humanitarian efforts and disaster response for civilians.

Once back in New York, Rolon became a firefighter for the New York City Fire Department in 2008—a job that gave him a practical education in emergency management, he said. He pursued more theoretical education too, earning a bachelor's degree in fire and emergency management in 2017 and a master's of public administration in emergency management in 2020, all while working fullZtime as a firefighter and part-time in the Army Reserve.

Rolon said that being an interagency coordinator actually has him working much more closely with disaster victims than he did as a firefighter. Helping someone through what could easily be one of the worst days of their life, he said, keeps him going when things get tough on the job.

To anyone considering a career in emergency management, "I would tell them to go for it," said Rolon. "There's a lot of positions out there. And we need new young people ready to come in and change [emergency management] for the better."

"There's a lot of positions out there. And we need new young people ready to come in and change [emergency management] for the better."

By **Elise Cutts** (@elisecutts), Science Writer

Read these profiles at Eos.org

JEN WALTON

Chaser of Storms and Lava

For many years, Jen Walton helped scientists share their work as a communications manager. But the Denver resident also harbored a deep secret.

"I just really wanted to go see a tornado," she said. "Severe weather has always been a passion."

Walton repeatedly tried to convince storm-chasing scientists to take her with them. But those trips never panned out. In 2018, shortly after being diagnosed with type 1 diabetes, Walton decided to stop waiting.

That summer, she joined a storm-chasing tour that took her to Montana, South Dakota, and Wyoming. When she got back, Walton learned how to read radar

Jen Walton photographs a storm brewing in eastern Colorado.

Walton founded Girls Who Chase to promote women in STEM.

data from a meteorologist at NOAA's National Severe Storms Laboratory. Before long, she was packing supplies, camera gear, and food into her Honda CR-V and driving east to chase extreme weather herself.

While documenting the fury—and beauty—of storms, Walton met fellow chasers. The chasing community has its own unique way of socializing, she said: "Typically, you go out to dinner to see your friends. We drive to the middle of nowhere to see ours." Walton was surprised to encounter other women storm chasers.

Women, when they are included in magazine articles or TV shows about storm chasing, are commonly portrayed as a tagalong sidekick or girlfriend, she said. "I had kind of internalized that."

In 2021, she created an Instagram page highlighting women storm chasers. There was an immediate positive response. "The chase community just kind of went nuts over it," said Walton.

Walton spent the next several months developing a platform called Girls Who Chase, which now encompasses a website, podcast, and workshops for people interested in learning how to chase storms.

Today Walton describes herself as a storm and volcano chaser, photographer, and entrepreneur. Her work regularly takes her to the Great Plains, and in 2022 she traveled to Hawaii to document the eruption of Mauna Loa. Walton takes great pride in collaborating with the National Weather Service. Her on-the-ground observations of storms provide data for future decision-making and training, she said.

Hearing from readers and listeners who are inspired by Girls Who Chase is extremely rewarding, Walton said. "That's the stuff that gets me up in the morning."

And the best way to finish off the day? Walton answered like a true weather nerd: "My ideal day ends with a very photogenic supercell."

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

Credit: Matt Hollamon Photography

DAWN WRIGHT

Diving Deep to Discover the Secrets of the Ocean

The chief scientist at Esri wound her path into and out of academia.

Since she was 8 years old, Dawn Wright knew she wanted to be an oceanographer. In 2022, she became the first Black person to visit Challenger Deep, the bottom of Earth's greatest ocean abyss.

Today, Wright is chief scientist at Esri (purveyor of ArcGIS, the mapping tool ubiquitous in the geosciences.) As a child born in Maryland but raised in Hawaii, Wright watched the *Undersea World of Jacques Cousteau*, devoured novels, and wondered at Apollo missions taking men to the Moon.

"I thought about being an astronaut for about 5 minutes, but then I immediately pivoted back to wanting to explore the deep sea," she said. "I thought, 'If those men could make it to outer space and explore the Moon, why can't I go in the opposite direction and explore the deep ocean?'" So she did.

After Wright completed an undergraduate degree in geology and a master's degree in geological oceanography, she began working as a seagoing ocean technician for the Ocean Drilling Program (now the International Ocean Discovery Program) on board the drilling ship *JOIDES Resolution*. For 3 years, she traveled through remote parts of the world's oceans to sample the seafloor. Along the way, she saw penguins and icebergs, visited intriguing ports, and even played the role of shipboard Santa.

When Wright left to pursue her Ph.D. at the University of California, Santa Barbara, her reputation as a seafaring scientist preceded her. One professor, Rachel Haymon, had just returned from an expedition to the seafloor with data collected via cutting-edge software at the time: ArcInfo, the precursor to ArcGIS. Haymon recruited Wright to unlock the information within. "That basically changed my life," Wright said.

> **"If those men could make it to outer space and explore the Moon, why can't I go in the opposite direction and explore the deep ocean?"**

Wright's first journey to the seafloor, during her doctoral studies, was to the East Pacific Rise aboard the submersible *Alvin*. As the first Black woman to dive to the seafloor, Wright incorporated the data into her geographic information system (GIS)–based doctoral research. Using GIS to meld different data sets would be an easy task today, but in the 1990s, that had not been done with deep oceanographic data, she said.

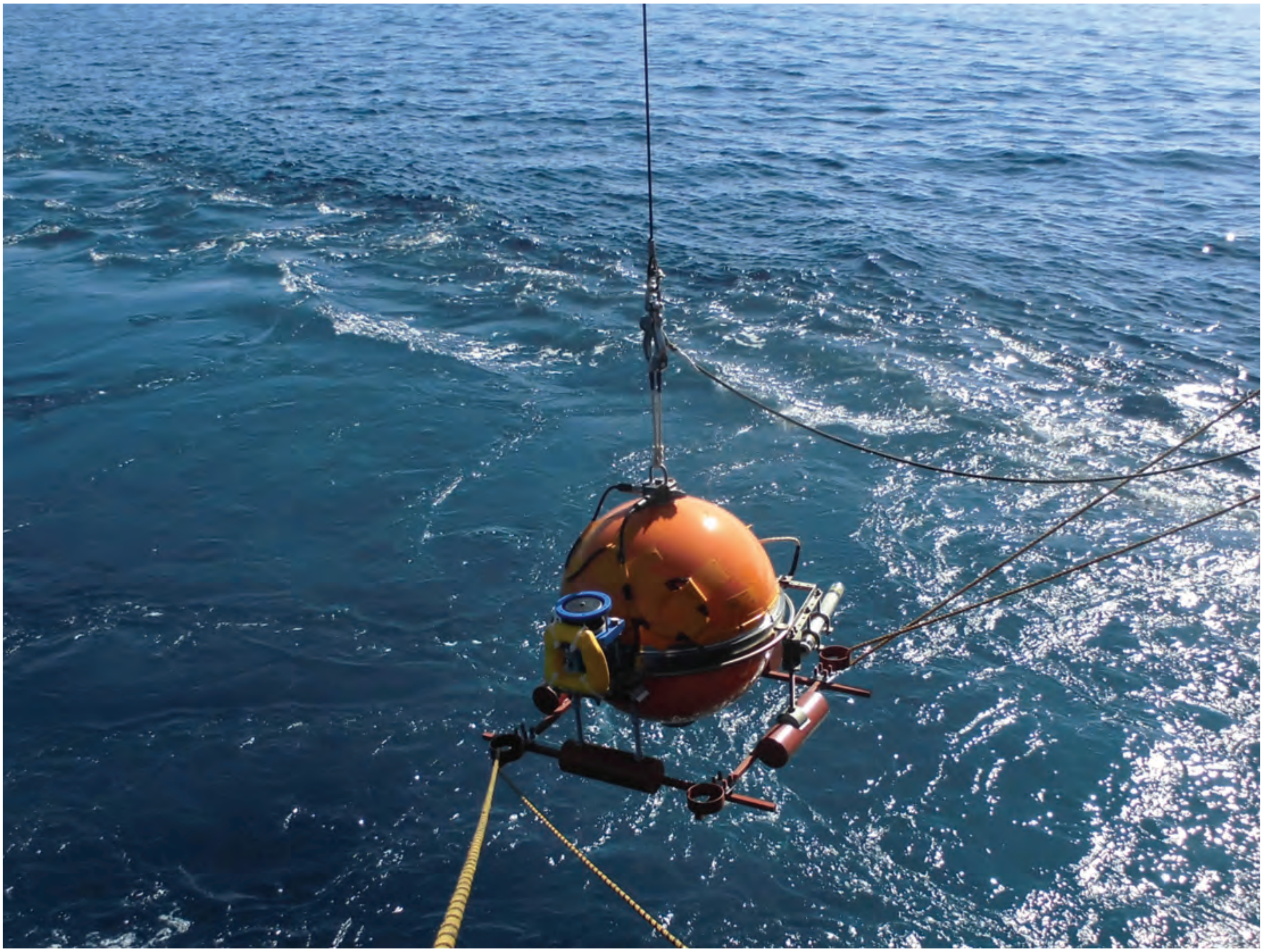
Wright went on to spend 17 years as a professor at Oregon State University, where she ran her own lab, aptly named Davey Jones' Locker. In 2011, she received a letter from Esri's president and chief software architect asking whether she would consider coming to the company. She eventually left academia, describing the feeling as exhilarating. "There are so many wonderful paths, and you do not have to be a clone of your professor," she said.

Dawn Wright climbs out of Victor Vescovo's submersible The Limiting Factor, *which took both Wright and Vescovo 10,919 meters (35,823 feet) below sea level, into Challenger Deep. Credit: Dawn Wright*

Now Wright helps Esri connect with scientists ranging from oceanographers to political scientists. "We want to broaden the utility of our software to those communities, but also to participate in those scientific endeavors," she said.

By **Alka Tripathy-Lang** (@DrAlkaTrip), Science Writer

Small-Scale Convection Shuffles the Oceanic Lithosphere



Scientists used data from ocean bottom seismometers to determine how the Japan Basin formed. Credit: Earthquake Research Institute, University of Tokyo

The formation of ocean basins is complex. New oceanic lithosphere forms at mid-ocean ridges as the seafloor spreads, but over time, large basins are influenced by smaller-scale mantle convection, stagnated pieces of lithosphere, and tectonic forces from nearby plates. These factors can produce a solid, outer layer of Earth with different structures at different depths.

In a new study, *Ai et al.* discovered that the Japan Basin beneath the Sea of Japan has two distinct layers. Their findings suggest that the basin formed through seafloor spreading, but its structure was bifurcated and reorganized later by small-scale mantle convection.

The researchers used ocean bottom seismometers to record seismic waves, create a structural model, and see into the depths of the lithosphere.

They discovered a distinct discontinuity in the mid-lithosphere. Toward the surface, seismic wave speeds differed depending on their direction—a phenomenon called seismic anisotropy. However, this directional preference attenuated deeper in the mantle.

The researchers attribute these differences to the structure of the lithosphere. The crystal lattices of the minerals in the upper lithosphere have preferred orientations, which the team says formed during seafloor spreading 20–15 million years ago. That directionality in the minerals' organization produces seismic anisotropy.

After seafloor spreading ceased, convection in the mantle shuffled the orientations of minerals in the innermost lithosphere. The now-jumbled organization reduces the anisotropy at the lithosphere-mantle boundary. Similar small-scale convection could be randomizing the orientation of minerals in regions experiencing seafloor spreading today, the authors say. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1029/2022JB025581, 2023) **—Sarah Derouin,** *Science Writer*

Mapping the Fizzy Brines and Fluid-Filled Fractures Beneath a Volcano

Earth's crust contains pockets of water, metal-rich brines, gas, and molten rock, especially near volcanoes and other sites of geothermal activity. Knowing where these fluids are and their precise composition can help scientists assess volcanic hazards, harness geothermal energy, and find useful metals, but mapping them is not an easy task.

In a new study, *Hudson et al.* mapped geothermal fluids beneath a volcano using earthquake wave data collected by seismometers.

The researchers used data from 1,356 earthquakes captured between April 2010 and October 2012 by 33 seismometers distributed near Uturuncu volcano in the Bolivian Andes. Uturuncu, which rises by about 1 centimeter per year, lies above the world's largest known magma body.

From the earthquake data, the researchers identified fluids based on how the crust absorbed energy from earthquake waves. They measured seismic anisotropy, which describes how the speeds of earthquake waves differ depending on direction. In addition, they used pressure, temperature, and electrical conductivity measurements to narrow down the likely composition of the fluids.

The scientists identified water and metal-rich brines located along faults and fractures. Some of the fluids contained carbon dioxide—similar to sparkling water.

Most of the region's crust was only partially saturated with fluids, although the researchers did find a few fully saturated pockets. They hypothesize that one of these pockets, located southeast of Uturuncu, represents the shallow, cooled remnants of a hydrothermal system that formed during a prior period of active volcanism.

The team also identified a deeper pocket directly beneath Uturuncu, which appears to contain water or metal-rich brines as supercritical fluids. Here the temperature and pressure are so high that the fluids no longer exist as distinctly liquid or gas.

The technique, now shown to be effective, can be used to peer into the fluid world beneath volcanoes in similar regions around the world. (*Geophysical Research Letters*, https://doi.org/10.1029/2022GL100974, 2023) **—Sarah Stanley,** *Science Writer*

A new study mapped fluids in Earth's crust near Uturuncu volcano in the Bolivian Andes. Credit: Ceky/Wikimedia Commons, CC BY-SA 3.0 (bit.ly/ccbysa3-0)

Fine-Tuning Air Pollution Models

Air pollution doesn't affect everybody equally. In a new study, researchers developed a method to improve estimates of how different communities within cities are exposed to fine particulate matter ($PM_{2.5}$).

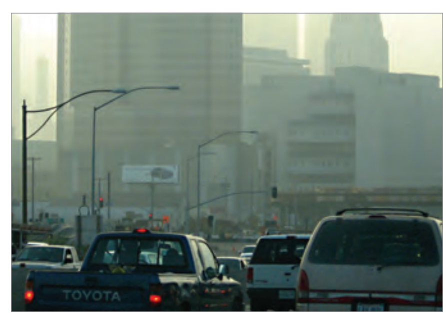
Globally, $PM_{2.5}$ is estimated to cause 4.7 million premature deaths each year, and in the United States, communities of color face the most intense doses.

To assess levels of exposure to air pollution, the Intervention Model for Air Pollution (InMAP) estimates air quality with fine spatial resolution, especially in densely populated areas. Because the model can parse differences in pollution exposure within cities, it can be useful in designing policies that incorporate environmental justice.

However, InMAP underestimates particulate sulfate and overestimates particulate ammonium.

To correct those biases, *Gallagher et al.* developed scaling factors for InMAP using pollution monitoring data collected on the ground by the U.S. EPA and satellite data processed by Washington University in St. Louis. Comparing InMAP's predictions with these data sources allowed them to gauge and correct for errors.

The authors tested how InMAP performed with and without scaling factors, using an established goal of 10% error in its predictions. Without the scaling factors, InMAP underestimated or overestimated $PM_{2.5}$ concentrations by more than 10%. Introducing city-specific scaling factors, however, improved model fit and reduced the error to below the 10% threshold. In addition, the authors found that their method was most effective in the most densely populated areas of cities.



Urban air pollution doesn't affect all residents equally. Credit: SreeBot/Wikimedia Commons, CC BY 3.0 (bit.ly/ccby3-0)

The authors published their scaling factors for public use and recommend they be used when researching how air pollution exposure differs across race, ethnicity, income, and other demographic traits. (*GeoHealth*, https://doi.org/10.1029/2023GH000788, 2023) **—Sarah Derouin,** *Science Writer*

The Greenhouse Gas Burden of Inland Waters

Inland waters (including Crescent Lake in Lake Clark National Park and Preserve in Alaska) are an underappreciated source of natural greenhouse gas emissions. Credit: U.S. National Park Service, Public Domain

In a pair of new studies, a team of scientists reassessed greenhouse gas emissions from rivers, streams, lakes, and reservoirs. The studies update previous estimates of greenhouse gas emissions from inland water sources at a global scale.

A decade ago, the Regional Carbon Cycle Assessment and Processes initiative (RECCAP-1) reported that these water bodies could emit as much as 7.7 petagrams of carbon dioxide (CO_2) each year. Recently, in a pair of papers by *Lauerwald et al.*, the team introduced the inland water chapter of RECCAP-2. This latest effort synthesizes recent emissions estimates to include two additional greenhouse gases: methane (CH_4) and nitrous oxide (N_2O).

The first study reviews state-of-the-art estimates of greenhouse gas emissions from inland waters. The second pairs those estimates with global inland water surface maps to provide regionalized estimates of emissions.

The study's authors found that inland waters contribute 5.5 petagrams of CO_2 per year, of which one third emanates from South American rivers. Meanwhile, inland waters emit 82–135 teragrams of CH_4 annually, one third of which comes from North American and Russian lakes. N_2O emissions were comparatively small at 248–590 gigagrams per year, with a quarter of N_2O emissions coming from North American inland waters.

Inland waters could emit approximately 20% of total annual global CH_4 emissions, the authors found. In contrast, the contributions of inland waters to global CO_2 and N_2O budgets are relatively minor.

These estimates are conservative because they do not include ephemeral water bodies, small wetlands, and water bodies smaller than 0.1 square kilometer, the authors say. Nevertheless, the results will improve climate models and global greenhouse gas budgets while spotlighting natural systems' roles in climate change. (*Global Biogeochemical Cycles*, https://doi.org/10.1029/2022GB007657 and https://doi.org/10.1029/2022GB007658, 2023)

—Aaron Sidder, *Science Writer*

Opposite: Water Resources Mission Area, USGS

Plants Leave Chemical Fingerprints on an Ozone-Depleting Gas

New research suggests that club moss (Selaginella kraussiana) *breaks down atmospheric methyl chloride using an as-yet unknown mechanism. Credit: JMK/Wikimedia Commons, CC BY-SA 3.0 (bit.ly/ccbysa3-0)*

Methyl chloride (CH_3Cl) is one of the most common chlorine-based gases in Earth's atmosphere. Along with related chemicals, it depletes the ozone layer, exposing life on the planet to more of the Sun's ultraviolet radiation. The sources and processes that emit the gas and remove it from the atmosphere are still unclear.

In a new study, *Hartmann et al*. discovered that plants called royal ferns (*Osmunda regalis*) emit methyl chloride with an isotopic composition different from that emitted by industrial sources. Their analysis also revealed that another plant, called club moss, breaks down methyl chloride using an as-yet undiscovered mechanism. Isotope analysis, they say, could help elucidate the distribution of the gas's origins and removal.

The researchers first investigated methyl chloride production by the royal fern, which is common in temperate and subtropical regions and emits large amounts of methyl chloride. They collected and analyzed samples of royal ferns from a botanical garden in Germany.

They found that the proportions of carbon, hydrogen, and chlorine isotopes in methyl chloride produced by the royal ferns differed significantly from those produced by industrially manufactured methyl chloride.

Next, the researchers analyzed the isotopic composition of methyl chloride when it is broken down by club moss (*Selaginella kraussiana*). They discovered a unique isotopic pattern that differs from those produced by other methyl chloride–degrading plants, suggesting that club moss uses an unknown mechanism to process the gas.

These chemical fingerprints, the researchers say, could be used in future research to clarify inputs and removals of methyl chloride in the atmosphere. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2022JG007256, 2023) **—Sarah Stanley,** *Science Writer*

RCUH Research Corporation of the University of Hawai'i

CIMAR UHSLC POSTDOCTORAL RESEARCHER (INTERDISCIPLINARY) – ID# 223409

The University of Hawai'i Sea Level Center (UHSLC) is hiring **postdoctoral researchers** to engage in interdisciplinary research focused on the mechanisms, statistics, and impacts of coastal variability and change. We are specifically interested in candidates with broad interests that are willing to learn and apply concepts, data, and models outside one's specific area of training. In particular, the UHSLC is currently engaged in multiple efforts to understand the dynamics and implications of coupling between various combinations of water level, waves, hydrology, and biology. The UHSLC offers postdoctoral positions with competitive salaries and full benefits with up to 6 months of remote work per year if desired. We also provide time and financial support for professional development activities, including proposal writing to develop one's own research program and reputation, as well as travel to meetings and trainings to build a professional network and expand one's skillset.

INQUIRIES: Nicole Wakazuru-Yoza 808-956-5018 (Oahu).

Please apply directly on the RCUH website to be considered for the position.

APPLICATION REQUIREMENTS: Please go to **www.rcuh.com** and click on "**Job Postings.**" You must submit the following documents online to be considered for the position: **1)** Cover Letter, **2)** Resume, **3)** Supervisory References, **4)** Copy of Degree(s)/Transcript(s)/Certificate(s). All online applications must be submitted/received by the closing date (11:59 P.M. Hawai'i Standard Time/RCUH receipt time) as stated on the job posting. If you do not have access to our system and the closing date is imminent, you may send additional documents to **rcuh_recruitment@rcuh.com**. If you have questions on the application process and/or need assistance, please call (808)956-7262 or (808)956-0872.

CLOSING DATE: July 27, 2023, or until filled. Applications received after this deadline may be considered only if the position is not filled or up to the date a selection has been approved by the RCUH (whichever comes first).

RCUH's mission is to support and enhance research, development and training in Hawai'i, with a focus on the University of Hawai'i.

We are an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity or expression, pregnancy, age, national origin, disability status, genetic information, protected veteran status, or any other characteristic protected by law.

Cornell University

POSTDOCTORAL ASSOCIATE IN WATER RESOURCES SYSTEMS MODELING UNDER DEEP UNCERTAINTY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
CORNELL UNIVERSITY

Professor Patrick Reed's Decision Analytics for Complex Systems research group within the School of Civil and Environmental Engineering at Cornell University seeks **one or more postdoctoral associates**. The positions can be remote (but the home location needs to be in the United States). The position(s) will initially be available for one year with a potential renewal for two or more years.

Candidates should have strong computational skills, ideally with a focus on water resources systems modeling at the river-basin scale. Experience with high-performance computing, uncertainty analysis, and coupled human-natural systems modeling is desirable. Additionally, emerging advancements in control and machine learning (e.g., deep reinforcement learning) are of interest but not required. Ideally, candidates would have a Ph.D. in water resources engineering, hydrology, or a related field. The focus of this research will be on the risks, resilience, and sustainability of major regional water resources systems (e.g., the Mid-Atlantic, the Colorado River Basin, and the Central Valley). The research will have a particular emphasis on understanding the implications of human responses to evolving climate extremes.

TO APPLY: Application materials must be submitted on-line through AcademicJobsOnline at **https://academicjobsonline.org/ajo/jobs/24936**

Through this website, applicants are to submit a curriculum vitae, graduate transcript, and the names and contact information for at least three references. The successful applicant anticipated hire date is **September 1, 2023** (or earlier based on candidate's availability). Review of applications will begin immediately and will continue until the position is filled. Questions can be directed to **cee_search@cornell.edu**

The School of Civil and Environmental Engineering at Cornell embraces diversity and seeks candidates who will contribute to a climate that supports students, faculty and staff of all identities and backgrounds. We strongly encourage individuals from underrepresented identities to apply.

Diversity and Inclusion are a part of Cornell University's heritage. We are a recognized employer and educator valuing AA/EEO, Protected Veterans and Individuals with Disabilities. We also recognize a lawful preference in employment practices for Native Americans living on or near Indian reservations. Cornell University is an innovative Ivy League university and a great place to work. Our inclusive community of scholars, students, and staff impart an uncommon sense of larger purpose, and contribute creative ideas to further the university's mission of teaching, discovery, and engagement.

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DEPUTY DIVISION DIRECTOR, DIVISION OF RESEARCH, INNOVATION, SYNERGIES AND EDUCATION

The National Science Foundation's Directorate for Geosciences (GEO) announces a nationwide search to fill the position of **Deputy Division Director**, for the Division of Research, Innovation, Synergies, and Education (RISE). The position provides an unparalleled opportunity to lead the Division in supporting novel, complex, or partnership projects in both research and education and to share in the management responsibility of the Directorate for Geoscience to advance NSF's mission.

The Deputy Division Director for RISE leads a team of professional and administrative staff in managing a broad portfolio of investments in research and education addressing the frontiers of knowledge that advance the Nation's prosperity, health, and infrastructure. RISE's principal goals are to develop innovative means to initiate and support geoscience education, attract underrepresented groups to careers in the geosciences, foster the interchange of scientific information nationally and internationally, and join with other parts of NSF in major integrative research and education efforts. The division makes strategic investments in multidisciplinary research areas, international activities, as well as education, diversity, and human resource development activities.

The Deputy Division Director plays a key role in positioning and advocating for program activities within the context of NSF's strategic plan, and in managing resources effectively to advance ongoing efforts and nurture emerging opportunities. The Deputy Division Director works proactively across NSF and in partnership with other federal and state agencies, industry, private foundations, and the academic community. The position offers a challenging and demanding opportunity to effect change and provide intellectual leadership.

The successful candidate will possess an established record of significant achievement in research administration as well as leadership responsibility in academia, industry, or government. In addition to having a strong record of research and education accomplishments within their technical communities, the Deputy Division Director must be experienced and competent in technical, financial, and administrative management. They must work well with people, be an effective communicator, and act as a mentor to continuously develop the diversity of talents and skills of their colleagues at all levels.

A description of the RISE is provided at **https://www.nsf.gov/div/index.jsp?div=RISE**.

Inquiries regarding the division can be directed to the Canvassing Committee Coordinator: Dr. Timothy Patten, (703) 292-7196, **tpatten@nsf.gov**.

The position, qualification requirements, and application procedures are described in the vacancy announcement **(GEO-EXEC-2023-0001) at USAJOBS – Job Announcement**. Hearing-impaired individuals may call TDD at 703-292-5090. Applications must be submitted by the closing date listed in the announcement.

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The application deadline is in October. To learn more and to apply, visit www.nas.edu/jsf.

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T K W W D M J D N M Z K I L K Q J A M K R K Y J N Q X P O E
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Y V B X O G T G U R O S S E F O R P S N A Y F Y P L J S A Q
J T J C F O S S I L S A Q I A N R G K K N D S U V A E L D V

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career change
career paths
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consulting
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fossils
geohazards
geology
geophysicists
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inclusion
industry
jobs
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