Eos

SCIENCE NEWS BY AGU

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The Career Issue

Let these scientists inspire you to forge a unique path to a rewarding profession.

Thirsty Data Centers

Iceberg Initiated Landslides

Viking Food Security

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Charting the Paths to a Scientific Career

A small business owner, a former U.S. Navy captain, and "the *New York Times* volcano guy" are just a few of the scientists whose stories you'll find in this issue. The pathways to a scientific career are numerous, branching in many different directions from the most well-known road leading to an academic institution.

Our special September issue highlights 17 of these pathways in our feature on page 24. Fushcia-Ann Hoover is that small business owner who took her education in science and engineering and her passion as a "maker" and used them to launch an organization that offers consultation to communities on urban green infrastructure. Zdenka Willis, our military veteran, loved the challenge of transitioning the Navy to digital charts and went on to become the president of an international society that brings businesses, policymakers, educators, and others together to advance marine technologies.

Some of these scientists followed whatever path would connect them with the outdoors. As a child; Kristel Chanard dreamed of Himalayan expeditions. Today she's checked off the Himalayas, the French Alps, and so many more summits to conduct her work as a research geophysicist for an institute in Paris. Darcy L. Peter wanted to stay closer to her Gwich'in Athabascan home. As an environmental scientist, she's most proud of her ability to build relationships that connect Western science with Indigenous Knowledges. Meanwhile, Robin George Andrews traveled to the volcanoes of New Zealand to get his Ph.D. but found a better home for his passion in writing, becoming the go-to science reporter for some of the world's biggest publications.

Why follow a system when you can help create a better one? That's what Aisha Morris asked herself before leaving academia and joining the National Science Foundation, where she gets to play a tangible role in creating a more diverse scientific community. Karen Layou, a geoscientist and professor at Reynolds Community College, is part of a movement to broaden participation in the sciences by highlighting the 2-year college pathway. And of course, there's the system, and then there's The System. Ashlee Wilkins's passion for astronomy led her first to NASA and then to the U.S. House of Representatives, where she's a professional staff member for the Subcommittee on Space and Aeronautics.

Before you head over to read about these inspiring pathways, flip first to the opinion on page 20, where the authors deftly describe this approach to modern career pathways as a "braided river," eschewing the old model of a pipeline. Our lives are increasingly complicated, and the challenges we face as a society are increasingly complex. We all benefit from scientific workforce development that is designed with flexibility and compassion.

We hope you enjoy this issue and are inspired by the wide world of opportunities these scientists prove are available to everyone.

Heather Goss, Editor in Chief

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An Iceberg May Have Initiated a Submarine Landslide

The CCGS Hudson *sails in front of an iceberg that scientists later found had initiated a submarine landslide in Southwind Fjord, Baffin Island. Credit: Alex Normandeau*

In August 2018, Alexandre Normandeau was on a research cruise in the Southwind Fjord of Canada's Baffin Island, attempting to study landslides on the seafloor. Normandeau, a research scientist at the Bedford Institute of Oceanography in Dartmouth, N. S., was aboard the CCGS *Hudson* collecting bathymetry data and core samples of the seafloor when the crew spotted an iceberg. "We took a bunch of photos and didn't think anything of it at the time," Normandeau remembered.

A year later, Normandeau and his colleagues determined that that same iceberg may have initiated a new submarine landslide. Scientists had never shown before that icebergs could cause landslides. Their findings were published in *Nature Geoscience* (bit.ly/iceberg-landslides).

An Iceberg Aground

Submarine landslides can threaten sea life, cause tsunamis, and damage infrastructure such as subsea Internet cables.

Despite these risks, scientists don't fully understand the causes of submarine landslides. In some cases, earthquakes are the culprits. But because most of the ocean floor is irregularly mapped, it is difficult to know when landslides occur and to link them with a causal event.

When the researchers returned to Southwind Fjord in 2019, they learned that a new landslide had occurred since their previous visit, providing a rare opportunity to look within a short time window and determine what might have caused it.

Because no earthquakes had occurred within 300 kilometers of Southwind Fjord, the researchers looked for other mechanisms. By comparing the bathymetry data from their two visits to the fjord, they found an intriguing piece of evidence. They noticed a characteristic pit left when an iceberg strikes the seafloor—right at the initiation point of the landslide—known as a head scarp. Using satellite images from Sentinel-2, they realized that the iceberg they saw the year before eventually ran aground. A few days later, it capsized and slammed into the ocean floor, regrounding several meters away.

"We were hoping for something like this. But to see it happen? It was a lot of luck."

"We interpret that it's that impact that created the landslide, because when you look at where the iceberg regrounded, that's exactly where the landslide head scarp is," said Normandeau. "We were hoping for something like this. But to see it happen? It was a lot of luck."

For further evidence that the iceberg initiated the landslide, the researchers went back to the core samples they had collected in 2018 near the landslide but before it occurred. By analyzing the sediment composition and the slope of the seafloor, they found that the sediment in the area was stable under gravitational load, but the estimated load of the iceberg would have been enough to initiate the slide.

Morelia Urlaub, a marine geoscientist at GEOMAR Helmholtz Centre for Ocean Research Kiel in Germany who wasn't involved in the study, is researching ways to monitor the seafloor and identify new landslides. She said that when studying submarine landslides, researchers must be in the right place at the right time. "That's what I found fascinating about this iceberg study. They basically caught one," Urlaub said. "The study is important because it brings up a new mechanism and because the observation is as good as it gets."

Iceberg Impacts Run Deep

After discovering the landslide in Southwind Fjord, the researchers explored maps of the seafloor in other locations. They found several other iceberg pits at landslide head scarps. "The most surprising result was off the continental slope of Nova Scotia," Normandeau said. "They're much bigger [landslides] than what we see in the fjords." Normandeau hypothesized that when there was an ice sheet in the region around 20,000 years ago, big icebergs broke off and struck the seabed, causing landslides. He's hoping to address this hypothesis in future research.

As climate change causes more icebergs to break off existing ice sheets, understanding the risks that icebergs pose could mitigate damage to new infrastructure projects. In Canada, there is a push to connect northern communities with subsea Internet cables, which would be especially at risk. But icebergs can also travel thousands of kilometers, potentially causing landslides far from the Arctic. "It's important to be aware of the triggering mechanisms when we're planning seafloor infrastructure," Normandeau said. The gouges left when icebergs collide with the seafloor might be only the tip of the problem.

By **Andrew Chapman** (@andrew7chapman), Science Writer

Tiny Kinks Record Ancient Quakes

Every so often, somewhere beneath our feet, rocks rupture and an earthquake begins. With big enough ruptures, we might feel an earthquake as seismic waves radiate to or along Earth's surface. However, a mere 15%–20% of the energy needed to break rocks in the first place translates into seismicity, scientists suspect.

The remaining energy can dissipate as frictional heat, leaving behind planes of glassy rock called pseudotachylyte. The leftover energy may also fracture, pulverize, or deform rocks that surround the rupture as it rushes through the crust, said Erik Anderson, a doctoral student at the University of Maine. Because these processes occur kilometers below Earth's surface, scientists cannot directly observe them when modern earthquakes strike. Shear zones millions of years old that now reside at the surface can provide windows into the rocks around ancient ruptures. However, although seismogenically altered rocks remain at depth, heat and pressure can erase clues of past quakes, said Anderson. "We need some other proxy when we're looking for evidence of earthquakes in the rock record."

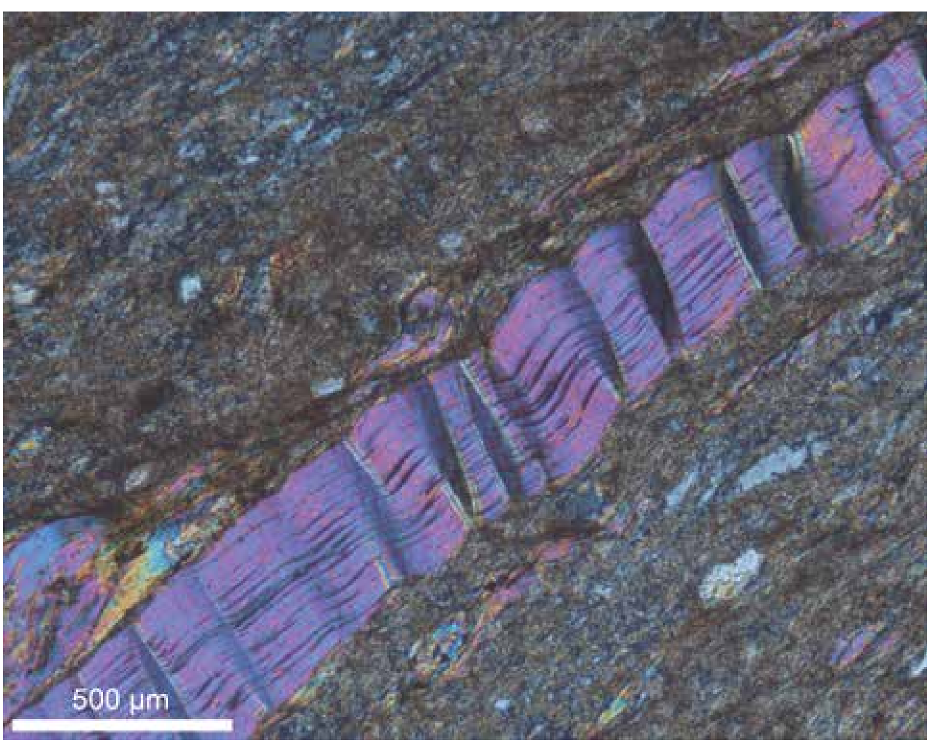
Micas—sheetlike minerals that can stack together in individual crystals that often provide the sparkle in kitchen countertops—can preserve deformation features that look like microscopic chevrons. On geology's macroscale, chevrons form in layered strata. In minuscule sheaves of mica, petrologists observe similar pointy folds because the structure of the mica leaves it prone to kinking, rather than to buckling or folding, said Frans Aben, a rock physicist at University College London.

In a new article in *Earth and Planetary Science Letters,* Anderson and his colleagues argue that these microstructures—called kink bands—often mark bygone earthquake ruptures and might outlast other indicators of seismicity (bit.ly/kink-bands).

Ancient Kink Bands, Explosive Explanation

To observe kinked micas, scientists must carefully cut rocks into slivers thinner than the width of a typical human hair and affix each rock slice to a piece of glass. By using high-powered microscopes to examine this rock and glass combination (aptly called a thin section), Anderson and his colleagues compared kink bands from two locations in Maine, both more than 300 million years old. The first location is rife with telltale signs of a dynamically deformed former seismogenic zone, like shattered garnets and pseudotachylyte. The second location exposes rocks that changed slowly, under relatively static conditions.

With micas, once they're kinked, they will remain kinked, preserving records of ancient earthquakes in the hearts of mountains.



A kinked muscovite grain embedded within a fine-grained, highly deformed matrix of other minerals displays asymmetric kink bands. Credit: Erik Anderson

Comparing the geometry of the kink bands from these sites, the researchers observed differences in the thicknesses and symmetries of their microstructures. In particular, samples from the dynamically deformed location displayed thin-sided, asymmetric kinks. The more statically deformed samples showcased equally proportioned points with thicker limbs.

Kink bands, said Aben, can be added to a growing list of indicators of seismic activity in otherwise cryptic shear zones. The data, he said, "speak for themselves." Aben was not involved in this study.

To further cement the link between earthquakes and kink band geometry, Anderson and colleagues analyzed 1960s era studies largely driven by the development of nuclear weapons. During that time, scientists strove to understand how shock waves emanated from sites of sudden, rapid, massive perturbations like those produced at nuclear test sites or meteor impact craters. Micas developed kink bands at such sites, as well as in complementary laboratory experiments, said Anderson, and they mimic the geometric patterns produced by dynamic strain rate events—like earthquakes. "[Kink band] geometry," Anderson said, "is directly linked to the mode of deformation."

Stressing Rocks, Kinking Micas

In addition to exploring whether kinked mica geometry could fingerprint relics of earthquake ruptures, Anderson and his colleagues estimated the magnitude of localized, transient stress their samples experienced as an earthquake's rupture front propagated through the rocks, he said. In other words, he asked, might the geometry of kinked micas scale with the magnitude of momentary stress that kinked the micas in the first place?

The stresses experienced by these rocks...were about 9 times the pressure at the Mariana Trench.

By extrapolating data from previously published laboratory experiments, Anderson estimated that pulverizing rocks at the deepest depths at which earthquakes can nucleate requires up to 2 gigapascals of stress. Although stress doesn't directly correspond to pressure, 2 gigapascals is equivalent to more than 7,200 times the pressure inside a car tire inflated to 40 pounds per square inch. For reference, the unimaginably crushing pressure in the deepest part of the ocean—the Mariana Trench—is only about 400 times the pressure in that same tire.

By the same conversion, kinking micas requires stresses 8–30 times the water pressure in the deepest ocean. Because Anderson found pulverized garnets proximal to kinked micas at the fault-filled field site, he and his colleagues inferred that the stresses momentarily experienced by these rocks as an earthquake's rupture tore through the shear zone were about 1 gigapascal, or 9 times the pressure at the Mariana Trench.

Aben described this transient stress estimate for earthquakes as speculative, but he said the new study's focus on earthquake-induced deformation fills a gap in research between very slow rock deformation that builds mountains and extremely rapid deformation that occurs during nuclear weapons testing and meteor impacts. And with micas, he said, "once they're kinked, they will remain kinked," preserving records of ancient earthquakes in the hearts of mountains.

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

Where Do a Volcano's Metals Go?

Hawaii's Kīlauea volcano is very large, very active, and very disruptive. Its recent activity belched tons of sulfur dioxide into the air each day. But aside from gases, eruptions from basaltic volcanoes like Kīlauea release metals and metalloids, including ones considered pollutants, like copper, zinc, arsenic, and lead. These metal pollutants have been found in the ground, water, rain, snow, and plants near vents posteruption, as well as in the air downwind.

But how these volcanic metals are transported from active eruptions, their longevity in the environment, and how much and where they end up settling were open questions until recently. "We know that volcanoes are a huge natural source of these metals, which are environmentally very important," said Evgenia Ilyinskaya, an associate professor at Leeds University in the United Kingdom. "But there's just not very much known about what happens to them after emission—how long do they stay in the atmosphere, and where do they go?"

Sampling the Wind

To better understand how concentrations of metals change as a plume travels downwind during an active ongoing eruption, Ilyinskaya and fellow researcher and University of Cambridge doctoral student Emily Mason set up sampling stations around the Big Island of Hawaii. Intermittently over the course of almost a year, they collected samples as close as possible to Kīlauea's eruptive vent and at another six sites around the island. The farthest site was more than 200 kilometers distant, and all were in the path of the trade wind. They also collected samples 300 meters above the plume using a drone.

"Kīlauea is a wonderful natural laboratory for studying volcanism and particularly that type of basaltic volcanism," said Mason. "It's a well-understood system, and that makes it a very appealing target."

Their research, published in *Communications Earth and Environment*, is the biggest study of volcano metal emissions ever done (bit.ly/volcano-metal-emissions).

Ilyinskaya, Mason, and their colleagues found an enormous difference between pollutant levels during and after the eruption—up to 3 times higher than periods without volcanic activity. They discovered that different pollutants fall out at different rates: Some pollutants, like cadmium, remain in the plume for only a few hours, whereas others, like cerium, remain for much longer. "It was quite striking to see that there is such a large difference," said Ilyinskaya. "That's something we didn't really expect."

"Kīlauea is a wonderful natural laboratory for studying volcanism and particularly that type of basaltic volcanism."

The researchers think that metal deposition may be very sensitive to atmospheric conditions like wind, rain, and humidity. Different environments could mean different patterns of volcanic metal dispersal and pollution. For example, drier and colder environments, like Iceland, may have patterns different than hot and humid environments like Hawaii.

A researcher wearing protective gear walks toward a laze plume created by Kīlauea's lava entering the ocean. Credit: Evgenia Ilyinskaya/USGS

Researchers working at Kīlauea's still-active fissure 8, located on the volcano's lower East Rift Zone. Credit: Emma Liu/USGS

Laze Plumes and Copper

Mason also studied laze plumes, created when the heat of lava very quickly evaporates seawater, by taking samples where the lava entered the ocean. The phenomenon is relatively rare, as there aren't that many basaltic volcanoes near sea level where lava can reach the ocean. But laze plumes are worth studying, said Mason, because historically there have been much larger basaltic eruptions that created large igneous provinces, like the Deccan Traps. These eruptions may have released tons of metals and metalloids into the surrounding environment. "It's possible that laze plumes are a slightly underestimated force in those events," said Mason.

The amount of copper being released by laze plumes is surprising, said Mason. Seawater is rich in chlorine, and she thinks it enables more copper to de-gas. Laze plumes could even release more copper into the environment than large magmatic plumes, she said. This copper would also be released directly into the ocean and could affect marine environments, by either worsening ocean acidification or adding nutrients. "The fact that copper emissions could be comparable between the laze plume and the magmatic plume is definitely surprising to me," said Mason.

Volcanologist and geochemist Tobias Fischer of the University of New Mexico, who was not involved in either study, said this research is "a really nice approach and really advances our understanding of not only the quantity of metal emissions but also their life cycle in a volcanic plume like this one."

Health Risks

At some point during the 3 hours the plume took to reach the closest sampling station, its metals were radically depleted. The researchers hypothesized that the heavy-metal pollutants may have formed a very water soluble chemical species that fell out in rain close to the eruption site. Ilyinskaya is collecting samples from Iceland's Fagradalsfjall volcano to learn more about what happens in those first 3 hours of a plume's lifetime.

"If this process is really happening, then it could be disproportionately impacting people living close to the volcano," she said. "On the other hand, it may be lessening the impact on the communities further away."

Volcanic pollutants have been linked to health problems like thyroid cancer, multiple sclerosis, and respiratory diseases. One goal of studies like Ilyinskaya's and Mason's is to create a pollution map that models where the plume will go, the concentrations of metals, and the atmospheric conditions, to help communities avoid exposure. Fischer said a pollution map would be a wonderful contribution. "Then you can probably make some pretty good predictions of where you get high concentrations of metal deposition and what kinds of metals," he said.

More research needs to be done on how metals are stratified within a plume and also their long-term accumulations in water and plants, said Mason. "Volcanic metals are an insidious threat in terms of the way that they build up in the environment," said Mason.

By **Danielle Beurteaux** (@daniellebeurt), Science Writer

A Remarkably Constant History of Meteorite Strikes

Thousands of tons of extraterrestrial material pummel Earth's surface each year. The vast majority of it is too small to see with the naked eye, but even bits of cosmic dust can reveal secrets.

By poring over more than 2,800 grains from micrometeorites, researchers have found that the amount of extraterrestrial material falling to Earth has remained remarkably stable over millions of years. That's a surprise, the team suggested, because it's long been believed that random collisions of asteroids in the asteroid belt periodically send showers of meteoroids toward Earth.

When asteroids collide, Earth doesn't always experience an uptick in meteorite strikes. Credit: iStock.com/dottedhippo

Astronomy by Looking Down

Birger Schmitz, a geologist at Lund University in Sweden, remembers the first time he looked at sediments to trace something that had come from space. It was the 1980s, and he was studying the Chicxulub impact crater. "It was the first insight that we could get astronomical information by looking down instead of looking up," said Schmitz.

Inspired by that experience, Schmitz and his Lund University colleague Fredrik Terfelt, a research engineer, have spent the past 8 years collecting more than 8,000 kilograms of sedimentary limestone. They're not interested in the rock itself, which was once part of the ancient seafloor, but rather in what it contains: micrometeorites that fell to Earth over the past 500 million years.

Some of the reactions that ensued were impressive, said Terfelt, who recalled black smoke filling their laboratory's fume hood.

Dissolving Rocks

Schmitz and Terfelt used a series of strong chemicals in a specially designed laboratory to isolate the extraterrestrial material. They immersed their samples of limestone—representing 15 different time windows spanning the Late Cambrian to the early Paleogene—in successive baths of hydrochloric, hydrofluoric, sulfuric, and nitric acid, to dissolve the rock. Some of the reactions that ensued were impressive, said Terfelt, who recalled black smoke filling their laboratory's fume hood. "The reaction between pyrite and nitric acid is quite spectacular."

The chemical barrage left behind grains of chromite, an extremely hardy mineral that composes about 0.25% by weight of some meteorites. These grains are like a corpse's gold tooth, said Schmitz. "They survive."

Schmitz and Terfelt found that more than 99% of the chromite grains they recovered came from a stony meteorite known as an ordinary chondrite. That's perplexing, the researchers suggested, because asteroids of this type are rare in the asteroid belt, the source of most meteorites. "Ordinary chondritic asteroids don't even appear to be common in the asteroid belt," Schmitz told *Eos.*

An implication of this finding is that most of Earth's roughly 200 known impact structures were likely formed from ordinary chondrites striking the planet. "The general view has been that comets and all types of asteroids were responsible," said Schmitz.

When Schmitz and Terfelt sorted by age the 2,828 chromite grains they recovered, the mystery deepened. The distribution they found was remarkably flat except for one peak roughly 460 million years ago. We were surprised, said Schmitz. "Everyone was telling us [we would] find several peaks."

Making It to Earth

Sporadic collisions between asteroids in the asteroid belt produce a plethora of debris, and it's logical to assume that some of that cosmic shrapnel will reach Earth in the form of meteorites. But of the 15 of these titanic tussles involving chromite-bearing asteroids that occurred over the past 500 million years, that was the case only once, Schmitz and Terfelt showed. "Only one appears to have led to an increase in the flux of meteorites to Earth," said Schmitz.

Perhaps asteroid collisions need to occur in a specific place for their refuse to actually make it to our planet, the researchers propose in the *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/asteroid-collisions). So-called Kirkwood gaps—areas within the asteroid belt where the orbital periods of an asteroid and the planet Jupiter constitute a ratio of integers (e.g., 3:1 or 5:2)—are conspicuously empty. Thanks to gravitational interactions that asteroids experience in these regions of space, they tend to get flung out of those orbits, said Philipp Heck, a meteorist at the Field Museum of Natural History in Chicago not involved in the research. "Those objects tend to become Earth-crossing relatively quickly."

We're gaining a better understanding of the solar system by studying the relics of asteroids, its oldest constituents, said Heck. But this analysis should be extended to other types of meteorites that don't contain chromite grains, he said. "This method only looks at certain types of meteorites. It's far from a complete picture."

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

U.S. Data Centers Rely on Water from Stressed Basins

Thanks to our ever increasing reliance on the Internet, the amount of data online is skyrocketing. The global data volume is expected to grow sixfold from 2018 to 2025. It might seem like that information is swirling in the cloudy sky, but it's actually stored in physical data centers.

Landon Marston, an assistant professor at Virginia Polytechnic Institute and State University, recently noticed news articles addressing the growing energy requirements of the data center industry. As an expert in water resources engineering, he wondered how those energy requirements translated into water consumption. "We know data centers use a lot of energy, and energy uses a lot of water. So how much water is being used?" said Marston. "We suspected that there could be large impacts at a very local scale, but there hadn't really been a spatially detailed analysis looking at the environmental impact of data centers."

In a study recently published in *Environmental Research Letters,* Marston and colleagues attempted to map how and where data centers in the United States consume energy and water (bit.ly/data-center-energy). The results showed that it takes a large amount of water to support the cloud and that the water often comes from water-stressed basins.

Connecting Water Consumption to Data Centers

The researchers identified more than 100,000 data centers using previously collected information from the Lawrence Berkeley National Laboratory and the websites of commercial data centers. While most of the data centers are small operations run by individual companies, the majority of servers in the United States are housed in fewer than 2,500 "colocation" and "hyperscale" data centers, which store data for many companies and the public simultaneously. Hyperscale data centers are the biggest type of data center, typically housing more than 5,000 servers, but are designed to be more energy efficient by using cutting-edge cooling methods and servers.

All data centers consume water directly to cool the electronics at the site and indirectly, through electricity generation at the power plants that service the sites. Using records from the U.S. Environmental Protection Agency and the U.S. Energy Information Association, and data from previous academic studies, the researchers matched the data centers with their most likely sources of electricity and water. Then they estimated the data centers' annual energy, direct water, and indirect water consumption based on their energy and cooling requirements. By piecing all this information together, "we can have a spatially explicit representation of the environmental footprints associated with each of the data centers," said Marston.

"We know data centers use a lot of energy, and energy uses a lot of water. So how much water is being used?"

They mapped the U.S. data center industry's carbon footprint, water footprint, and water scarcity footprint. The latter calculates the pressure that water consumption puts on a region based on local water availability and needs.

Hot, Dry, and Hydroelectric

The results revealed that data centers use water from 90% of watersheds in the United States. The water consumption of individual data centers varies dramatically depending on where they are located and their electricity source. For example, data centers in the Southwest rely on water-heavy hydroelectric power, and the hot climate there leads to more evaporation compared with other regions in the country. Data centers in the cooler, wetter climates of the East Coast also tend to use more solar and wind energy, which require less water.

Of the total water footprint attributed to data centers, 75% was from indirect water use at power plants and 25% was from on-site water use. "This is important, because most [data center] operators don't really look at their power consumption as part of the overall water footprint," said David Mytton, a researcher at Imperial College London and a member of the Data Center Sustainability Research Team at the Uptime Institute. Mytton was not involved in the new study.

A. B. Siddik, a graduate student at Virginia Tech and the study's lead author, explained that on-site water consumption has a bigger impact on the water scarcity footprint, indicating that many data centers are in water-stressed regions. "Most often they are in the middle of a desert, or in the Southwest, like California, Nevada, and Arizona," said Siddik. "Those are hubs of data centers." The overall water scarcity footprint was more than double the water footprint, suggesting that data centers in the United States disproportionately consume water from water-stressed regions.

A Google data center in Council Bluffs, Iowa. Credit: Chad Davis, CC-BY-2.0 (bit.ly/ccby2-0)

Planning for the Digital Future

As the demand for data storage grows, so will the need for hyperscale data centers. Although these buildings are more efficient than smaller data centers, concentrating the energy and water demands in fewer locations could tax the local environment.

Further innovations in energy-efficient technology and investments in renewable energy will help curb energy and water usage, but Marston also recommended building new data centers in regions with smaller carbon and water-scarcity footprints. “Simple real estate decisions could potentially be the solution here,” he said.

Technology companies have already tried extreme locations for data centers. For example, Google converted an old mill in frigid northern Finland into a data center, and Microsoft experimented with putting data centers in the ocean. But according to the study, locations such as New York and southern Florida that have an abundance of water and renewable energy sources would have a lower environmental impact.

“Simple real estate decisions could potentially be the solution here.”

Mytton agreed that it’s important to consider the locations of future data centers, adding that climate change complicates these decisions because places that are not water stressed now might become drier and hotter over time. Plus, many other factors contribute to where data centers are built, such as the local taxes, regulations, and workforce. Strategically placing data centers based on water resources is also an important economic consideration for the industry, Marston said, because water-stressed regions are prone to electricity blackouts and brownouts, which are detrimental to the operation of data centers.

“Data [are] so critical to the way our society functions, and data centers underpin all that,” Marston said. “It’s not just about the environmental footprint. It’s also a potential risk for these data centers.

By **Andrew Chapman** (@andrew7chapman), Science Writer

Getting to the Bottom of Trawling’s Carbon Emissions

Trawling nets like these disturb delicate ocean floor ecosystems and inadvertently release stored carbon. Credit: Alex Proimos, CC BY 2.0 (bit.ly/ccby2-0)

Bottom trawling, a controversial fishing practice in which industrial boats drag weighted nets through the water and along the ocean floor, can unintentionally dig up seafloor ecosystems and release carbon sequestered within the sediments. For the first time, researchers have attempted to estimate globally how this fishing technique may be remineralizing stored carbon that, as the seabed is tilled, ends up back in the water column and possibly the atmosphere, where it would contribute to climate change.

“The ocean is one of our biggest carbon sinks,” said Trisha Atwood, who researches aquatic ecology at Utah State University. “So when we put in more human-induced CO_2 emissions, whether that’s directly dumping CO_2 into deep waters or whether that’s trawling and enhancing remineralization of this carbon, we’re weakening that sink.”

Atwood helped build a model that shows that bottom trawling may be releasing as much as 1.5 billion metric tons of aqueous carbon dioxide (CO_2) annually, equal to what is released on land through farming. Her work was part of a paper recently published in *Nature* that presents a framework for prioritizing the creation of marine protected areas to restore ocean biodiversity and maximize carbon storage and ecosystem services (bit.ly/framework-mpa).

“The ocean is one of our biggest carbon sinks, so when we put in more human-induced CO_2 emissions…we’re weakening that sink.”

Estimating Carbon Loss from the Ocean Floor

To create the model, Atwood and her coauthors first needed to figure out how much of the ocean floor is dredged by trawlers. They turned to data from the nonprofit Global Fishing Watch, which recently began tracking fishing activity around the world, and compiled data on industrial trawlers and dredgers from 2016 to 2019.

The next step was to find data on how much carbon is stored in the world's ocean sediments. Because that information was not readily available, Atwood and colleagues built a data set by analyzing thousands of sediment cores that had been collected over the decades.

Last, they dug through the scientific literature, looking at studies that examined whether disturbances to the soil in coastal ecosystems, such as seagrasses, mangroves, and salt marshes, exposed carbon that was once deep in marine sediments and enhanced carbon production in the ocean.

"We lean really heavily on that literature," said Atwood. "We used a lot of the equations [in previous papers] to build our model and extend it into the seabeds in these more open ocean locations. And from there, we were able to come up with this first estimate."

A group of twin-rigged shrimp boats trawl the northern Gulf of Mexico off the coast of Louisiana. The trawlers are trailed by plumes of sediment, suggesting that their nets are scraping the seafloor. Credit: SkyTruth Galleries, CC BY-NC-SA 2.0 (bit.ly/ccbyncsa2-0)

"We in no way intended our model to be the end-all in the trawling conversation. We hope that many more studies will come along that help produce more localized results."

Their investigation did not attempt to determine whether sequestered carbon that has been released by bottom trawling remains in the water column or is released into the atmosphere, although they noted potential problems either way. In the paper, the authors note that it is likely to increase ocean acidification, limit the ocean's buffering capacity, and even add to the buildup of atmospheric CO_2.

Atwood and the lead author of the paper, Enric Sala, a conservation ecologist who is also a National Geographic Explorer-in-Residence, are working with Tim DeVries, who studies ocean biogeochemistry at the University of California, Santa Barbara, and scientists at NASA's Goddard Space Flight Center to build atmospheric models to try to figure out where the released carbon goes.

Existing Trawling Data May Be Too Scant

Not everyone, however, is convinced that Atwood and Sala's model on bottom trawling and loss of carbon sequestration in marine sediments is accurate. Sarah Paradis, who is studying the effects of bottom trawling on the seafloor for her Ph.D. at the Institute of Environmental Science and Technology in Barcelona, is skeptical.

In an email to *Eos,* Paradis noted that since the 1980s, fewer than 40 studies have addressed the impacts that bottom trawling has on sedimentary organic carbon. These few studies are not enough to build a model on, she said, and in addition, the studies reached different conclusions. Some studies observed that bottom trawling decreased organic carbon content of the seafloor, whereas others showed that it increased organic carbon.

In addition, Paradis wrote that less organic carbon on the seafloor does not necessarily mean its remineralization to CO_2. Rather, it could simply mean loss of organic carbon through erosion, which means that the carbon moves to another area of the seabed but very little is remineralized into CO_2. She pointed to several studies, including one she was a part of that showed loss of organic carbon through erosion.

"I want to emphasize that [the authors] address a very important issue regarding how bottom trawling, a ubiquitous and very poorly regulated anthropogenic activity, is affecting the seafloor," she wrote. "But the values they propose are far from being credible."

Atwood disagreed. "We don't need lots of studies on the effects of trawling because we built our model using decades of carbon cycling research," she wrote in an email to *Eos.* "Trawling is simply a perturbation that mixes and re-suspends sediments, leading to increases in carbon availability. All we needed to know about trawling to apply a carbon model to it is where trawling occurs and how deep in the sediment the trawls go."

In addition, Atwood said, "We in no way intended our model to be the end-all in the trawling conversation. We hope that many more studies will come along that help produce more localized results."

By **Nancy Averett** (@nancyaverett), Science Writer

Dyes and Isotopes Track Groundwater from Sink to Spring

Tom Greenhalgh introduces tracer dye into a sinkhole at Lake Miccosukee. Credit: Ming Ye

Beneath Florida's cities and swamps lies a complex network of karst conduits. The same chemical weathering that carves truck-sized tunnels through the calcium carbonate rock also leads to sinkholes at the surface. For Florida insurance agents, sinkholes are a headache. But for the state's hydrogeologists, every sinkhole is an opportunity to understand the aquifer below.

Sinkholes allow surface water, as well as contaminants, to flood into an aquifer. By mapping the network of entry points and exit springs, hydrogeologists can better understand the underground system and better protect drinking water at its source. That understanding is important to populations outside Florida: Karst aquifers provide drinking water for 25% of people on Earth.

Isotope analysis helps hydrogeologists trace water origins, but the technique's use generally has been limited to sinkhole lakes and springs no more than 4 kilometers apart. Recently, however, a team in Florida used isotope ratios to connect points 32 kilometers apart. It's the farthest hydraulic connection between a sinkhole and a spring yet documented and the first connection involving a first-magnitude spring (a spring discharging an average of 100 cubic feet—2.8 cubic meters—of water per second).

"Dyeing" to Know

"Normally, for hydrogeology, we only care about subsurface water flows," explained Ming Ye, a hydrogeologist at Florida State University and a coauthor of the research, published in *Groundwater* (bit.ly/sinkhole-spring). But when studying sinkholes, he said, scientists have to consider surface water flows, too.

In 2010, two sinkholes appeared at the edge of Lake Miccosukee in north central Florida, and in 2018 Ye and his colleagues used a technique called dye tracing to detect water flows from sinkhole to spring.

Dye tracing requires guesswork, Ye said. It's "like hunting a treasure."

Florida Geological Survey technicians poured lime-green fluorescein dye into the sinkholes, then placed monitors at likely outflow sites downslope. None detected the diluted dye. The researchers also placed cheaper charcoal packets at less likely locations. One of those sites, Natural Bridge Spring, 32 kilometers away, turned up evidence of the dye.

The method would remove the guesswork of dumping dye into a sinkhole and expand the understanding of the karst aquifer at lower cost and effort.

Heavy Signatures

Connecting the dots with dye was only step one. The team next explored whether isotopes could also establish the hydraulic connection.

Isotope signatures are a common method for assessing groundwater origins. A small percentage of oxygen molecules are ^{18}O, "heavy isotopes" that evaporate less readily than common ^{16}O isotopes, giving lake signatures a substantially higher proportion of ^{18}O than groundwater or rainfall. Knowing the isotope signatures of the sinkhole, spring, and groundwater, the researchers determined that roughly 8.5% of Natural Bridge Spring water originated at Lake Miccosukee.

That mixing fraction was based on pairs of water samples. Using weekly water samples, the researchers compared isotopes from Natural Bridge Spring to isotopes collected earlier at Lake Miccosukee. They found that the dye reached the spring 18 days after application at Lake Miccosukee, and the presence of the dye at Natural Bridge Spring peaked at day 34. Removing the effects of rainfall, the isotope ratios at both sites were perfectly correlated 35 days apart, demonstrating a hydraulic connection and validating the expected transit time.

Connecting Dots Underground

The researchers now plan to reverse the process, tying a spring back to its source and using isotopes as a primary confirmation method.

By collecting regular water samples from area springs and sinkhole lakes, researchers can look for isotope ratio trends over time. Possible connections can be confirmed with dye tracing. The method would remove the guesswork of dumping dye into a sinkhole and expand the understanding of the karst aquifer at lower cost and effort, researchers said.

"What they're exposing here is a very sound method to backtrack type of infiltration," said Joanna Doummar, an assistant professor of hydrogeology at American University of Beirut who was not involved in the research.

Using isotopes to connect the dots allows hydrogeologists a wider window of sampling and evidence. "[Dye] tracing is very important, but it's very static," said Doummar. "It doesn't tell you how this is varying through time."

Ultimately, knowledge of the subsurface system will help water managers protect spring water at its upslope entry point. Knowing the transit time and the mixing fraction will also help managers gauge threats, as contaminants may decay or dilute while traveling through the aquifer.

"It's really important, given the heterogeneity of this infiltration, to detect all these areas and identify all the transit times," Doummar said. "With the assumptions that [Ye and his team] have taken, which are very legitimate, they have exposed a method to backtrack the percentage of water coming from the sinkhole."

Until the system is developed, Ye and his collaborators will continue treasure hunting. A 1,618-hectare Florida lake completely drained into a sinkhole in early June, offering another chance to explore the aquifer with bags of organic dye.

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

Food Security Lessons from the Vikings

Viking and pre-Viking agricultural practices (as presented here in the living history of Fotevikens Museum in Sweden) were influenced by climate and may help modern communities adjust to climate change. Credit: Fährtenleser/Wikimedia

Farming practices of the Vikings and their ancestors could provide inspiration for resilient food systems today. This is thanks to a study exploring how Scandinavian societies adapted their agricultural activities in a period of European history marked by stark climate fluctuations.

The Viking Age kicked off around 800 CE as societies in Scandinavia expanded, partly as a result of a rise in temperature that allowed agriculture to flourish. Historians believe that a growth in population and the pressure it placed on available farmland were reasons Vikings began venturing beyond their homelands.

In popular culture today, a lot of focus is placed on Viking raids and attacks on religious sites, partly because many firsthand accounts were written by besieged Christian scholars. But archaeological evidence suggests that above all else, Vikings were agriculturalists who cultivated crops and reared livestock, often on self-sufficient farms.

"Our findings demonstrate that climate already changed in the past—it is not something new—and societies had to adapt to it already 1,500 years ago."

Less is known about farming practices in pre-Viking societies, those existing in an era known as the Dark Ages Cold Period. During this half millennium between 300 and 800 CE, northern Europe experienced cold climates driven by volcanoes spewing gases and dust into the atmosphere, which reduced the amount of solar radiation reaching Earth's surface.

Constructed between the 5th and 6th centuries, Rakni's mound is one of the largest barrows in northern Europe and near the site of new research into the farming practices of pre-Viking societies. Credit: Øyvind Holmstad/ Wikimedia, CC BY-SA 3.0 (bit.ly/ccbysa3-0)

Digging in the Mud Near Rakni's Mound

The new research finds evidence that a community in Norway responded to this climate turbulence by regularly adapting its cereal production and animal husbandry practices. It is one of the first studies from a multidisciplinary project called Volcanic Eruptions and their Impacts on Climate, Environment, and Viking Society in 500–1250 CE (VIKINGS).

"Our findings demonstrate that climate already changed in the past, it is not something new, and societies had to adapt to it already 1,500 years ago. This shows that we also have to adapt to the rapid climate change we observe today in order to maintain and improve our food production," said Manon Bajard of the University of Oslo, who presented the research in April at the European Geosciences Union General Assembly 2021.

"Over generations, hard-won experience taught a farmer what works and [that] experiments could be fatal."

Bajard's team analyzed sediments from Lake Ljøgottjern in southeastern Norway. Lake Ljøgottjern is located next to Rakni's mound, one of the largest barrows in northern Europe. Previous archaeological studies have dated the mound's construction to the mid-6th century and found extensive evidence of farming and food preparation activities in the area.

Bajard and her colleagues steered a raft to Ljøgottjern's deepest section, where lake bed sediments are least affected by lateral flows. By lowering a weighted tube, they retrieved a 6-meter sediment core. Muds have been accumulating at Lake Ljøgottjern since the last glacial retreat more than 10,000 years ago, so the sediments contain clues about the area's history.

Mud cores from Lake Ljøgottjern contain sediments dating back to the last glacial retreat. Credit: VIKINGS project/University of Oslo

To analyze the core, Bajard's group used carbon-14 dating to identify the section corresponding to 300–800 CE. Past temperature fluctuations were reconstructed from calcium deposits: During warmer periods, there was more biotic activity in the lake, which resulted in a greater accumulation of calcium carbonate deposits on the lake bed.

The key finding was that warmer phases were dominated by the cultivation of crops, whereas cooler phases were dominated by livestock farming. Manon's team, as well as archaeologists working at Rakni's mound, suggested that it is not surprising that farmers would rely more on animals during colder periods (when crop yields are reduced) and are reexamining archaeological evidence to support this theory.

Pollen grains in the core revealed the types and extents of staple crops, which included rye, wheat, and barley. Overall, cold periods corresponded to reduced crop yields, with barley being the most affected by climate shifts.

Animal grazing near the lake was inferred from the core's quantity of *Sordaria,* fungi that thrive on animal feces. Small quantities of DNA recovered from the core also revealed the presence of cows, pigs, and sheep.

Strategic Farmers

Bajard said Viking ancestors may have strategically prioritized the best land close to the community for crops. During warmer periods when harvests were more robust, animals were relocated to areas less suitable for crops, perhaps land that was still forested.

"Later, during the Viking Age and Middle Ages, both activities were occurring at the same time, but it was much warmer then, so the cultivation area could have been extended," Bajard said.

To build a more complete picture of how farming practices evolved, Bajard's team will try to collect more DNA samples from near the lake to start quantifying how the mix of animal types varied over time.

Peter Hambro Mikkelsen, an environmental archaeologist at Aarhus University in Denmark not involved in the VIKINGS research, said that food producers today might learn from this community's ability to diversify. "Over generations, hard-won experience taught a farmer what works and [that] experiments could be fatal. As opposed to modern farming where specialization is the key to large-scale production, traditional agriculture *knows* that when weather fails, livestock can perish—and the enemy can be at the gates of one's village."

By **James Dacey** (@JamesDacey), Science Writer

Astronomers for Planet Earth

NASA astronaut Karen Nyberg enjoys a view of Earth from the windows of the International Space Station in 2013. Credit: NASA

There is no escaping the reality of the climate crisis: There is no Planet B. A group of astronomers, united under the name Astronomers for Planet Earth (A4E), are ready to use their unique astronomical perspective to reinforce that important message.

A good number of exoplanets may potentially be habitable, but humans cannot simply cross the vast distances required to get there. And other planets of the solar system, although accessible, are all inhospitable. "Like it or not, for the moment the Earth is where we make our stand," Carl Sagan famously wrote in his 1994 book *Pale Blue Dot*. The book's title is based on the eponymous image showing Earth as small, fragile, and isolated. Sagan's reflection on the image shows that astronomers can have a powerful voice in the climate debate.

"Let's get real, and let's figure out how to make sustainability the key part of what our institutions do in addition to astronomy."

Astronomy, a Field with a Reach

The beginnings of A4E go back to 2019 when two groups of astronomers, one from the United States and the other from Europe, decided to join forces. Today the network numbers over a thousand astronomers, students, and astronomy educators from 78 countries. "We're still trying to get ourselves together," said Adrienne Cool, a professor at San Francisco State University. "It's a volunteer organization that's grown rapidly."

Astronomy, its practitioners note, has a surprisingly wide earthly reach. "We teach astronomy courses that are taken by, just in the U.S., a quarter million students every year," said Cool. "That's a lot of students that we reach."

And their influence goes way beyond students. Each year about 150 million people visit planetariums around the world. Astronomers also organize countless stargazing nights and public lectures. Perhaps more than any other discipline, some researchers think, astronomy has the opportunity to address masses of people of all ages and occupations.

Toward Sustainable Science

There is no guide for how best to incorporate climate science into an astronomy lecture. A4E works as a hub of knowledge and experience where astronomers can exchange teaching and outreach material. Members also learn about climate science and sustainability from regularly organized webinars.

However, although astronomers are spreading their message, they also acknowledge the need to address the elephant in the room: Astronomy can leave a significant carbon footprint. "I don't feel comfortable telling the public, 'Look, we really need to make a change,' and the next moment I'm jumping on a plane for Chile [to use the telescopes]," said Leonard Burtscher, a staff astronomer at Leiden University in the Netherlands. "That's a recipe for disaster in terms of communication."

On average, an astronomer's work-related greenhouse gas emissions are about twice as high as those of an average citizen in a developed country. The emissions per person are many times above the goal set by the Paris Agreement to limit the global increase in average temperature to less than 1.5°C relative to preindustrial levels.

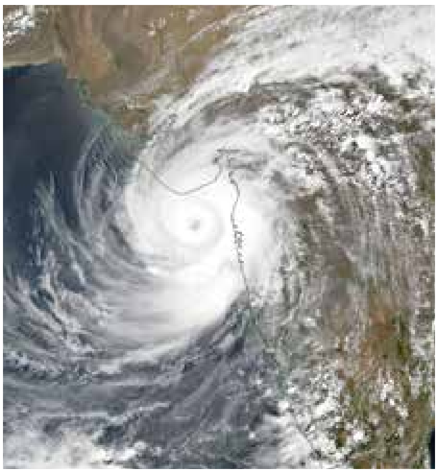
At a recent virtual conference of the European Astronomical Society, hosted by Leiden University, A4E organized a session in which astronomers and climate crisis experts discussed the measures that would help reduce the carbon footprint of astronomy. Observatories and institutes are moving toward a greater reliance on renewable energy, and plans for future facilities take carbon assessment into account.

Perhaps the most contentious topic of discussion in academia is air travel. One solution is to hold fewer in-person conferences, as studies have shown that moving conferences to a virtual setting dramatically reduces the carbon footprint. "Good things [come] out of virtual meetings," said Burtscher. "Better inclusivity, lower costs, often a higher legacy value, recordings of talks and discussions." On the other hand, proponents of face-to-face meetings argue that a virtual setting impedes the fruitful collaborations and networking that are especially important for young scientists. In the end, the community will likely have to make a compromise.

The impetus for change is strong. More than 2,700 astronomers signed an open letter released on Earth Day 2021 in which they recognized the urgency of the climate crisis and called for all astronomical institutions to adopt sustainability as a primary goal (bit.ly/astronomer-letter). But this is just the beginning, and the time for action is ticking away. "So let's get real, and let's figure out how to make sustainability the key part of what our institutions do in addition to astronomy," said Cool.

By **Jure Japelj** (@JureJapelj), Science Writer

Cyclone Tauktae Documents a Climate Trend in the Tropics



Cyclone Tauktae was the strongest cyclone to hit the Indian state of Gujarat in more than 20 years. Credit: NASA

On 18 May, Cyclone Tauktae hit the coast of Gujarat, a state in western India, with peak wind speeds of about 220 kilometers per hour. Other western states like Maharashtra, Goa, Karnataka, and Kerala and the union territory of Lakshadweep also witnessed heavy rains and storm surges. As of late May, the death toll stood at more than 90.

Cyclone Tauktae documented a startling climate trend, given that the Arabian Sea, with its cooler temperatures, was once considered to be calm relative to the warm and stormy Bay of Bengal on India's eastern coast.

"Unlike Bay of Bengal, the Arabian Sea was not entirely a warm pool until recently. Hence, while Bay of Bengal had two to three cyclones a year, the Arabian Sea had almost none or barely one. Now that is changing due to the rapid warming," said Roxy Mathew Koll, a climate scientist at the Indian Institute of Tropical Meteorology (IITM) and author of several reports released by the Intergovernmental Panel on Climate Change (IPCC).

Rapid Intensification

Vineet Kumar Singh, a research fellow at IITM, agreed. "We have observed that the Arabian Sea has warmed up by around 1.4°C in the last 40 years in the premonsoon season, which can be attributed to global warming," he said. "We have [also] observed that the intensity and frequency of cyclones in the Arabian Sea [are] increasing."

In fact, according to data from the India Meteorological Department, Cyclone Tauktae marked the first time in 40 years that premonsoon (April–June) cyclones appeared for four consecutive years (2018–2021) in the Arabian Sea.

In addition, "recent cyclones in the Arabian Sea are exhibiting rapid intensification, where they intensify from a weak cyclone to a severe cyclone in a short time," said Koll. An intensification of 55 kilometers per hour in less than 24 hours is defined as rapid intensification.

"Cyclone Tauktae underwent rapid intensification—[it] intensified by 45 knots [83 kilometers per hour] in the 24 hours," Singh explained. He noted that in addition to sea surface temperatures being 1.5°C–2°C higher than normal prior to the genesis of Cyclone Tauktae, "the ocean heat content, which is a proxy of the surface and subsurface combined ocean energy, also was very high."

Singh is the lead author of two papers—one based on Cyclone Fani (bit.ly/fani-study) and another on Cyclone Ockhi (bit.ly/ockhi-study)—that show how warm ocean surface and subsurface conditions are fueling the rapid intensification of cyclones in the northern Indian Ocean.

"We need to disaster-proof these regions, using both natural and artificial defenses and methods."

Warm Ocean Pools

According to IPCC's Fifth Assessment Report, oceans have absorbed more than 93% of excess heat from greenhouse gas emissions since the 1970s. "This is causing ocean temperatures to rise," the report stated.

Such warm temperatures provide conditions conducive to the formation of tropical cyclones. Koll explained how tropical cyclones generally form over warm pools in the ocean, where temperatures are permanently above 28°C. Cyclones draw their energy from the heat and moisture supplied by the warm ocean waters below.

Previous research by Koll noted how the western Indian Ocean has been warming for more than a century, at a rate faster than any other region of the tropical oceans.

Assessing and Strengthening India's Preparedness

India is reeling under the COVID-19 pandemic; as Cyclone Tauktae struck, the country recorded 259,551 new cases and more than 4,200 deaths. Despite these immense challenges, India did a good job dealing with Cyclone Tauktae, Koll said. He pointed to how weather and ocean agencies forecast the cyclone's impacts well in advance and how disaster response teams and local administrations worked together to evacuate people in time.

As for what India should prepare for in the future, Koll said that "there is a heightened risk on the west coast that we need to assess and work on in terms of adaptation and mitigation. What we need to do first is a risk assessment that can demarcate the regions where the risks of cyclones and other severe weather events are largest. Based on that, we need to disaster-proof these regions, using both natural and artificial defenses and methods."

Coastal mangroves, for instance, are a natural form of floodwater defense in India. According to a 2005 study that analyzed storm protection functions of the Bhitarkanika mangrove ecosystem in the eastern Indian state of Odisha, villages that were located behind mangroves during the 1999 Odisha cyclone suffered less damage than those that did not have mangrove wetlands (bit.ly/mangrove-storms).

Gujarat, the state hardest hit by Cyclone Tauktae, has one of the largest areas of coastal wetlands in the country, and several organizations are developing mangrove restoration programs to help mitigate damage from cyclones and other effects of climate change.

By **Rishika Pardikar** (@rishpardikar), Science Writer

Higher Education During the Pandemic: Truths and Takeaways

The changes to teaching and learning at colleges and universities that many of us thought would last a few weeks in the spring of 2020 have turned into more than a year's worth of disruptions. For both students and instructors, these disruptions have interrupted, set back, and, in some cases, irrevocably altered personal and professional lives and relationships, and they have severely strained mental—if not also physical—health.

The forced adaptations have also exposed unresolved and problematic realities in academia that long predate the pandemic, leading to difficult discussions but also creating welcome space for fresh perspective and growth. We reflect here on some of the negative and positive outcomes we've seen over the past year, as informed by our own experiences with students and colleagues.

Displaced and Disrupted

Pandemic disruptions to teaching, learning, and life took many forms. When colleges and universities instituted social distancing measures and turned to remote instruction, undergraduate students were rushed off campus. Many returned to family homes, where they were isolated from friends and lost the autonomy they had been cultivating while living independently. Subjected once again to household rules set by parents or other guardians, these students were essentially infantilized during the pandemic. Yet their institutions expected them to be mature adults and to keep to academic schedules as if nothing had changed. Many of our students relayed to us that they felt untethered, overwhelmed, and unable to sift through endless directions and FAQ pages from the schools about rapidly evolving pandemic protocols.

When colleges and universities turned to remote instruction, many undergraduate students returned to family homes, where they lost the autonomy they had been cultivating.

Meanwhile, graduate students lost access to facilities integral to their research, from offices to laboratory analytical equipment to field sites. They were expected to teach and learn online skillfully and to adjust without complaint. Their support networks became frayed as colleagues and mentors dispersed from campus.

For some students, the burdens of these changes were especially acute. As educators we both work at large public institutions, where up to one quarter of our students are the first in their family to attend college and up to 20% are international students. These students' lives were suddenly and disproportionately upended by displacement, underresourcing, isolation, and, in some cases, repatriation.

At the same time that students were doing their best to adjust to the new landscape of higher education, so too were faculty and instructors. Among other challenges, individuals had to adapt in-person course materials, teaching styles, and mentoring duties to fully remote environments, on the fly. They had to reconfigure research programs to account for pandemic restrictions. And many faced the added complexity of maintaining professional responsibilities while caring full-time for loved ones also displaced from their usual routines. We, like many of our colleagues, often reminded ourselves of the phrase "I am not working at home because of the pandemic; I'm at home due to the pandemic—trying to work."

Remote teaching brought important changes to student-teacher relationships. Prior to the pandemic, we took for granted the simple joys of greeting students when they arrived at class, helping facilitate discussions around our course content, and getting to know students—their career aspirations, their challenges, and their interests. During the pandemic, we have still held classes and office hours, conducted research, and mentored students—but all virtually. Although Zoom and other such tools are amazing technological innovations that have enabled us to perform our work, they tend to dull the emotional and personal connections that face-to-face contact builds.

Emotional Tolls

Although we hope the vaccines developed to protect against COVID-19 will enable a full return to prepandemic life, the experiences we have shared with students and colleagues throughout the pandemic will remain with us, with some hanging as shadows over the coming years of social and economic recovery. Of course, these experiences have also been influenced strongly by events not directly related to the pandemic, such as the attack on the U.S. Capitol and the murders of George Floyd and others as well as the large-scale demonstrations in support of racial justice. Among other effects, these events have brought heightened attention to systemic racism and injustice in many institutions, including our own, and have added substantially to the emotional and physical stress of the pandemic for many in academia, particularly people of color.

We put ourselves through secondary trauma in supporting our students, colleagues, family, and friends while trying to carry on ourselves and maintain our own well-being.

Against this backdrop, the pandemic has forced academia to grapple with declining mental health among students and faculty, a trend that began well before 2020 [*National Academies of Sciences, Engineering, and Medicine* (*NASEM*), 2021a], particularly in science. Research has shown that in many cases, student learning and grades have improved during the pandemic, although these successes came with emotional costs.

In spring 2019, prior to COVID-19, three out of five college students reported experiencing extreme anxiety, and two out of five reported debilitating depression sometime in the preceding 12 months [*American College Health Association*, 2019]. In the past academic year, the trends in mental health have drastically worsened [*NASEM*, 2021a] as students were deprived of the ability to engage with others; to participate in educational extracurricular activities and travel; and to pursue many professional and personal opportunities such as internships, fieldwork, and spring break. Moreover, many of our students have contracted COVID-19, including students in our research groups and in all of the courses we teach, and those who have not tested positive themselves have still had to deal with the virus affecting friends and family.

Faculty, who have long faced tremendous dysfunction in career expectations and work-life balance—especially those who are early-career, women, and people of color—are also depressed, stressed, and burned out [*NASEM*, 2021b]. As of last fall, almost 9 out of 10 faculty surveyed agreed (33%) or strongly agreed (54%) that our jobs had become more difficult, 40% reported considering leaving the profession, and 48% of that number were early-career faculty (bit.ly/difficult-jobs). These stark figures partly reflect the emotional toll of taking on roles as informal, mostly untrained, and often poorly equipped mental health counselors to our students, which left faculty and students at risk.

Faculty became critical elements in the support networks for many of our students, requiring us to share additional empathy and to develop new ways to connect, in virtual environments, with students suffering emotionally and physically. We also became critical conduits for sharing university-wide information, from academic schedule changes and new grading modalities to rent relief options in the community and plans for packing up dorms and apartments. This role required keeping up to date with frequently changing policies and information so we could share it clearly and quickly.

Make no mistake: This emotional work, called affective labor, is difficult—and it is labor indeed. Affective labor is the work associated with managing your own feelings when things are going to pieces around you—when others are upset, frightened, or angry. We put ourselves through secondary trauma in supporting our students, colleagues, family, and friends while trying to carry on ourselves and maintain our own well-being.

Because this care work has been borne mostly by women faculty and faculty of color, resulting impacts on careers—such as decreased research productivity and delayed promotions—will fall disproportionately on these groups and will affect academia for years to come.

Lights in the Tunnel

Despite the disruptions and added affective burdens placed on students and faculty throughout the pandemic, there have been some positive outcomes to emerge. We speak here not about the learned benefits of technology or of asynchronous learning and other pedagogical adaptations but, rather, of the emotional rewards we experienced during this time.

Students and faculty bonded like teammates in spring 2020. We struggled with the technology needed for remote instruction, our students struggled with the technology, and we all learned it together. When pets, children, and spouses made visits to our home offices, our students loved seeing us get rattled, because it reminded them of our humanity. They started sharing their pets on screen, and everyone enjoyed getting to know more about one another. Students also shared the stresses of their family situations. We made as many adjustments as we could to help them get through each semester, including changing deadlines, amending or canceling assignments, and just simply listening to them.

The door to richer teaching and learning experiences has been opened during the pandemic.

Not surprisingly, the camaraderie waned as the pandemic progressed, and by the end of the spring 2021 semester, many students were exhausted from remote learning and the loss of the college environment. This transition only increased the emotional workload for faculty and led to increased frustration and fatigue.

Nonetheless, the door to richer teaching and learning experiences has been opened during the pandemic. Faculty have opportunities to embrace the role we play in helping students transition to adulthood and to recognize that course content is not the only currency of value to our students. It humanizes us, and our students, when we take the time to get to know them, to open up ourselves, and to admit to the stresses, emotions, and frustrations with which we struggle.

Faculty in science, technology, engineering, and mathematics (STEM) disciplines have historically taken a pass on doing this

It can make a big difference in helping STEM faculty and their students recover from the myriad disruptions of the pandemic and reshape what postsecondary teaching and learning look like.

sort of emotional work. In our classrooms, we traffic in content—observations, calculations, and hypotheses—not in personal stories and cultural issues. We have often told ourselves, "Science doesn't see color or gender," "I couldn't possibly deal with racism because I teach science," and "Science is not driven by society," although in each case there is much evidence to the contrary. If we have learned nothing else from the pandemic, we have seen that both we and our students value a more personal approach to instruction.

Outside the classroom as well, there are many things that faculty can do to help themselves and each other: foster, renew, and make new connections with mentors, advisers, colleagues, friends, and family; and develop or continue activities that provide a sense of community among instructors. At the University of Michigan, for example, faculty have set up monthly teaching circles—held virtually during the pandemic—at both departmental and college levels. Teaching has often been a lonely endeavor and not the topic of hallway discussions at research universities, so these regular opportunities to meet have enabled needed support networks and chances to learn and grow professionally. AGU's Education section also provides resources and a venue in which to find, connect with, and support other Earth and space science faculty, both professionally as colleagues and personally as friends.

The affective labor of connecting more deeply with students and colleagues takes time and energy—but it matters. It can make a big difference in helping STEM faculty and their students recover from the myriad disruptions of the pandemic and reshape what postsecondary teaching and learning look like.

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REIMAGINING STEM WORKFORCE DEVELOPMENT AS A BRAIDED RIVER

Career prospects for trainees in science, technology, engineering, and mathematics (STEM) are growing, but today's opportunities are not always like the traditional science careers of the past. Individuals move in and out of roles and positions in which they consult, start businesses, and hold jobs across disciplines and sectors. People take many paths through school and weave careers around an assortment of circumstances, such as rearing families, serving in the military or volunteer corps, fulfilling caregiving responsibilities, or reengaging with formal education. These experiences bring new ideas that are more creative, practical, and interdisciplinary solutions to science.

The traditional "pipeline" model of workforce development—whereby an individual follows a fairly linear, predictable, and structured path through K-12, undergraduate, and graduate education into career-length government or academic positions—no longer captures the reality of a modern STEM career. Nor does it represent the broad range of interdisciplinary and innovative opportunities that STEM professions now offer across a wide range of industries, nonprofits, and other organizations. The pipeline model has also contributed to the historical exclusion of individuals from minoritized ethnic, racial, sexual and gender identity, disability, and service status communities [e.g., *Bernard and Cooperdock*, 2018].

It is time for us to dismantle the pipeline. Instead, let's take inspiration from the natural world we study and envision a new model that captures the opportunity, variability,

A braided river in New Zealand. Credit: Findley Watt, stock.adobe.com and responsiveness of a modern STEM career; that embraces the diversity and experiences of the people who engage in it; that recognizes the many on-ramps, pathways, and career pivots that real life induces; and that provides a framework in which there is a place in STEM for everyone. This is the braided river model.

A New Analogy for a Modern Career Path

A braided river is a wide, shallow system comprising numerous interwoven and changeable channels separated by small islands. Braided rivers usually originate in steep, mountainous regions and contain varying amounts of water and river substrate, with the riverbed constantly changing and adapting to flow and sediment load. The water's movement shapes landscapes, transports nutrients, and supports life. The braided river provides an ideal analogy for inclusive, responsive, and modern career development.

Using the braided river as a model for STEM, and specifically for geoscience workforce career development, challenges us to think holistically about learning ecosystems, as illustrated in Figure 1. This model allows us to perceive varied pathways into and within STEM careers and to better appreciate unusual entry points, evolving occupational goals, and opportunities for lifelong continuing education. In this way we normalize the idea of individuals changing pace and direction as circumstances and opportunities arise, and we can create support structures that accommodate and empower people to stay in the field. The model allows us to recognize that barriers present different degrees of challenges for each person, and in response we can create flexible and adaptable solutions and assign real value to the skills, tenacity, and insights brought to our science when these challenges are overcome.

Fostering a system in which many paths can meet and diverge requires us to envision scientific knowledge and training as part of an ecosystem. Rather than the solitary path down a pipeline, we acknowledge that STEM work benefits from partnerships with nonscientific experts and industries, policymakers, and communities, which together help us to understand and address the changes in our physical and human landscape—and to elevate the value of STEM skills across a wide range of professions.

By intentionally working to structure professional and career development to embrace the wide, varied, and inclusive pathways that careers in STEM offer, we create a more inclusive and supportive environment. Scientists from all backgrounds and identities can thrive in an environment that values their contributions, works with rather than against their lived experiences, and is responsive to future opportunities.

How might the braided river model look in practice? At each stage of development, we draw from the now extensive knowledge of diversity and inclusion in STEM [e.g., *National Academies of Sciences, Engineering, and Medicine*, 2011, 2016, 2019, 2020]. We consider not just whom to reach and where they might enter the field, but how we are making sure that each individual is engaged and supported along their journey.

A braided river is a wide, shallow system comprising numerous interwoven and changeable channels separated by small islands.

Accommodate Many Water Sources

A pipeline has one main entry point. If you miss that entry, you might be left out of the pipe permanently, or, if you're fortunate or ambitious enough, you might be able to painstakingly plumb in your own entry point. The braided river model allows people to flow from multiple points into a STEM career.

While we strive to inspire and encourage students to pursue an interest in the geosciences throughout their precollege schooling, we know that opportunities to engage in the geosciences in school are highly variable and often not equitable. Fostering robust partnerships with community organizations that can engage young minds with Earth science topics through informal learning, especially in disadvantaged communities, and working with teachers to bring geoscience content to their classrooms can gently direct more potential scientists to a river they otherwise might not have known existed.

For students who make their way to college, many discover through electives that their love of the geosciences offers a career path—a so-called "discovery major." Yet few community colleges and minority-serving institutions offer geoscience classes, so many students don't discover the discipline at all. Let's expand to more students opportunities for the discovery of this exciting discipline that can lead to a rewarding profession.

Colleges and universities can work with local schools to raise awareness of geoscience careers. Partnerships between community colleges and research-intensive universities can help build bridges through aligned prerequisites, transfer support, and extracurricular opportunities. Research internships, such as those offered by the Research Experiences for Undergraduates (REU) program, offer learners the opportunity to apply their skill sets to geoscience research, while community-based participatory research programs and crowdsourced science projects can connect geoscience concepts with community needs. Apprenticeships can be developed that demonstrate how geoscience skills are used in industry and offer students the opportunity to observe and learn from professional geoscientists, and professional organizations can develop resources that help students understand the pathways to geoscience careers.

What about people who begin in non-STEM professions or disciplines but become inspired to change career paths? We can facilitate their transition into the geosciences by recognizing and encouraging them to capitalize on the diverse skill sets they'll bring with them. Employers should facilitate this entry by offering tailored training programs or certificates, short continuing education courses, career mentorship programs, and more inclusive recruiting that would help create easily traversable channels from one stream to another.

We must also recognize that so much geoscience knowledge lies within communities and outside of formal education institutions. The pathways of our river do not solely represent careers—they also represent the relationships we make to enrich our scientific work. We must become better at weaving our knowledge with that of Indigenous and local communities who have historical connections with the land we study. It should be a natural part of our research to create partnerships with the communities whose lives and livelihoods are affected by the challenges we are working to solve. Similarly, we should more openly engage with industry and nongovernmental organizations that have the resources, networks, and infrastructure that could be better used to serve our planet with direct access to our scientific research.

Support Braided Pathways

Once we've guided someone to one of the many entry points to a geoscience career, we

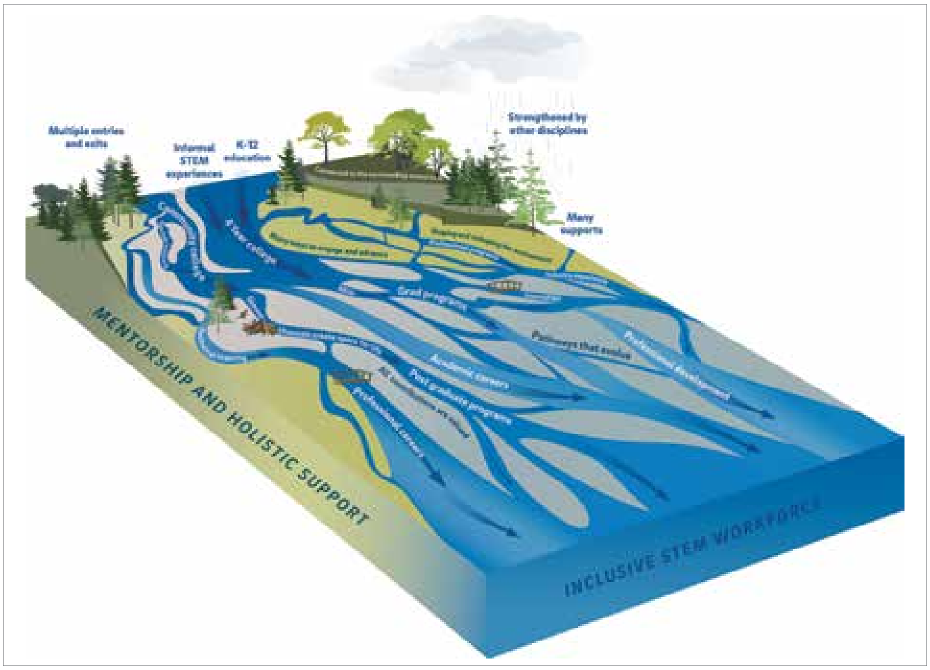

Fig. 1. A braided river system illustrates a new, holistic STEM workforce career development model. Credit: Jennifer Matthews

must keep in mind the individualized pathways they will take throughout that career. Embracing the braided river system as a model means creating ways to support, retain, and, as necessary, reengage science professionals, whatever their route, wherever they join, and whatever the speed of their journey.

A new system, however, requires systemic changes. Educational and scientific institutions need to rethink graduation, promotion, and tenure requirements to account for more varied pathways and timetables. Interdisciplinary learning tracks can lead to degrees that connect social and physical sciences, or offer supplemental education that can be pursued while working in industry or nonprofit sectors. If the scientific community wants to include large swaths of people who deal with even basic life events, employers must provide reasonable parental leave and realistic part-time opportunities, and create clear pathways for reentry into the community, such as funding opportunities specifically for midcareer scientists who return after other life ventures.

Rather than mentoring programs directed at supporting only young scientists, we should promote mentor relationships at all career levels and stages, across disciplines and industry-academia boundaries, and even among peers. Let's normalize the idea of having multiple mentors, sponsors, cohorts, and other professional support to reduce dependence on a single gatekeeper, diversify our knowledge of our colleagues' experiences, and enhance our overall feeling of belonging to this rewarding professional community.

Finally, we cannot make progress in building a more flexible career model if we do not recognize and value the work of broadening participation, in practice and in reward structures, and if we do not acknowledge that mentoring, true collaboration, and community partnerships take time to develop. Success in science should be measured not just in citations but also in broader positive impacts.

Dismantling the Pipeline

As our climate changes and technology evolves, we need more people with exceptional science skills and the creativity that comes from diverse teams with different experiences to solve the quandaries of our time. The pipeline career model no longer works to characterize the array of educational and career pathways into and within STEM, nor does it meet our need for developing a diverse, engaged, and supported workforce.

The braided river illustrates the larger ecosystem that scientific professions—and the institutions that support them—are a part of. We can move toward this model by working consciously to know and share the varied opportunities that a modern geoscience career encompasses; by profiling careers that serve our communities, protect our environment, and engage across all sectors; and by recognizing these contributions in our teaching and professional development offerings. Students and their families will see meaningful, well-paying jobs that expand the vision of what "being a geoscientist" might be. We'll recruit or retain midcareer professionals. We want people from all backgrounds and identities to thrive and to tackle the pressing challenges facing our planet.

Acknowledgments

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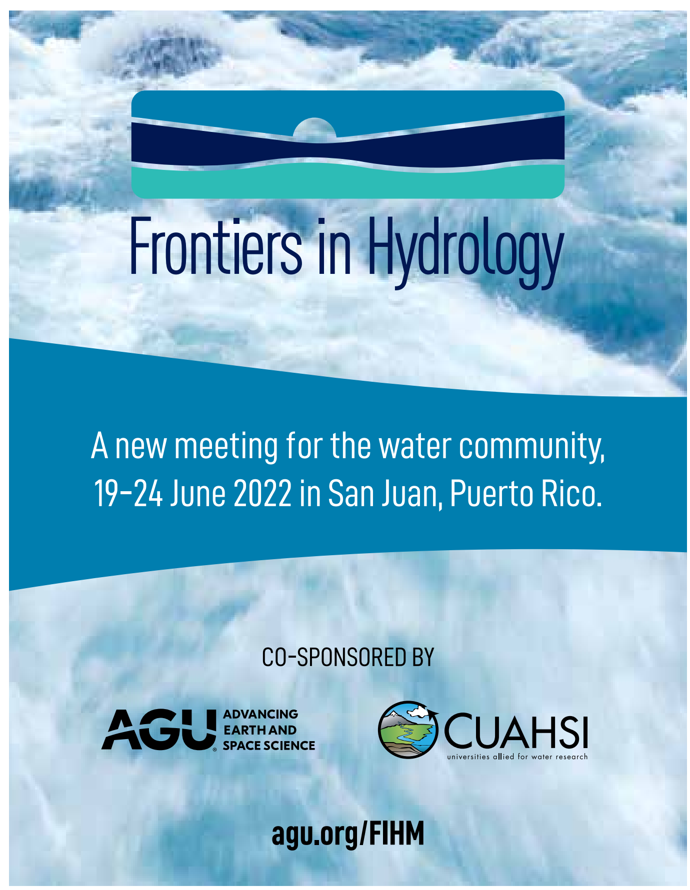
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Choose Your *Own* ADVENTURE

There's no one way to be a scientist. Read on to meet a group of professionals who discovered that their route wasn't limited to the well-lit avenue.

IS THERE A SINGLE PATH THAT LEADS ONE TO A CAREER IN SCIENCE? Do you start with a wide-eyed curiosity about the way the world works that leads you to an undergraduate science major, followed by a Ph.D. program to winnow your specialty, and, finally, into an academic institution to enrich the scientific body of literature with your discoveries? For many, this is a rewarding path, but it is not nearly the only one available to those who want to pursue science as their livelihood today.

In the following pages, you'll meet 17 scientists who have traversed a wide array of pathways to find exciting careers. They didn't always know exactly where they were headed! Many felt real fear in wandering off the main road. We are grateful to each of these scientists for giving us a glimpse of the journey that has led them to both personal and professional success.

Featured here are museum officials and historians, business owners and military veterans, policy wonks and journalists, and yes, academic researchers—all of whom have enriched our global community with their scientific expertise. Together, the paths they've forged create a captivating map of the world of science available to all of us. We hope you share this with the wide-eyed, curious youngsters in your life who are looking ahead to a career of discovery or even use it to find a new adventure for yourself. Either way, please enjoy the travels of our featured scientists in this special careers issue.

—The Editors

Gladkov/Depositphotos

Chanard (third from right) on the "Roof of the World" in Nepal, where she helped install a GNSS station with Bharat Koirala (second from left), Thomas Ader (second from right) and John Galetzka (far right) and their porters. Credit: Kristel Chanard

KRISTEL CHANARD

Trekking and Tracking Mountains

AS A CHILD, KRISTEL CHANARD loved reading books about mountaineering adventures. She often imagined herself going on expeditions through the Himalayas. But at home in the suburbs of Paris, she was a tinkerer—like her father, who enjoyed taking things apart to show his daughter how they worked.

Chanard spent her first 2 years at university studying math and science, with an eye toward becoming an engineer and building satellites. Then she realized that the students studying geology and Earth-related problems got to spend significant parts of their studies outside. "Geology is what got me out into the field," she said.

Chanard switched her focus to the geosciences, and within a month she was hiking the French Alps, exhausted but loving every minute of the fieldwork. Soon she was even working on data from the Himalayas, after she landed an internship at the California Institute of Technology investigating the Asian monsoon cycle with Jean-Philippe Avouac.

When she completed her bachelor's in physics at École Normale Supérieure in Paris, Chanard planned to take some time off. Avouac, however, needed a field engineer in Nepal. Chanard spent a year trekking through the Himalayas—by plane, by horse, and on foot—installing GPS stations to track the movement of tectonic plates.

Then Chanard returned to Paris to pursue her master's and switched her focus from observational fieldwork to experimental work, creating earthquakes in the lab. She realized that to do the kind of research she was interested in—understanding how the solid Earth and climate interact—she would need both approaches.

"To understand some of the questions that we have in Earth science, you need to see it with different perspectives," she said.

Now Chanard is a research scientist in geophysics and geodesy at the Institut de Physique du Globe de Paris and the Institut Géographique National in Paris. She spends her free time in the mountains, hiking and climbing, drawing inspiration for the research questions she wants to ask next, and thinking about how to answer them. "I have the coolest job," she said.

> **"Geology is what got me out into the field."**

Keep up with Chanard's research and adventures by following her website (kristelchanard.weebly.com) and her tweets (@KristelChanard).

—Kate Wheeling

Jennifer Arrigo stands in front of underwater gliders used in a global ocean observing system at the OceanSITES meeting at the National Oceanography Center in Southhampton, U.K. in 2016. Credit: Jennifer Arrigo

JOY SANTIAGO

Charting Safety Through Mapmaking

JOY SANTIAGO settled into the field of geography because of the fascinating way it connected far-reaching topics in ecology, communications, technology, and sociology.

"Geography is kind of a jack-of-all-trades," Santiago said. She became particularly interested in urban planning and the use of geographic information systems (GIS) to make maps. After graduating from the University of the Philippines with her bachelor's degree, she got a job providing technical assistance to users of mapping software.

JENNIFER ARRIGO

Seeking Clean Water for Everyone

JENNIFER ARRIGO was going to be a writer. As an English major at Boston University, she took an environmental science class to fulfill an elective requirement. It ended up changing the course of her career.

Arrigo grew up around Adirondack Park in New York, a region where acid rain and industrial pollution left hundreds of lakes and ponds devoid of life and the Hudson River sediment laced with toxic polychlorinated biphenyls (PCBs). She came of age in a town divided over whether dredging the river would make existing water quality issues better or worse.

> **"I feel like a trusted partner to the academic community."**

So Arrigo was always keenly aware of the kinds of environmental issues that closely affect peoples' lives, and the class opened her eyes to solutions. "I started to understand the science of why [water quality issues] were happening and how you could decide whether one course of action or the other was the right one," she said. "That's when I started thinking this would be a really interesting way to spend my career."

After school, Arrigo worked for a citizen's water quality monitoring network that partnered with the U.S. Geological Survey and the Environmental Protection Agency to collect data used for regulatory requirements. Hooked on fieldwork, she headed back to Boston for a Ph.D. in geography.

Though hydrology was still her focus, Arrigo became increasingly interested in how water and climate interact. As an assistant professor at East Carolina University, Arrigo sought out interdisciplinary opportunities and found what she was looking for in a fellowship at the Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI). After three summers of research and mentoring students with CUAHSI, an opportunity arose for Arrigo to join the organization full-time. As a program director and later deputy director, she helped the organization advocate for the water science community, running conferences, fellowship programs, and working groups.

"It felt like being in grad school because I was expanding my knowledge base of water science, all the different disciplines it sits in, and all the different places that it becomes relevant," she said.

CUAHSI also gave Arrigo a window into the next phase of her career at federal science agencies. She had stints at NOAA and the U.S. Global Change Research Program before landing at the Department of Energy (DOE), where she uses her scientific expertise to solicit and evaluate research proposals and boost collaborations among researchers as a program manager with DOE's Terrestrial Ecosystem Science program. "I feel like a trusted partner to the academic community," she said.

"One of the hardest things for me was figuring out that I wanted something different than academia but not knowing exactly what that was and not knowing how to find the resources and the networks to do that," she said. "Now when people ask me about my career path, I can tell a nice story, and it sounds like a path, but at the time it was really trial and error."

You can follow Arrigo on Twitter (@wxwaterjen) or keep up with her work through DOE's Environmental System Science program (ess.science.energy.gov/).

—Kate Wheeling

> **"I have the satisfaction of helping the Filipino people."**

Two years later, an opportunity arose for her to enter academia, and Santiago became a researcher at Project NOAH (Nationwide Operational Assessment of Hazards), the flagship program of the Philippines for disaster risk reduction, later institutionalized as the University of the Philippines (UP) NOAH Center, which is the core component of the UP Resilience Institute. The Resilience Institute is dedicated to "providing Filipinos with innovative information vital to lifesaving climate change actions and disaster risk reduction efforts" and is a multidisciplinary hub for science, technology, arts, and humanities.

Santiago has moved up through the ranks, first to a supervisory role and then to her current position as a chief scientific research specialist. She and her colleagues work with local governments, performing hazard simulations and risk assessments. As a registered environmental planner, Santiago uses this information to guide local officials on development and land use.

"I have the satisfaction of helping the Filipino people," she said.

The NOAH team interacts directly with local communities, including helping people understand hazards in their neighborhoods. "We'll have tabletop activities where they draw parts of their community, and then afterwards we'll present the hazard maps," said Santiago. In one instance, Santiago and her coworker Jake Mendoza volunteered with an AGU Thriving Earth Exchange project involving island communities in Manila Bay. Santiago created maps to help the communities assess potential impacts of a proposed airport development.

Santiago is currently pursuing a master's degree and hopes to pursue a doctorate to secure her voice in the academic community.

Santiago encourages audiences to learn more about the Resilience Institute's activities on Facebook or Twitter.

—Jack Lee

Credit: Cooper Elsworth

COOPER ELSWORTH

Cycling-Inspired Science

COOPER ELSWORTH can trace many of his career decisions back to his long-standing obsession with cycling. From a young age, he was amazed by the mechanics of the bikes that carried him along the roads and trails of rural Pennsylvania, where he grew up.

He was always interested in understanding how things worked. That interest fueled his undergraduate and master's degrees in engineering, during which he worked on numerical methods to study fluid dynamics. When it came time to pursue a Ph.D., it was the hours he had spent biking, hiking, and kayaking with his family that inspired him to turn to the geosciences.

As Elsworth thought about how to apply his theoretical skills in fluid dynamics to applied science, studying ice sheets seemed a natural transition. "The ice sheets are really just very, very slow moving fluids," he said. "Even more than that, I was excited about working on something climate related. The response of the ice sheets to climate change is one of the biggest unknowns in our projections of

ZDENKA WILLIS

Sailing into a High-Tech Future

ZDENKA WILLIS always loved the ocean. Every summer, her family trekked from Indiana to South Carolina, where Willis and her sisters combed the beaches for sharks' teeth, watched the dolphins swim, and wondered what other marvels were out there, just out of view.

When it came time for college, Willis returned to the Eastern Seaboard to study marine science at the University of South Carolina. Encouraged by her father, who had emigrated from Czechoslovakia and joined the Army Reserves after settling in the United States, Willis applied for a Reserve Officers' Training Corps scholarship. When she graduated in 1981, she became a U.S. Navy oceanographer.

Willis's first assignment at sea was aboard a 122-meter hydrographic research vessel, where she led a small boat crew mapping the ocean floor off the coast of Haiti. In those days, Navy ships were still using paper charts, but as technology evolved and Willis's responsibilities expanded, she helped the Navy transition to digital charts and adopt new weapons systems. Willis loved both the challenges and the opportunities presented by a military career. "You're always being challenged with new ideas and new tasks, and that makes it exciting," she said. "You certainly don't get bored in your job."

In the military, "you're always being challenged with new ideas and new tasks, and that makes it exciting. You certainly don't get bored in your job."

Willis retired from the Navy as a captain in 2006 and went to work for NOAA. There, she became the founding director of the agency's U.S. Integrated Ocean Observing System office, which aims to connect data, tools, and people all along the nation's coasts. It was her broadest mission yet. Willis had spent her Navy career thinking about how what she was learning about the ocean might affect naval operations and warfare, whereas "at NOAA, I had to care about everything from microbes to whales and everything in between," she said.

Willis currently serves as president of the Marine Technology Society, an international organization that "brings together businesses, institutions, professionals, academics, and students who are ocean engineers, technologists, policymakers, and educators" in the advancement and application of marine technologies.

Willis (seated, third from left) with students at Rutgers University and a model of RU 29, *an autonomous underwater vehicle that was part of the Challenger mission in the Indian Ocean. Credit: Zdenka Willis*

Willis is working to make both the organization and the field of marine science in general more equitable and inclusive, adding programs and positions to support young professionals and promote women leaders. She is committed to providing young professionals the same kind of opportunities and support she received in the Navy, where shipmates take care of each other. "The Navy gives you responsibility, expects you to perform, but is a very supporting environment."

To learn more about the Marine Technology Society and its programs, Willis encourages people to follow the society on Twitter (@MTSociety) or through its website (mtsociety.org/).

—Kate Wheeling

> **"It's really valuable, especially in sustainability research, to break down those silos and to realize that we're all moving toward a common goal."**

sea level rise, so it seemed like a really impactful area of research to go into."

Initially, Elsworth felt empowered by basic science research and the opportunity to help answer outstanding questions about the climate system. Like most grad students, he planned to stay in academia. That began to change with the 2016 U.S. presidential election. He watched the results come in from Antarctica, where he was studying how subglacial meltwater influences the large-scale ice flow, and afterward he grew increasingly troubled by the environmental deregulation and climate inaction of the Trump administration.

"We've had climate science saying this is something we need to act on for decades," Elsworth said. He became increasingly interested in how to take that basic climate science and turn it into climate action. Now a Ph.D. candidate in geophysics at Stanford University, he turned his professional interest to the private sector.

Elsworth became an applied scientist and, more recently, a program manager at the sustainability start-up Descartes Labs, where he leads the production of sustainability tools that use remote sensing to track things like carbon emissions from agricultural and consumer goods supply chains.

Now he tells students stressing about life decisions after grad school that academia, private industry, and the public sector aren't as siloed as they seem, nor should they be: "It's really valuable, especially in sustainability research, to break down those silos and to realize that we're all moving toward a common goal and we're trying to solve a common problem."

Elsworth encourages people to reach him through LinkedIn (linkedin.com/in/coopere/) or his personal website (cooperelsworth.com).

—Kate Wheeling

RICK JONES

Finding the High School Spirit

Rick Jones personalizes a Tropical Atmosphere Ocean array buoy with the Billings Senior High School mascot during a Teacher at Sea cruise in 2010. Credit: Rick Jones

IN THE EARLY 1980S, when Rick Jones was studying geology as an undergraduate at the University of Wyoming, the U.S. oil business was booming. He anticipated a well-paid position following graduation and a stable career as a geologist. Then the oil industry went bust.

"[The economy] changed my trajectory," said Jones. He was able to find work at companies that did groundwater monitoring, and in the mid-1980s, Jones found himself overseas, working with a nongovernmental organization installing water utilities in refugee camps. He became involved in sanitation education and quickly saw how "a little bit of education can go a long way." When he came back to the United States, Jones decided to go back to school, getting a second bachelor's degree in science education as well as a master's in natural sciences at the University of Wyoming.

> "I realized that I really need to make sure that I give an opportunity to my students, so that they can definitely go wherever they want to go."

His first job after graduation was as a middle school science teacher in Lihue, Hawaii. The experience was eye-opening: "I got to realize really quicky that I had it pretty easy," Jones said. "I realized that I really need to make sure that I give an opportunity to my students, so that they can definitely go wherever they want to go."

A family circumstance led Jones and his wife to return to the mainland, to Billings, Mont. There, Jones was a middle and high school teacher for nearly 2 decades, teaching everything from Earth science to biology to physics.

"The thing that you're most proud about when you're teaching," Jones said, "is when somebody that you really didn't think that you connected with comes back and says, 'It's because of you that I am a success.'"

Jones has continued to pursue his passion for teaching and learning, both inside and outside academia. He twice participated in the NOAA Teacher at Sea program and obtained a doctorate in education from Montana State University.

Jones has since moved back to Hawaii and is now a geoscience educator at the University of Hawaiʻi–West Oʻahu. He is also president of the National Earth Science Teachers Association, where he aims to instill a love of learning in the next generation of science teachers.

> **"Science is a verb—it's a process, a way of knowing. If science is just a noun, just...facts in the book, well, people aren't going to be interested in being science people, right? It's all about the discovery."**

Find out more about Jones on Twitter (@mtzennmaster), where you can follow his science advocacy as well as see his quilt designs and updates about his 55-year-old Volkswagen convertible, or at his website (bit.ly/career-Jones).

—Jack Lee

Astronomer Munazza Alam researched at Las Campanas Observatory in Chile's Atacama Desert while studying for her bachelor's degree. Credit: Munazza Alam

MUNAZZA ALAM

Searching for New Worlds

FOR MUNAZZA ALAM, pondering the stars is part of being human. "Everyone, at some point, has looked up at the sky and contemplated the cosmos," she said.

Yet as a New Yorker, Alam grew up without truly seeing the stars, because of light pollution. It took a couple of pivotal mentors and a trip to Arizona to bend her trajectory toward the Ph.D. in astronomy that she recently earned from Harvard University.

"I was always a curious child," Alam said. In high school, she channeled this curiosity into physics class, where she was captivated by the way her teacher, Betty Jensen, unveiled the inner workings of the universe. Jensen was also the first woman Alam met who'd earned a Ph.D. in physics. Because of her, Alam started wondering whether academics could be her path too.

Alam wanted to stay in New York City after high school, so she joined the Macaulay Honors College at Hunter College, City University of New York. This selective program covers its students' tuition, which allowed Alam to attend college without going into debt.

Alam knew she wanted to major in physics, but her scheduling adviser told her she needed to choose a specific research direction. Try astronomy, her adviser suggested.

At age 19, a year into her career as an astronomy researcher, Alam traveled to Kitt Peak National Observatory in Arizona. For the first time in her life, the Milky Way stretched before her, without interference from streetlights and apartment buildings. Alam was starstruck. "It's just etched in my brain," she said. The trip solidified her decision to become an astronomer.

> For the first time in her life, the Milky Way stretched before her, without interference from streetlights and apartment buildings. Alam was starstruck.

Alam chose Harvard University for her graduate work because she found the astronomy department exciting and innovative. Her work focused on exoplanets, and she hopes it will one day reveal whether life exists outside our solar system.

> "In my childhood, I remember always asking my parents, 'Why?'"

Although Alam loved her work, she initially found graduate school exhausting. One of the most valuable lessons she learned is that it's OK to take breaks.

As Alam begins a postdoctoral position at the Carnegie Science Earth and Planets Laboratory, she says she's most proud of the network of mentors she's built. She described her Ph.D. thesis adviser, Mercedes López-Morales, as "an absolute phenom," and she's also formed lasting connections with other faculty, staff, and students. To round out the crew, Alam still keeps in touch with her high school physics teacher, who attended Alam's Ph.D. defense this past spring.

Alam welcomes messages through her website, https://bit.ly/career-Alam.

—Saima Sidik

MORGAN REHNBERG

The Making of a Museum Chief

Morgan Rehnberg, at the Fort Worth Museum of Science and History in Texas, where he is chief scientist. Credit: Fort Worth Museum of Science and History

MORGAN REHNBERG described his decision to pursue a job outside the traditional academic career track like choosing to step off a cliff. "You've got to be really sure that there's going to be something out there to catch you," he said. With the fast pace of academic research and the fact that many early-career fellowships disappear a few years after a researcher gets a Ph.D., he feared that "there's no going back 5 years down the road and saying, 'Oops, actually I think I'd like to go back to being a postdoc or something.'"

In some ways, Rehnberg's decision was not about whether to take that leap, but which cliff to leap from. He was on track to finish his Ph.D. studying Saturn's rings at the University of Colorado (CU) Boulder in May 2017, just 4 months before NASA's Cassini mission would take its fatal plunge into Saturn's atmosphere. He knew that the in situ data he needed for his research would soon dry up without an active satellite mission. "It wasn't just that I was going to have to change missions. I was going to have to find a new [sub]field," he said. "Balanced with that, the leap to try something outside of academia didn't seem like that much more of a risk."

> Whether it's astronomy, climate change, paleontology, or the ways in which science influences our lives, his job is all about showcasing science to thousands of museum visitors.

Rehnberg used the relative security that graduate school afforded him to explore his career options. He started an astronomy blog and earned paid science writing gigs; he volunteered at CU Boulder's planetarium, gave science talks to the public, and helped start a space news podcast. He soon found himself enjoying his outreach work just as much as his academic research. "The promise of getting to do more of that was worth taking what felt to me like a pretty big career risk at the time," he said.

After graduate school, Rehnberg landed in his current role as chief scientist at the Fort Worth Museum of Science and History in Texas, where he's been for the past 4 years. Whether it's astronomy, climate change, paleontology, or the ways in which science influences our lives, his job is all about showcasing science to thousands of museum visitors. Part of his job is designing new exhibits, like the museum's tribute to Apollo 12 astronaut and Fort Worth native Alan Bean for the fiftieth anniversary of the

KAREN LAYOU

A Wider 2-Year Track

KAREN LAYOU started her college career as a chemical engineering major. But after a year and a half, she realized she hated it. One day she stumbled upon a small museum on the Penn State campus, tucked away in the geology building.

"It was like being reunited with old friends," Layou said. She'd collected rocks as a child and even categorized them for a third-grade science fair project. The mineral samples and fossils in the museum's collection reawakened her childhood interests, including a passion for paleontology sparked by a family road trip to the Grand Canyon when she was in high school.

At the museum Layou decided to go upstairs to the geology office and ended up speaking with the dean, and changed her major that day. Layou graduated and went on to complete a master's program at the University of Cincinnati before working for what is now the Texas Commission on Environmental Quality. While she learned a lot, she wasn't satisfied.

"I decided that, no, I need to go back and get [a] Ph.D. to fulfill that promise I made to myself, to get myself back out to landscapes I love," Layou said. She earned a Ph.D. in geology at the University of Georgia and then obtained a position at the College of William and Mary in Williamsburg, Va., as a sabbatical replacement. She found that she enjoyed teaching and "cobbled together" a career by working as an adjunct professor at several schools. In 2013, she became a profes-

> **"Success is how you define it, and it's most likely going to be this squiggly trajectory…[and] it may even loop back on itself."**

“We’re trying to communicate with people the ways in which the scientific endeavor is working to improve their lives… and the ways in which we can all participate in that endeavor, even if we’re not practicing research scientists.”

Moon landing in 2019. The exhibit incorporated interactive technologies and historical artifacts from Bean’s training and spaceflight to connect Fort Worth residents with their piece of moonshot history. With that exhibit and more since, “I’m proud of how much work we’ve done to expand the reach of the ways in which the people can interact with science,” he said.

In grad school, “if I had known that this was the thing I was going to stumble into, I would have run off the cliff looking for it.”

Rehnberg (@MorganRehnberg on Twitter) encourages audiences to visit the Fort Worth Museum of Science and History (@fwmsh).

—**Kimberly M. S. Cartier**

sor of geology at Reynolds Community College in Richmond, Va.

Since then, Layou has been involved in Supporting and Advancing Geoscience Education at Two-Year Colleges, or SAGE 2YC. The project aims to broaden participation in the geosciences, clarify transfer and workforce pathways for students at 2-year colleges, and emphasize best teaching practices for faculty. Layou especially loves sharing science with nonscience majors and “spreading the love—the geo love.”

SAGE 2YC has also been able to provide mentoring for students and send them to the annual Virginia Geological Field Conference. “We were able to bring 2-year college students to mix with professional geologists and just talk about a day in the life of their jobs,” Layou said. She will also continue to further geoscience education as the incoming president of the Geo2YC division of the National Association of Geoscience Teachers.

Layou encourages audiences to learn more about SAGE 2YC and also to check out the free online textbook she’s been working on (bit.ly/Historical-Geology).

—**Jack Lee**

AISHA MORRIS

Opening the Door to Science

AISHA MORRIS’S interest in geology runs deep. Growing up, she collected and cleaned rocks, and then sold them to the kids around her suburban Minnesota neighborhood. But despite this early financial success, it wasn’t until college that she seriously considered geology as a career path.

Morris was hooked as an undergraduate at Duke University, after Jeff Karson (now at Syracuse University) offered her a research opportunity studying mid-ocean rifts. “It was a challenge, because I was learning how to do research and ask questions,” Morris said, “but it was also very empowering to create knowledge as an undergrad.”

Aisha Morris in the Alvin *submersible in 1999. Credit: Aisha Morris*

The project culminated in a senior thesis and a chance to dive in the *Alvin* submersible. With *Alvin,* she was able to see directly the rift she had been studying, through a porthole instead of on a screen.

Later, as a grad student at the University of Hawai‘i, Morris was wary of work-life imbalances and the lack of diversity in academia. She found a postdoc position with Karson that allowed her to work on both research and broadening participation activities among underrepresented groups.

She quickly learned that the work she was doing to create and support a more diverse scientific community was more fulfilling than the research. So Morris left academia in 2013 to further pursue that community building, first at UNAVCO and then at the National Science Foundation (NSF), where she is now a program director for Education and Human Resources.

“Sometimes you have to create your own pathway. Who knows what kind of path you’re opening up for others in your forging ahead?”

Not everyone understood Morris’s decision to leave the academic path. “Sometimes you have to create your own pathway,” she said. “Who knows what kind of path you’re opening up for others in your forging ahead?”

At NSF, Morris is working to bring previously excluded groups into the geosciences through programs like the Improving Undergraduate STEM Education (IUSE) initiative. IUSE funds projects for precollege, undergraduate, and graduate students with a focus on service learning and outreach to historically excluded groups and from nongeoscience degree programs.

Success in the sciences doesn’t look like a tenure-track professorship at an R1 institution for everyone, she said. For Morris, the ultimate success would be to work herself out of a job by creating a community so welcoming it no longer needed the kind of broadening participation initiatives to which she’s dedicated her career.

To keep up with Morris’s work, follow her on Twitter (@volcanogirl17) or the Education and Human Resources portal at NSF’s Division of Earth Sciences.

—**Kate Wheeling**

FUSHCIA-ANN HOOVER

The Business of Environmental Justice

BY HER BEDSIDE, Fushcia-Ann Hoover still has the iron table lamp she welded as a 13-year-old in her junior high industrial technology class. "I like working with my hands," Hoover said.

Now an assistant professor of environmental planning at the University of North Carolina at Charlotte, her passion as a "maker" drew her not only to engineering but also to business. In 2020, she founded EcoGreenQueen LLC to help people better integrate environmental justice into their work.

Hoover began her bachelor's degree in mechanical engineering at the University of St. Thomas in Minnesota in 2005. During a summer abroad course in Germany studying renewable energies and her research on ethynyl as a McNair Scholar, she thought she'd found her calling. But when she graduated from college at the height of the Great Recession, the environmental engineering jobs she wanted required either a master's degree or substantial work experience.

Instead, she took a job as a tutor in her hometown at Saint Paul Public Schools while researching graduate schools. "I used that time to really try and focus on where and what to study," she said. Working as a tutor had a lasting impact on her career: Hoover noticed that her students, many of whom were people of color, faced challenges both inside and outside the classroom that made it difficult for them to excel. She had a realization that would serve as a guiding principle in her master's and doctoral work in ecological science and engineering at Purdue University 2 years later. "Whatever it was that I was going to do, if it wasn't going to somehow make [the students'] lives better, then I wasn't interested in doing it."

Hoover embarked on transdisciplinary research at Purdue, work that would pave the way to consulting in her specialty of urban green infrastructure. In her dissertation, she not only conducted an analysis of watersheds but also interviewed Black residents in Chicago's South Side and city planners about Chicago's green infrastructure practices. She sees a dire need for geoscientists to include communities in projects and critically examine power structures.

During her second postdoc, Hoover founded her consulting company to assist professionals, researchers, and government officials looking to incorporate environmental justice or interdisciplinary methods into their business, scholarship, or city plans.

Looking back at her career, she's proudest of how she's upheld her values. "I don't have to leave out race or leave out water," she said. "I get to bring everything in and say, 'No, this is all important…and we're going to talk about it.'"

—Jenessa Duncombe

Darcy Peter demonstrates water sampling to environmental science students at the Polaris Project's field site near Bethel, Alaska. Credit: Darcy L. Peter

DARCY L. PETER

Harnessing Alaska's Native Knowledge

A GWICH'IN SCIENTIST from Beaver, Alaska, Darcy L. Peter spent her childhood on the land around her Alaska Native village hunting, fishing, and trapping. Now she studies the Arctic tundra with the Woodwell Climate Research Center, where she investigates climate change while building bridges between Indigenous communities and research scientists.

Peter majored in environmental biology at Fort Lewis College in Durango, Colo. After graduating, she returned to Alaska for a 1-month Arctic research program with the Polaris Project.

That summer shaped Peter's career in two pivotal ways: One, she fell in love with field research, and two, she found a workplace that valued her ideas. She pointed out an opportunity for Polaris to connect with the local people near their field site, so the project leaders invited her back the next two summers. It was "really cool as an Indigenous young career person to have my voice be valued and heard."

For the next 2 years, Peter took jobs at several Alaskan Native nonprofits working with Alaska Native communities on issues such as permafrost erosion and contamination cleanup. She began volunteering on half a dozen boards that control the state's fishing and river regulations to increase Indigenous participation.

Peter started graduate studies in wildlife biology at the University of Alaska Fairbanks 2 years after graduating college but quickly felt stifled. She had to pass up job offers, like an executive director position at an Alaska Native organization, and was already familiar with the communities she was now reading about in papers. She left after 3 months and soon landed her "dream job" back where she'd started her career: the Polaris Project at Woodwell Climate.

"I am trained to be a scientist, but the cutting-edge science that is being done is not what I'm most proud of. It's definitely the relationship building, making sure that the science is communicated, making sure the science is ethical, making sure that we're incor-

> "There's a community of people building a bridge between researchers and Indigenous People so that they can have the resources that they need."

porating Traditional Knowledge into our science…that is the most rewarding work."

White-dominated spaces, including academia and workplaces, can be taxing on the mental health of scientists of color, particularly women of color, Peter said. But at Polaris, Peter is encouraged to think creatively, and when she presents an idea, her supervisor often tells her to "run with it." Case in point: Peter wrote a guide for equitable research in the Arctic. "That's something I'm pretty proud of because it's gotten a lot of traction in the science world," she said.

Peter encourages people to follow her on Twitter (@darcypeter1) and familiarize themselves with the Woodwell Climate Research Center's guiding principles for working in local northern communities (bit.ly/Woodwell-principles).

—**Jenessa Duncombe**

ROBIN GEORGE ANDREWS

"The *New York Times* Volcano Guy"

SCIENCE JOURNALIST ROBIN GEORGE ANDREWS remembers first seeing a volcano—albeit an imaginary one—in *The Legend of Zelda: Ocarina of Time*. The ominous Death Mountain had sentient lava and monsters prowling its hollowed-out insides.

"It was all very fantastical," Andrews said, and as a 10-year-old growing up in the United Kingdom, Death Mountain set him on a quest to visit real-life volcanoes around the world as a scientist. Now Andrews writes about volcanoes for *National Geographic*, the *New York Times*, the *Atlantic*, and other publications.

> "I actually prefer telling these stories of science much more than doing it."

Andrews started out on a typical academic track. After earning strong grades in high school and encouragement from geography teachers, he attended a special program at Imperial College London. The program allows secondary students to earn a master's degree in geology in just 4 years, bypassing a bachelor's degree.

His next stop, after a year of rest, took Andrews to the volcano-ridden islands of New Zealand, where he studied at the University of Otago for his Ph.D. and helped create laboratory experiments that modeled volcanic eruptions. Although his work took him around the world, living in a quiet university town left the highly extroverted Andrews feeling isolated. Academia was losing its sheen too: Chasing funding frustrated him, and he didn't like the prospect of leaving friends and family every few years for new posts.

Andrews started writing blog posts for Nature's Scitable, the Earth Touch News Network, Discover, and Forbes—and found he actually preferred telling stories of science to doing it.

Andrews didn't know any journalists, let alone science journalists, but after he graduated, he emailed an editor he admired at Gizmodo and scored a gig writing articles for her. From there, he cold-pitched *National Geographic*, *Scientific American*, and the *New York Times*, landing articles in publications he thought would take years to break into. "I put so much work into getting to that point," Andrews said, bypassing sleep for almost a year and a half to build his reputation as "the *New York Times* volcano guy." His own stubbornness and the emotional support from his partner and parents helped him make the jump from science to journalism.

> *The Legend of Zelda*'s Death Mountain set Robin George Andrews on a quest to visit real-life volcanoes around the world.

Now Andrews freelances full-time and writes for a dozen publications. "Most science journalists have a beat of some sort, and my beat is generally things that explode in space or on Earth." His first book, *Super Volcanoes: What They Reveal About Earth and the Worlds Beyond*, comes out this November. In it, readers can learn about strange volcanoes across the cosmos, like Tharsis on Mars, which tipped the entire planet 20 degrees. "To me, it sounds like magic sorcery"—or perhaps something out of a video game, he said.

Andrews welcomes messages from those interested in science writing through his website (robingeorgeandrews.com) or on Twitter (@SquigglyVolcano).

—**Jenessa Duncombe**

Navakanesh M Batmanathan mapped faults in Sabah, Malaysia, in April 2017. Credit: Eric Chiang Hinn Yuen

NAVAKANESH M BATMANATHAN

Customizing Hazard Outreach

IN JUNE 2015, a magnitude 6.0 earthquake struck Sabah, a state of Malaysia in the northern part of the island of Borneo.

"It was a big surprise in Malaysia because, actually, we never experienced a magnitude 6 [earthquake] in that region," said Navakanesh M Batmanathan. The seismic event was located away from active plate boundaries. M Batmanathan was in the perfect position to investigate what happened. He'd been fascinated with rocks ever since he was a child and, at the time, was pursuing a master's degree in geophysics and seismology at Curtin University in Malaysia. His adviser encouraged him to focus on the Sabah earthquake, given its surprising nature.

M Batmanathan mapped faults that contributed to the quake by using a combination of satellite data and on-the-ground field measurements. These methods also allowed him the opportunity to engage with residents in Sabah. He learned not only about how the event affected people living in the area but also that there was a lack of awareness about earthquake hazards in the region.

As the recipient of a National Geographic Young Explorer grant, M Batmanathan helped to produce a short documentary that combined locals' stories with educational information about the Sabah earthquake. He and his colleagues also taught schoolchildren in Sabah.

M Batmanathan is now a Ph.D. student at the National University of Malaysia and continues to study earthquakes—but from a slightly different perspective. He's exploring potential connections between tectonics and sea level rise, not only in East Malaysia, where Borneo is located, but in peninsular Malaysia as well. He's also a research assistant at the Southeast Asia Disaster Prevention Research Initiative.

M Batmanathan has done outreach on a range of science topics and attributes at least some of his success to tailoring content to different audiences, depending on their immediate concerns: He spoke about earthquakes with kids from Sabah, for instance, but focused on climate change and sea level rise with children from coastal communities in peninsular Malaysia. Determining the emphasis of community-focused outreach "depends on the region," he said.

In the future, M Batmanathan hopes to continue educating people in Malaysia and, someday, Southeast Asia more broadly. The region is one of the most geologically active in the world—in addition to earthquakes, it is home to volcanoes, tsunamis, and landslides. "Southeast Asia is huge—we definitely need more groups to work on this," he said.

"It's a good time for young geoscientists... to investigate and try to identify what are the main causes for earthquakes."

M Batmanathan recently presented his work on the earthquake geology of Borneo at a webinar from the U-INSPIRE Alliance, an alliance of youth, young scientists, and young professionals working in science, engineering, technology, and innovation to support disaster risk reduction and resilience building, in line with the U.N. Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction. He also regularly posts about earthquakes on Instagram (@navakanesh).

—Jack Lee

Ashley Walker during a trip to the Green Bank Observatory in West Virginia as an undergraduate at Chicago State University. Credit: Ashley Walker

ASHLEY LINDALÍA WALKER

Leading a Celebration of Black Scientists

ASHLEY LINDALÍA WALKER'S academic interests started close to home and have traveled millions of kilometers. "I'm a nontraditional student," said the Chicago native. "I started off in community college" in 2015, she said, studying forensic chemistry. "I really wanted to help understand what was happening and solve some of Chicago's crime and things of that nature. But [then] I received a scholarship at my now alma mater, Chicago State University (CSU), the only Black 4-year college in Illinois."

Once at CSU, Walker took an opportunity to participate in an astronomy research project, which quickly became her primary research focus. While still studying forensic chemistry, she interned at Harvard University researching planet-forming disks and at Johns Hopkins University studying aerosol hazes in the atmosphere of Saturn's moon Titan.

Many community college students earn their associate's degree within 2 years and then complete their bachelor's degree in another 2 years, she explained. "However, it took me a little bit longer." After graduating from CSU in 2020 as the first astrochemist in the university's history, she became a

REBECCA CHARBONNEAU

The Future of Scientific History

REBECCA CHARBONNEAU is a Cuban American historian who recently earned a Ph.D. from the University of Cambridge researching the history and philosophy of science. She is also a Gates Scholar who has studied, among other things, settler and colonialist science, the search for extraterrestrial intelligence, and Soviet and Cold War rocket and space science.

Before she earned her master of science from the University of Oxford, however, Charbonneau was an astronomy major at Mount Holyoke College in Massachusetts. After leaving Mount Holyoke for personal reasons, she ended up at Rollins College in Winter Park, Fla., to be near family. There Charbonneau double majored in art history and critical media and cultural studies ("like sociology, but with applied elements") and double minored in sexuality, women's, and gender studies and English.

Charbonneau said that having a varied undergraduate background in liberal arts is something she brought to her graduate studies of science: "A lot of the contemporary challenges that exist in the sciences, especially the space sciences today, have historical roots."

"Scientific fields tend to take objectivity for granted," she said, explaining that "[scientists] often don't realize how they have inherited a lot of their ways of thinking." Charbonneau has continued to unpack these ways of thinking with stops at the National Radio Astronomy Observatory and the Whipple Library at Cambridge's Department of History and Philosophy of Science, as well as at NASA's History Office. Since last fall, she has been at the Harvard & Smithsonian Center for Astrophysics as their historian-in-residence.

"I was incredibly intimidated when I started entering spaces like Oxford, Cambridge, NASA," Charbonneau said. "There are pieces of dust in there that are older than me and have seen more of history that I have even studied.... I think that we build up these places as larger than life, and that prevents us from seeing how we belong in those places.... If I had managed to learn that earlier, I might have gotten to the place that I am more quickly."

Charbonneau identified two mentors who helped her overcome some initial intimidation. "Two people from Rollins were incredibly influential to me: Kim Dennis and Mackenzie Moon Ryan. Having women professors and academic role models was really valuable in helping me see that I could attain this. And this was especially valuable because my field of history of science, especially history of physics and astronomy, is really male dominated."

"I think that we build up these places as larger than life, and that prevents us from seeing how we belong in those places."

Her identity as a Cuban American helped contextualize Charbonneau's academic interests. In particular, she is interested in "giving voices to people in history who haven't had their voices acknowledged. I mean communities that have been affected by colonialism, but I also mean people who have not been able to enter the historical record for a variety of reasons."

"I'm actually really proud of the work I've done in Russia, for example. Because of the Putin administration's crackdown on access to records, it's really, really hard to do history of Soviet science. And because of that, there's this image that there weren't a lot of contributions from the Soviet astronomers, the Russian astronomers. Part of what I've done is a lot of oral history interviews where I've gone over and I've spoken to people and tried to record their stories. It's really a beautiful thing for me to be able to preserve these people's voices."

—Camilo Garzón

postbaccalaureate researcher at NASA Goddard Space Flight Center investigating Titan's atmospheric chemistry.

For the past few years, Walker has also focused on science communication, especially highlighting the experiences and amplifying the voices of Black scientists. As calls for racial justice increased during 2020, Walker founded and organized the first Black In Astro week on social media and co-organized Black in X events in other disciplines.

"I wanted to show some of the issues that we face as Black astronomers, aerospace engineers, space policy people, and so on," Walker said. "I really wanted to show last year: This is what's happened to us. There's not many of us in the field or within these spaces. How can you all make us feel better? How can you all make us feel comfortable? This is what we see through our eyes and through our lens. This year we're focusing on a celebration versus trauma. Now that we told our story and people know our story, we want to focus on celebrating us and how can we retain us and continuously recruit more of us."

"Most people don't understand their learning style when they're going into a Ph.D.... Luckily for me, I learned mine a little bit prior to that, and now that I'm going into graduate school, it makes it a little bit easier."

She plans to continue her work as a science communicator as she pursues a doctoral degree in atmospheric science at Howard University starting this fall. Walker (@That_Astro_Chic) encourages everyone to join in celebrating and amplifying Black experiences in space-related fields with Black In Astro (@BlackInAstro) during the annual #BlackInAstro events on social media and all year round.

—Kimberly M. S. Cartier

ASHLEE WILKINS

A Space Scientist Goes to Washington

ASHLEE WILKINS realized that she might not want to be an academic researcher before she started graduate school.

Wilkins was an intern at NASA's Jet Propulsion Laboratory in Pasadena, Calif., in the summers before and after her senior undergraduate year at Cornell University in Ithaca, N.Y. She was working with the deputy project scientist of the Wide-field Infrared Survey Explorer (WISE) mission just before its launch in late 2009, and that same scientist was already planning for the telescope's postmission life, named NEOWISE. It gave Wilkins the chance to see the final stages before a mission launches as well as the first stages as a new idea takes hold.

"I had long been interested in politics separately from science, but I had not really seen how science policy was a whole field in and of itself."

"I was learning a lot about...prioritizing the right time to do what kind of mission, or how you decide on big-picture science questions and fitting missions into a larger strategy," Wilkins said. "That was just really exciting to me."

The desire to learn about mission planning influenced her decision to attend graduate school at the University of Maryland (UMD) in College Park, not far from NASA Goddard Space Flight Center in Greenbelt, where Wilkins worked for a time. In addition to her graduate research about exoplanets, she helped start and lead an initiative called GRAD-MAP, which connects UMD graduate students with undergraduates from minority-serving institutions in the mid-Atlantic region. The program "continued this evolution of my interest in how we do the science, and who gets to do the science, and the strategy for science, and not just the actual research itself."

Wilkins's shift toward a policy focus was ushered along with her election to student government in graduate school. "As a graduate student there are a lot of opportunities to get involved at very high levels of the university," she said. Moreover, living so close to the nation's capital offered her the chance to attend hearings and see science policy in action. After graduate school, she became the John Bahcall Public Policy Fellow at the American Astronomical Society, which is "specifically designed to take a Ph.D. scientist and provide them with the opportunity to learn... about the world of science and space policy."

Ashlee Wilkins focuses on space and aeronautics as staff of the House Committee on Science, Space, and Technology. Credit: Architect of the Capitol

"I was lucky in the timing because it was in my second year of the fellowship when the Democrats took the House in 2018," she said. The results of the election meant that the former minority party would soon be hiring staff for the committees they would run, and it just so happened that a position opened up in the Subcommittee on Space and Aeronautics. "I had the experience of the fellowship behind me—and I had interacted with the person who was my future boss through my work as the Bahcall Fellow."

Out of 35 or so staffers in the majority office of the House Science Committee, Wilkins is one of three who focus on space topics. You can follow Wilkins on Twitter (@ashleeeeew) and the subcommittee for updates on science and space policy.

—Kimberly M. S. Cartier

The Wildfire One-Two: First the Burn, Then the Landslides

Debris flows from heavy rain after the 2009 Station Fire damaged part of the Angeles Crest Highway in Southern California. Credit: Jason Kean/ U.S. Geological Survey

After the record-breaking 2020 wildfire season in California, the charred landscapes throughout the state faced elevated risks of landslides and other postfire hazards. Wildfires burn away the plant canopy and leaf litter on the ground, leaving behind soil stripped of much of its capacity to absorb moisture. As a result, even modest rains pose a risk for substantial surface runoff in the state's mountainous terrain.

California has a history of fatal landslides, and the steep, burned hillsides are susceptible to flash flooding and debris flows. Fire-prone regions in the state rely on rainfall thresholds to anticipate the conditions under which postfire debris flows are more likely.

In a new study, *Thomas et al.* combined satellite data and hydrologic modeling to develop a predictive framework for landslides. The framework uses inputs, including vegetation reflectance and soil texture, among others, and physics-based simulation of water infiltration into the soil to simulate the hydrologic triggering conditions for landslides. The output offers thresholds to monitor the probability of landslides in the years after a burn.

The researchers tested their model against postwildfire soil moisture and debris flow observations from the San Gabriel Mountains in Southern California and found that their results were consistent with recent debris flow events and previously established warning criteria. In addition, they suggest that rainfall patterns, soil grain size, and root reinforcement could be critical factors in determining the probability of debris flows as burned landscapes recover.

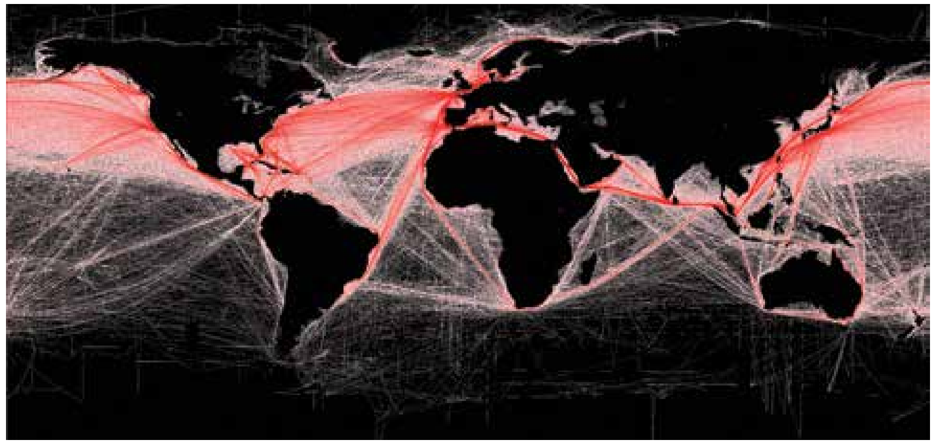
The results suggest that the model could track soil hydraulic conditions following a fire using widely available rainfall, vegetation, and soil data. Such simulations could eventually support warning criteria for debris flows. The simulation framework, the authors note, could be beneficial for regions that have not historically experienced frequent fires and lack monitoring infrastructure. (*Journal of Geophysical Research: Earth Surface*, https://doi.org/10.1029/2021JF006091, 2021) **—Aaron Sidder,** *Science Writer*

Monitoring the Agulhas Current Through Maritime Traffic

As Earth's climate changes, so too will its oceans. Water temperatures are climbing, sea levels are rising, and ocean currents are shifting. To study the ocean surface, researchers typically use radar altimeters, which send microwave pulses toward the ocean and measure the time they take to rebound, but the usefulness of altimetry data is limited to large areas and long temporal scales. In a new study, *Le Goff et al.* turn to maritime data to create a more precise picture of ocean currents.

Historically, data on ocean surface currents were based on ships' logs, which tracked how intense currents affected a vessel's course or speed. But today's ships are equipped with much more precise geopositioning technologies. Merchant ships continually transmit their position, bearing, and speed through the Automatic Identification System (AIS), providing mountains of data that are more precise than ever. Previous studies have shown that surface current velocities from AIS data match well with those predicted by high-frequency radar measurements.

The research team focused on the northern reaches of the Agulhas Current, a strong current that roughly follows the continental shelf break off the eastern coast of South Africa. The current, which has surface velocities of up to 2 meters per second, passes through a region with heavy maritime traffic. Using AIS data from vessels in transit through the region in 2016 and mathematical modeling, the team reconstructed the surface current. The authors used surface current estimates collected by satellites and drifting buoys to validate the AIS-based observations. The study shows how AIS data could be a critical part of a more comprehensive current monitoring system.



A world map shows relative commercial shipping density. Credit: B. S. Halpern (derived from T. Hengl and D. Groll)/Wikimedia, CC BY-SA 3.0 (bit.ly/ccbysa3-0)

According to the authors, the methods could be applied to other regions with heavy maritime traffic, such as the Mediterranean Sea. Monitoring ocean currents is critical because shifting currents will lead to changes in sea surface temperature and salinity that will ripple throughout marine ecosystems. (*Journal of Geophysical Research: Oceans*, https://doi.org/10.1029/2021JC017228, 2021) **—Kate Wheeling,** *Science Writer*

How Much Carbon Will Peatlands Lose as Permafrost Thaws?

Just as your freezer keeps food from going bad, Arctic permafrost protects frozen organic material from decay. As the climate warms, however, previously frozen landscapes such as peatlands are beginning to thaw. But how much fresh carbon will be released into the atmosphere when peat leaves the deep freeze of permafrost?

In a new study, *Treat et al.* used a process-based model to explore how different factors may affect the carbon balance in peatlands by the end of this century. The scientists simulated more than 8,000 years of peatland history to ensure accuracy, and they examined six peatland sites in Canada to cover a gradient from spottier southern permafrost zones to continuous permafrost sites north of the Arctic tree line.

Their results reveal great variation, depending on each site's history. According to the simulations, some areas will release carbon as permafrost thaws or disappears altogether. Others will accumulate and store carbon at greater rates as vegetation responds to warmer temperatures and longer growing seasons. Overall, little carbon—less than 5%—will escape by 2100 compared with how much will remain stored.

Before peat is preserved stably in permafrost, it spends time in an active layer that freezes and thaws seasonally. Unfrozen peat continues to decay, so by the time it is permanently frozen, peat might be highly degraded. When such frozen peat ultimately thaws, limited further decomposition is possible, so the carbon loss is much slower than might be expected. Therefore, most of the carbon that peat will release escapes before it ever enters the permafrost. Accordingly, in simulations of future years, the upper active layer, not deeper or newly thawed peat, continued to release the most carbon.

Previous field studies showed a range of carbon balance outcomes as permafrost thaws, from the release of large amounts of carbon to the storage of additional carbon. This simulation helps explain that variation, linking carbon balance results to specific variables such as site history and active layer depth. Future models could continue to refine the picture by incorporating new variables, such as ice melt and vegetation productivity. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2020JG005872, 2021) **—Elizabeth Thompson,** *Science Writer*

Particles at the Ocean Surface and Seafloor Aren't So Different

An Oceanic Flux Program time series sediment trap deployed at 3,200-meter depth comes on board R/V Atlantic Explorer. *Credit: J. C. Weber*

Although scientists often assume that random variations in scientific data fit symmetrical, bell-shaped normal distributions, nature isn't always so tidy. In some cases, a skewed distribution, like the lognormal probability distribution, provides a better fit. Researchers previously found that primary production by ocean phytoplankton and carbon export via particles sinking from the surface are consistent with lognormal distributions.

In a new study, *Cael et al.* discovered that fluxes at the seafloor also fit lognormal distributions. The researchers analyzed data from deep-sea sediment traps at six different sites, representing diverse nutrient and oxygen statuses. They found that the lognormal distribution didn't just fit organic carbon flux; it provided a simple scaling relationship for calcium carbonate and opal fluxes as well.

Uncovering the lognormal distribution enabled the researchers to tackle a long-standing question: Do nutrients reach the benthos—life at the seafloor—via irregular pulses or a constant rain of particles? The team examined the shape of the distribution and found that the highest 29% of the measurements accounted for 71% of the organic carbon flux at the seafloor, which is less imbalanced than the 80:20 benchmark specified by the Pareto principle. Thus, although high-flux pulses likely do provide nutrients to the benthos, they aren't the dominant source.

The findings will provide a simple way for researchers to explore additional links between net primary production at the ocean surface and deep-sea flux. (*Geophysical Research Letters*, https://doi.org/10.1029/2021GL092895, 2021) **—Jack Lee,** *Science Writer*

Establishing a Link Between Air Pollution and Dementia

More people around the world are falling ill and dying from dementia now than in the past. Between 2000 and 2019, the diagnosis rate of dementia increased by 86% and deaths from the cognitive disorder more than doubled. Longer life spans and aging populations in much of the world partly explain these trends. However, evidence suggests that lifestyle and environmental causes, namely, air pollution, excessive alcohol consumption, and traumatic brain injury, may also play a role.

In new research, *Ru et al.* explored the role of air pollution in the rising number of dementia cases. The authors perused existing literature to find links between dementia and fine particulate matter 2.5 ($PM_{2.5}$)—defined as particulates having a diameter less than or equal to 2.5 micrometers. $PM_{2.5}$ arises from both anthropogenic and natural sources, like burning gas for vehicles and wildfires. In addition, cigarettes produce fine particulate matter, which is inhaled by the smoker and by others through secondhand smoke. When these pollutants enter the body, they can affect the central nervous system and lead to cognitive disorders.

The study's findings indicate that in 2015, air pollution caused approximately 2 million occurences of dementia worldwide and around 600,000 deaths. The countries most affected were China, India, Japan, and the United States. What is more, Africa, Asia, and the Middle East face increasing burdens from the disease as living standards and pollution climb. The analysis concludes that air pollution causes roughly 15% of premature deaths and 7% of disability-adjusted life years (which accounts for mortality and morbidity) associated with dementia, with estimated economic costs of around $26 billion.

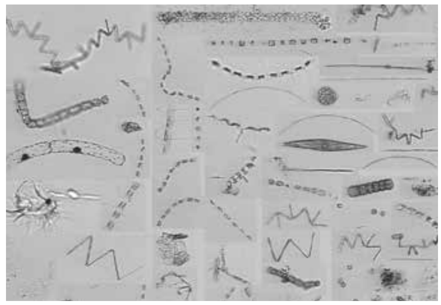
Environmental activist Sumaira Abdulali measures particulate matter emitted by a burning roadside garbage dump near Mumbai, India. Credit: Sumaira Abdulali, Wikimedia Commons, ccbysa4-0, (bit.ly/bysa4-0)

The study establishes air pollution as a potentially significant risk factor for dementia. It suggests that reducing air pollution may help prevent dementia in older populations. However, the researchers note high uncertainty in the relationship. Future work that focuses on high-exposure regions will be necessary to clarify the link. (*GeoHealth*, https://doi.org/10.1029/2020GH000356, 2021) **—Aaron Sidder,** *Science Writer*

Gulf Stream Intrusions Feed Diatom Hot Spots

The Gulf Stream, which has reliably channeled warm water from the tropics northward along the East Coast of North America for thousands of years, is changing. Recent research shows that it may be slowing down, and more and more often, the current is meandering into the Mid-Atlantic Bight—a region on the continental shelf stretching from North Carolina to Massachusetts and one of the most productive marine ecosystems in the world.

Previous studies have suggested that this intrusion of Gulf Stream water, which is comparatively low in nutrients at the surface, could hamper productivity. But in a new study, *Oliver et al.* found that intrusions of deeper, nutrient-rich Gulf Stream water can also feed hot spots of primary productivity.



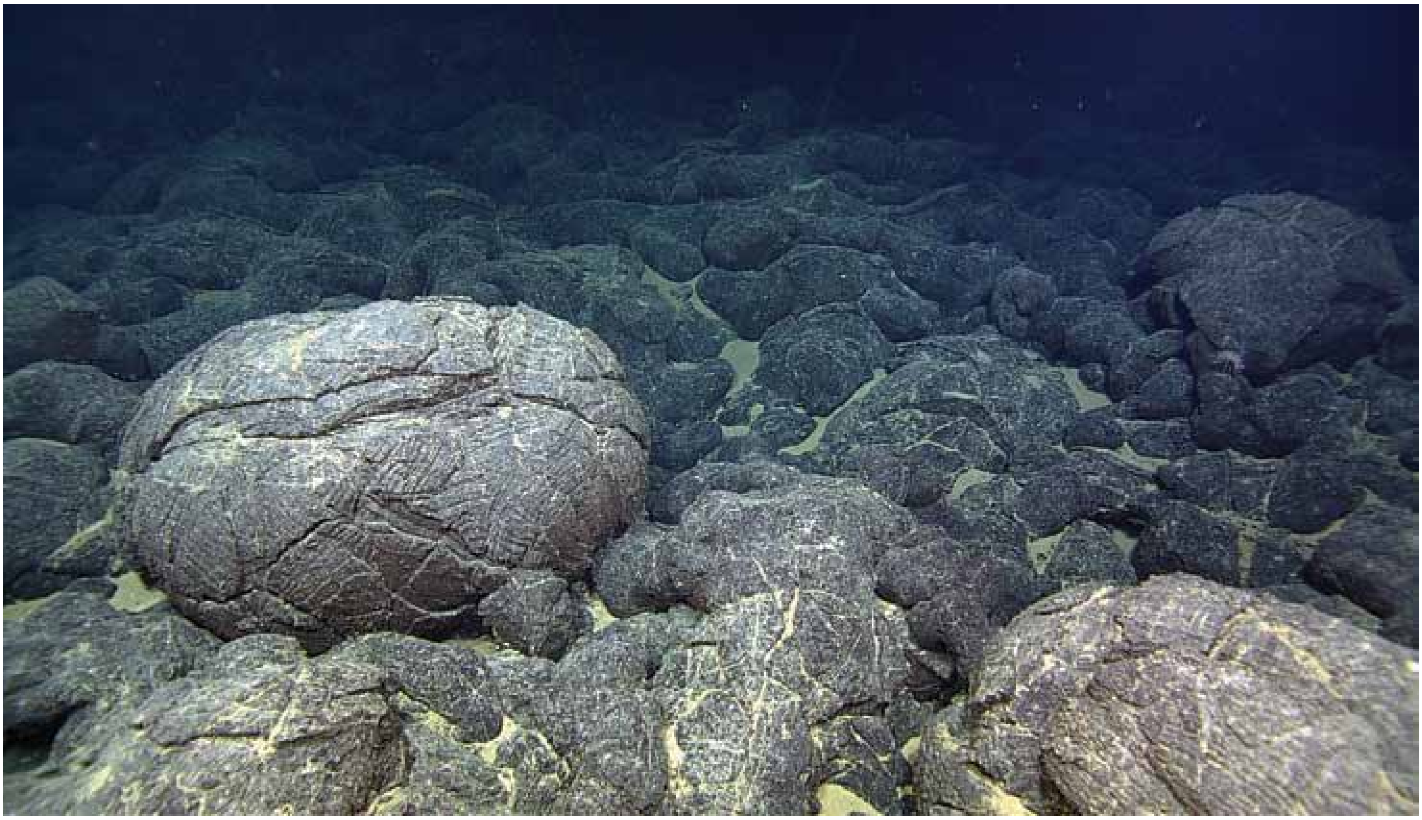
New research identifies diatom hot spots associated with Gulf Stream intrusions and dominated by a diverse assemblage of diatoms, pictured here, similar to Thalassiosira diporocyclus*. Credit: Oliver et al., 2021, https://doi.org/10.1029/2020GL091943*

By analyzing data collected by R/V *Thomas G. Thompson* in July 2019, the team spotted a series of hot spots about 50 meters below the surface, just east of a large eddy known as a warm-core ring. This ring had formed off the side of the Gulf Stream current and was pushing westward toward the continental shelf, drawing cool water into the slope region off the edge of the shelf.

The hot spots had chlorophyll levels higher than those typically seen in the slope region and were packed with a diverse load of diatoms, a class of single-celled algae. Studying images of the hot spots, the team found that the colony-forming diatom *Thalassiosira diporocyclus* was abundant in the hot spots.

The researchers used a model that combined upper ocean and biogeochemical dynamics to support the idea that the upwelling of Gulf Stream water moving northward into the Mid-Atlantic Bight could cause the hot spots to form. The study demonstrates how Gulf Stream nutrients could influence subsurface summer productivity in the region and that such hot spots should be taken into account when researchers investigate how climate change will reshape circulation patterns in the North Atlantic. (*Geophysical Research Letters*, https://doi.org/10.1029/2020GL091943, 2021) **—Kate Wheeling,** *Science Writer*

Magma Pockets Lie Stacked Beneath Juan de Fuca Ridge



Lava that erupted from the Juan de Fuca Ridge formed these pillow and sheet flow basaltic rocks on the seafloor off the coast of Oregon. Credit: University of Washington/NSF–Ocean Observatories Initiative/Canadian Scientific Submersible Facility ROPOS 2014

Off the coast of the U.S. Pacific Northwest, at the Juan de Fuca Ridge, two tectonic plates are pulling apart at a speed of about 5.6 centimeters per year. As they spread, periodic eruptions of molten rock give rise to new oceanic crust. Seismic images captured by *Carbotte et al.* now provide new insights into the dynamics of magma chambers that feed these eruptions.

The new research builds on earlier investigations into magma chambers that underlie the Juan de Fuca Ridge as well as other sites of seafloor spreading. Sites of fast and intermediate spreading are typically fed by a thin, narrow reservoir of molten magma—the axial melt lens—that extends along the ridge at an intermediate depth in the oceanic crust, still well above the mantle.

Recent evidence suggests that some seafloor spreading sites around the world contain additional magma chambers beneath the axial melt lens. These additional chambers are stacked one above another in the "crystal mush zone," an area of the actively forming oceanic crust that contains a low ratio of melted rock to crystallized rock.

Beneath the Axial Seamount portion of the Juan de Fuca Ridge (the site of an on-axis hot spot, which is a different tectonic setting compared with the rest of the ridge), a 2020 investigation showed evidence of stacked magma chambers in the crystal mush zone beneath the large magma reservoir that underlies this on-axis hot spot (bit.ly/stacked-magma-chambers). The researchers applied multichannel seismic imaging data collected aboard R/V *Maurice Ewing* and found geophysical evidence for these stacked chambers along normal portions of the ridge not influenced by the hot spot.

The new imaging data reveal several stacked magma chambers in the crystal mush zone at each of the surveyed sites. These chambers extend along the length of the ridge for about 1–8 kilometers, and the shallowest chambers lie about 100–1,200 meters below the axial melt lens.

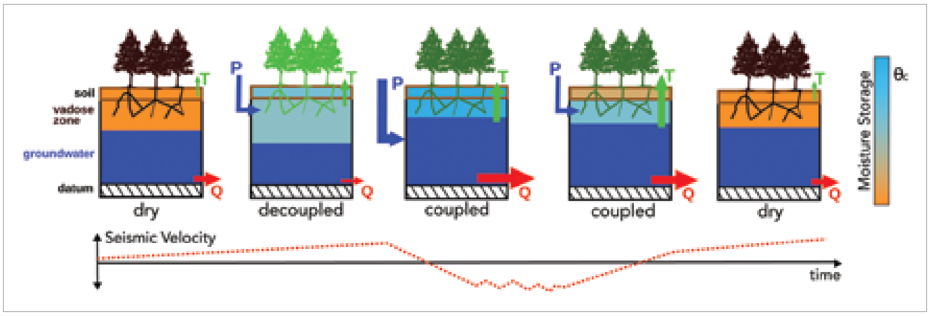
These findings, combined with other geological and geophysical observations, suggest that these stacked chambers are short-lived and may arise during periods when the crystal mush zone undergoes compaction and magma is replenished from the mantle below. The chambers do not cool and crystallize in place but instead are tapped and contribute magma to eruptions and other crust-building processes.

Further research could help confirm and clarify the role played by these stacked chambers in the dynamics of seafloor spreading. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1029/2020JB021434, 2021)

—Sarah Stanley, *Science Writer*

Understanding How Himalayan Water Towers Fill and Drain

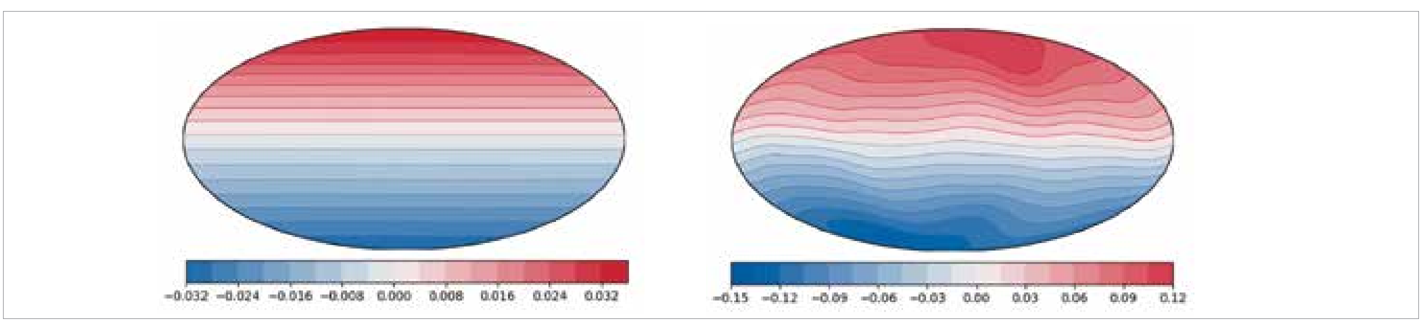
The Nepal Himalayas supply essential water resources to a large part of the population of South Asia. Most of this water drains through a mountain groundwater reservoir. Understanding how the reservoir fills and drains is crucial to the assessment of freshwater resources and to making predictions for the future with respect to global climate change. However, observing groundwater processes is challenging due to limited access to the subsurface, particularly in steep mountain landscapes.



Evolution of Himalayan groundwater reservoirs during the monsoon season. The arrows indicate the fluxes that control groundwater and subsurface moisture storage (T = transpiration, P = precipitation, Q = discharge). The colorbar indicates the scale for subsurface moisture storage where θc is the characteristic field capacity required to connect the precipitation input and the transpiration outtake to the groundwater. Tree colors indicate the evolving vegetation activity during one complete seasonal cycle. Credit: Illien et al., 2021

Illien et al. used ambient seismic noise—namely, ground vibrations continuously recorded by seismometers—to monitor groundwater dynamics within a Himalayan valley. Their findings shed new light on the mechanisms governing the water towers of the Himalayas. In particular, the researchers demonstrate key roles played by the thickness and properties of the soil and regolith layer, which is a gatekeeper to the fractured crystalline bedrock in which the groundwater reservoir is primarily located. (https://doi.org/10.1029/2021AV000398, 2021) **—Alberto Montanari**

Saturn's Dynamo Illuminates Its Interior



Left: The surface magnetic field for the preferred model developed by Yan and Stanley, with a stably stratified layer and enhanced polar cooling. The field is very symmetrical, as is observed for Saturn. Right: The model with no stable layer and with uniform cooling results in a less symmetric field than is observed. Credit: Yan and Stanley, 2021

NASA's Cassini spacecraft was able to carefully map Saturn's magnetic field during its final mission stages. The field is amazingly symmetrical, much more so than the fields of any other known planetary body. Although the reasons for this symmetry are unknown, it must arise from Saturn's internal structure.

Yan and Stanley suggest that the field's characteristics result from two factors. The first is the presence of a thick, stably stratified layer above the planet's convecting dynamo region; this layer damps out short-wavelength field characteristics. The second is stronger cooling of the stable layer at the poles, which induces thermal winds and produces a better match to the magnetic power spectrum.

A stably stratified layer on Saturn was expected based on theoretical arguments about helium rain-out, so this paper strengthens those arguments. A remaining puzzle is what mechanism could be causing the thermal winds posited in this model. (https://doi.org/10.1029/2020AV000318, 2021) **—Francis Nimmo**

ETH zürich

Professor of Alpine Mass Movements

ETH zürich WSL

→ The Department of Civil, Environmental and Geomatic Engineering (www.baug.ethz.ch) at ETH Zurich and the Swiss Federal Research Institute WSL (www.wsl.ch) invite applications for the above-mentioned position to establish a research group on Alpine Mass Movements. The joint position will be affiliated with the WSL Institute for Snow and Avalanche Research in Davos (Canton Grisons) and ETH Zurich.

→ The successful candidate is expected to develop a strong and visible research programme, which addresses the challenges caused by the ongoing changes in mountain regions and specifically focuses on mass movements and on providing solutions for natural hazards mitigation in mountain environments. Topics of interest for the professorship are, among others, the simulation of the dynamics of mass movements like avalanches, debris flows, landslides, and rockfall from the triggering to the runout zones, which are of importance as a basis for risk scenarios and planning of protection measures. Applicants have a strong background in the broad domain of computational mechanics, with specific reference to terrain instabilities that characterise mountain slopes. Computational methods to simulate the initiation and dynamics of mass movements supported by field and lab experiments as well as observations are at the core of the required expertise. The successful candidate has a strong mechanical background and proved, excellent, and international research record of accomplishments in numerical simulations with a demonstrated interest in experimental research. She or he will lead a research group in Davos at the WSL Institute for Snow and Avalanche Research (SLF) of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and will be a member of the Department of Civil, Environmental and Geomatic Engineering at ETH Zurich, where the teaching activities at undergraduate (German or English) and graduate level (English) take place.

→ **Please apply online: www.facultyaffairs.ethz.ch**

→ Applications should include a curriculum vitae, a list of publications, a statement of future research and teaching interests, and a description of the three most important achievements. The letter of application should be addressed **to the President of ETH Zurich, Prof. Dr. Joël Mesot. The closing date for applications is 30 September 2021.** ETH Zurich is an equal opportunity and family friendly employer, values diversity, strives to increase the number of women professors, and is responsive to the needs of dual career couples.

WSL

Swiss Federal Institute for Forest, Snow and Landscape Research WSL

The Swiss Federal Institute for Forest, Snow and Landscape Research WSL is part of the ETH Domain. It employs approximately 600 people working on the sustainable use and protection of the landscapes and habitats and a responsible approach to handling natural hazards. Please find further information on our homepage **www.wsl.ch.**

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Photo: Markus Bolliger

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Please send your complete application online to Human Resources WSL on www.wsl.ch/fellowship. Deadline for applications is 31 October 2021. Fellowships can start as early as summer 2022.

Top of the day, AGU fans!

Taking you to the Canadian High Arctic are Anna Grau Galofre (@agraugal), an Exploration Fellow at Arizona State University, and Shannon Hibbard (@ShannOnMars), a Ph.D. candidate at Western University. Anna and Shannon are riding off into the sunset on their fat-tire bikes to dig some baseline trenches across ice wedge polygon troughs on the eastern side of Axel Heiberg Island in Nunavut, Canada.

Anna and Shannon are geophysicists who use Arctic landscapes as analogue environments for places like Mars. Together the two have spent six field seasons in the Canadian High Arctic pursuing their research on topics like distinguishing subglacial channels from fluvial ones, and the region's crenellated so-called brain terrain. The trip was led by Gordon Oz Osinski (@drcrater), director of Western University's Institute for Earth and Space Exploration, and A. Mark Jellinek of the University of British Columbia. Anna and Shannon were also joined by Antero Kukko (@KukkoAntero), Chimira Andres (@RocksNRockets), and Etienne Godin.

Enjoy!

—**Shawn Chartrand** (@smchartrand), Simon Fraser University, Burnaby, B.C., Canada

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