VOL. 106 | NO. 8
AUGUST 2025

Eos

SCIENCE NEWS BY AGU

Hurricane Hunters' Wildest Ride

Cracks on Planets

A Sargassum Surge

The Career Issue

Be inspired by a dozen scientists who faced career crosswinds.

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From the Editor

Each year, we take a moment to appreciate the varied careers Earth and space scientists have forged.

In this issue we learn about 12 scientists who have found rewarding careers as they navigated their fields. Sometimes their plans shifted: One scientist ran for Congress (p. 23), another illustrated a book (p. 22), and another left the theater to study physics (p. 25). Sometimes they knew what they wanted to do and went for it. Inspired by fellow tribe members' concerns, one scientist studied conservation (p. 24). Another fulfilled a lifelong dream of working with Mars rovers (p. 16).

The political climate in the United States has made navigating a career even more challenging this year. In his Opinion on page 11, Mark Moldwin argues that senior scientists are well positioned to meet those challenges in support of their early-career and more vulnerable colleagues.

We hope you find these stories as uplifting as we do.

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Winds of Change

Read about how 12 Earth and space scientists found paths in academia, business, government, and nonprofits.

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AGU ADVANCING EARTH AND SPACE SCIENCES

Eos: Science News by AGU (ISSN 0096-3941) is published monthly except December by the American Geophysical Union, 2000 Florida Ave., NW, Washington, DC 20009, USA. Periodical Class postage paid at Washington, D.C., and at additional mailing offices. POSTMASTER: Send address changes to *Eos: Science News by AGU*, Member Service Center, 2000 Florida Ave., NW, Washington, DC 20009, USA

Member Service Center: 8:00 a.m.–6:00 p.m. Eastern time; Tel: +1-202-462-6900; Fax: +1-202-328-0566; Tel. orders in U.S.: 1-800-966-2481; service@agu.org.

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Janice Lachance, Executive Director/CEO

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The Wildest Ride on a Hurricane Hunter Aircraft

The seatbelt sign is always on when you're flying through a hurricane. Credit: Lt. Cmdr. Kevin Doremus, NOAA Corps

Frank Marks remembers the Diet Coke can floating in front of his face as the plane pitched violently. After several attempts to grab it, he gave up and focused on avoiding the other debris ricocheting around the cabin. Then an engine flamed out, and the pilots dumped 6,800 kilograms of fuel in a last-ditch effort to climb to relative safety without overheating the three working engines. The flight miraculously landed safely in Barbados a few hours later and went on to become legendary among NOAA meteorologists.

Rather than swearing off flying forever, many of the flight's passengers were back in the air 2 days later for another chance to chase that storm, Hurricane Hugo.

Most pilots give storms a wide berth, but those flying NOAA's two WP-3D Orion aircraft—known as Hurricane Hunters—head right for them. Their flights yield important data about storm structure and intensity that can help protect people on the ground. "There's only so much you can learn from remote sensing," said Todd Lane, an atmospheric scientist at the University of Melbourne in Australia who is not involved in hurricane hunter research. So scientists, pilots, and crew keep flying, despite the risks that severe turbulence poses.

New research published in the *Bulletin of the American Meteorological Society* shows that Marks's memorable flight through Hurricane Hugo in 1989 was rightly infamous—it ranks as the most turbulent NOAA Hurricane Hunter mission to date (bit.ly/bumpiest-flight). Data from it and other bumpy NOAA Hurricane Hunter flights could make future trips safer.

"We're scientists—let's try to figure this out."

The Bumpiest of Them All

Josh Wadler, a meteorologist at Embry-Riddle Aeronautical University in Daytona Beach, Fla., had his own wild ride aboard a NOAA Hurricane Hunter aircraft in September 2022. He and his colleagues were flying through Hurricane Ian to study how energy was being transferred from the ocean to the atmosphere and, ultimately, into the hurricane. That was by far the bumpiest of the 20 or so Hurricane Hunter flights he'd been on, with extreme turbulence lasting for 10 or so minutes.

When the team finally emerged into smooth air, Wadler and others on board couldn't help but wonder how their experience stacked up to the infamous 1989 flight through Hurricane Hugo. They decided to throw data at the question. "We're scientists—let's try to figure this out," Wadler said.

Wadler and his colleagues mined in-flight data collected automatically by onboard navigation systems for every NOAA Hurricane Hunter flight into a tropical cyclone from 2004 to 2023. Those data, recorded every second, were already digitized and freely available online. But amassing data for comparison—from two earlier flights, through Hurricane Hugo and Hurricane Allen, another notoriously bumpy storm in 1980—required a bit more finesse. "There's no record of them online," Wadler said. "They're just on tapes."

Enter the data-wrangling skills of Neal Dorst, a meteorologist with the Hurricane Research Division of NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami.

"Back in the day we would record the flight-level data on magnetic tapes," Dorst said. Reels of magnetic tape sit in a room just down the hall from Dorst's office. He's digitizing them all and processed the Hugo and Allen data out of sequence after a special request for this project.

For each NOAA Hurricane Hunter flight of interest, the team analyzed six different aircraft motions: three translational (forward and back, side to side, and up and down) and three rotational (roll, pitch, and yaw). For every second, the team calculated the aircraft's acceleration and jerk—that is, the rate of change of acceleration in time—in each of those six dimensions.

Because rotational motion depends on position relative to an axis of rotation, the team also considered a passenger's seat position when determining what acceleration and jerk someone on board would have experienced. "The farther away from the axis of rotation you are, the more you feel," Wadler said. "You're going to feel the rotational motions more in the front or back of the plane."

When the researchers tabulated a "bumpiness index" that took into account both acceleration and jerk, Wadler discovered that his memorable flight through Hurricane Ian in 2022 ranked second to the flight through Hugo. That finding wasn't wholly surprising, Wadler said. "There's a lot of folklore about that flight."

That infamous Hurricane Hugo flight pierced the storm just 1,600 feet (500 meters) above the Atlantic Ocean. That left dangerously little airspace for maneuvering and sent the plane directly into a region of the storm known for its extreme winds. (Nowadays, NOAA Hurricane Hunters fly roughly 6 times higher.)

"There's a lot of folklore about that flight."

Different Kinds of Bumpy

The in-flight data also corroborated something that those aboard the 1989 flight remember well: Their wild ride was characterized by extreme up and down motions. "Within a minute, we went through these huge three updraft/downdraft couplets," said Marks, a meteorologist who retired last year from the Hurricane Research Division of NOAA's Atlantic Oceanographic and Meteorological Laboratory.

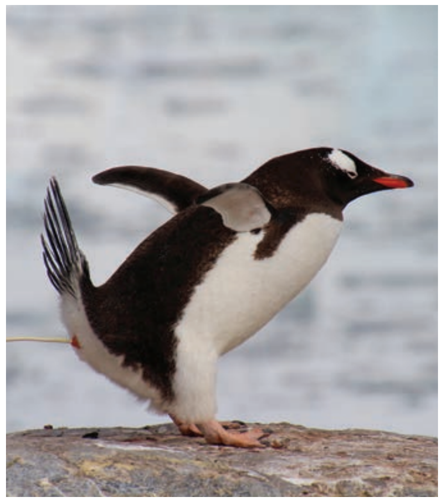
Wadler's trip through Hurricane Ian, on the other hand, involved strong turbulence directed largely sideways. "The side to side motions were unique," Wadler said.

Flights through Hurricanes Irma (2017), Sam (2021), and Lane (2018) rounded out the top five positions. Wadler and his collaborators found that turbulence tended to be stronger for large storms that went on to weaken in the next few hours. Bumpiness was also most pronounced near the inner edge of a storm's eyewall and near features known as mesovortexes, which are basically storms within a storm.

Beyond satisfying a personal curiosity, the finding could help make future NOAA Hurricane Hunter flights safer. "We know what to look for on radar when we're going into a mission," Wadler said. He hopes to take this new work in the direction of crew performance and cognition. "Is there a threshold of turbulence where humans are bad at making decisions?" he wondered. But instead of taking willing participants up on flights, Wadler plans to do turbulence experiments in the laboratory.

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

Pungent Penguin Poop Produces Polar Cloud Particles



A new study linked Adélie penguin poop to the formation of aerosols that can seed clouds over Antarctica. Pictured here is a gentoo penguin. Credit: Kamla S/Shutterstock

Ammonia released from penguin poop helps produce cloud-seeding aerosols in Antarctica, which can affect local climate by increasing cloud formation. This discovery came when scientists measured air downwind of two colonies of Adélie penguins on the tip of the Antarctic Peninsula.

Penguin poop emitted 100–1,000 times baseline levels of ammonia. New aerosol particles formed when that ammonia mixed with sulfur compounds from marine phytoplankton. The research was published in *Communications Earth & Environment* (bit.ly/penguin-poop-aerosols).

"This shows a deep connection between the natural ecosystem emissions and atmospheric processes, where emissions from both local seabird and penguin colonies and marine microbiology have a synergistic role that can impact clouds and climate," said Matthew Boyer, a doctoral student in atmospheric science at the University of Helsinki in Finland and lead author of the study.

Strong Whiffs of Ammonia

Although only trace amounts of ammonia exist in Earth's atmosphere, scientists have found that when it mixes with certain sulfur compounds it creates ultrafine particles (<0.1 micrometer in size). Those aerosols can grow into cloud condensation nuclei.

"Aerosol particles are necessary for cloud formation; liquid water will not condense to form cloud droplets without the presence of aerosol particles," Boyer explained.

The presence of these aerosols is especially important in pristine environments such as Antarctica that have low background levels of cloud-forming particles.

"The new particle formation process doesn't strictly need ammonia to proceed, but ammonia boosts the rate of the process considerably—up to 1,000 times faster," Boyer said. Gases emitted from natural sources such as penguins and the ocean are an important source of aerosols in the region, he added.

But the extremely low concentrations of gaseous ammonia, combined with the remoteness of Antarctica, have made understanding this cloud formation pathway challenging.

To tackle this problem, the researchers set up atmospheric samplers on the ground near Argentina's Marambio Station, located on Seymour Island near the northernmost tip of the Antarctic Peninsula. Two large colonies of Adélie penguins nested a few kilometers away, one with about 30,000 breeding pairs and another with roughly 15,000 penguin pairs, as well as 800 cormorant pairs.

From 10 January to 20 March 2023 (during austral summer), the team measured concentrations of ammonia, fine aerosol particles, and larger cloud condensation nuclei, as well as relative abundance of certain elements, cloud droplet distribution, and other atmospheric properties. By late February, the penguins left their breeding grounds and traveled to their wintering site, enabling the researchers to analyze the atmosphere with and without the birds present.

When wind blew air from the nesting grounds to the monitoring station, the team found that the penguin colonies emitted up to 13.5 parts per billion of ammonia, more than 1,000 times background levels without poop. However, when winds blew in from the sea, the Southern Ocean was a "negligible" source of ammonia.

Even after the penguins migrated, the poop they left behind continued to elevate ammonia to 100 times higher than background levels, which was the most surprising discovery for Boyer.

Researchers put sensors near the main buildings at Marambio Station on Seymour Island. Credit: Lauriane Quéléver

"This means that the footprint of ammonia emissions from penguins may cover more area of coastal Antarctica than indicated by the location of their colonies alone," he said.

The team found that 30 times more aerosol particles formed when gaseous ammonia mixed with sulfuric gases released by marine phytoplankton. When that combination mixed with dimethylamine gas, another penguin poop emission, aerosol formation increased 10,000-fold.

Gaseous ammonia lasts only a few hours in the atmosphere, but the aerosol particles it creates can survive for several days. Under the right wind conditions, those particles could travel out over the Southern Ocean and generate clouds where cloud condensation nuclei sources are limited.

The new results align with past research that examined the impact of Arctic seabirds on atmosphere and climate (bit.ly/Arctic-bird-ammonia). They also agree with past laboratory and modeling studies of Antarctic cloud formation, which in the past have been considered more reliable than in situ measurements.

"Measuring ammonia on its own under normal circumstances can be tricky," said Greg Wentworth, an atmospheric scientist with the government of Alberta in Canada who was not involved with the new research. "To do all the sophisticated measurements required to tease apart the details of new particle formation is remarkable, especially since they did this at the ends of the Earth!"

"The footprint of ammonia emissions from penguins may cover more area of coastal Antarctica than indicated by the location of their colonies alone."

Penguin Feedback Loops

"This study provides the most compelling evidence to date that ammonia and sulfur compounds...are an important source of cloud condensation nuclei during summertime in Antarctica," Wentworth added. "How remarkable is it that emissions from penguin poop and phytoplankton can kick-start chemistry in the atmosphere that can alter clouds and affect climate?"

The polar regions are experiencing dangerous levels of warming, and more cloud cover can help cool things down—sometimes. Higher concentrations of aerosol particles tend to create thicker, low-atmosphere clouds that are more reflective and can cool the surface, Boyer said. Thinner clouds high in the atmosphere tend to trap heat and warm the surface.

Understanding whether seabirds generate aerosols at a consistent, high-enough rate to cool local climate would require more atmospheric monitoring and climate modeling, he added.

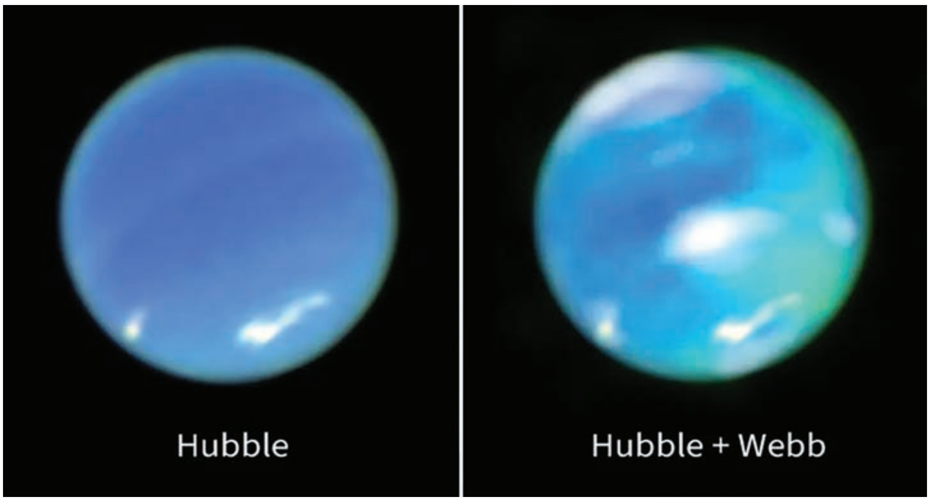
A connection between penguins and their environment means that when one is threatened, both feel the impacts. As climate change warms the polar regions and endangers the species that live there, the loss of those species could reduce cloud cover and further accelerate warming.

"It's important to understand how ecosystems, especially sensitive ones in remote regions, will respond to climate change," Wentworth said. "It's doubly important to understand those changes when components of those ecosystems also impact climate change."

"The more we understand about specific processes that impact ecosystems and climate change, the better we can predict and adapt to change," Wentworth said.

By **Kimberly M. S. Cartier** (@astrokimcartier.bsky.social), Staff Writer

After 30-Year Search, Scientists Finally Find an Aurora on Neptune



An enhanced color image from the Hubble Space Telescope (left) combined with infrared data from JWST (right) shows the intensity and extent of Neptune's auroral activity (cyan splotches) as well as several bright reflective clouds (white). Astronomers found the aurorae exactly where theories predicted they would be. Credit: NASA, ESA, CSA, STScI, Heidi Hammel (AURA), Henrik Melin (Northumbria University), Leigh Fletcher (University of Leicester), Stefanie Milam (NASA-GSFC), CC BY 4.0 (bit.ly/ccby4-0)

After decades of nondetections and tantalizing maybes, astronomers have definitively detected an aurora on Neptune. Using the James Webb Space Telescope (JWST), researchers identified for the first time an infrared auroral glow and the spectral signature of a key tracer of aurorae in Neptune's upper atmosphere. The spectrum of this ionized molecule also suggests that this region of Neptune's atmosphere has cooled significantly since Voyager 2's flyby 34 years ago.

Aurorae have been seen on planets and moons throughout the solar system. Theories predicted that Neptune should have aurorae, too, but previous attempts to detect them failed, said Henrik Melin, a planetary aurora researcher at Northumbria University in Newcastle upon Tyne, United Kingdom (U.K.).

"I've spent many, many nights up a mountain trying to detect this stuff using ground-based telescopes. You spend four nights staring at Neptune, and you see nothing," Melin said.

This auroral detection is "completing the set" of giant planet aurorae, he added. "We have Jupiter, we have Saturn, we have Uranus. We now have Neptune."

Anywhere they occur, aurorae can help scientists understand the inner workings of a planet's magnetosphere.

Chilly Aurora

Aurorae occur when charged particles from the solar wind or a nearby volcanic moon, for example, interact with a body's magnetosphere and upper atmosphere. Some aurorae, like those on Earth and some of Jupiter's moons, glow in visible light. Mercury's aurorae shine in X-ray light.

On planets with hydrogen-dominated atmospheres like Jupiter, Saturn, and Uranus, aurorae typically glow in the infrared or ultraviolet and are traced by the presence of the trihydrogen cation (H_3^+). Anywhere they occur, aurorae can help scientists understand the inner workings of a planet's magnetosphere.

"Auroral emissions provide important insight into the space environment of a planet, and this is particularly important for Neptune, which has a very bizarre magnetic field," said Jonathan Nichols, a planetary aurora researcher at the University of Leicester in the United Kingdom who was not involved with the new discovery.

"Auroral emissions provide important insight into the space environment of a planet."

Voyager 2's brief 1989 flyby suggested that Neptune's magnetic field is both tilted from its axis of rotation and offset from the center of the planet. The flyby also detected some hints of a possible aurora that astronomers have been hoping to confirm ever since. Models of Neptune's atmosphere and magnetic field have suggested that Neptune's aurorae should also be traceable by H_3^+ and have even predicted the longitudes at which they should appear. But detecting the aurorae proved elusive.

In June 2023, Melin and his colleagues obtained near-infrared JWST spectra of Neptune, originally intending to explore the circulation of Neptune's middle atmosphere. The observations revealed an unexpected infrared auroral glow as well as a shockingly clear infrared spectrum of H_3^+ emitted by the planet's upper atmosphere.

The intensity of the H_3^+ spectrum suggests that the upper atmosphere generating the aurora is 85°C (358 K), a significant cooldown from the 477°C (750 K) temperature measured by Voyager 2.

"That was quite a surprise," Melin said.

Neptune's seasons are roughly 41 Earth years long, so this dramatic cooling took place faster than the seasonal timescale. The researchers don't yet understand what might be driving the cooldown, Melin said, though it is likely unrelated to the unseasonably cool summer observed elsewhere in Neptune's atmosphere.

"The consequence of these really cold temperatures means that the auroral emissions are extremely faint," Melin said. That explains why Neptune's aurorae eluded the gazes of ground- and space-based telescopes before. "It was just really, really cold."

"It's great to see this addition to the family portrait of solar system auroras," Nichols said. "Now [that] we know how bright the infrared emission is, we can work out the intensity in other wavelengths such as ultraviolet, and we can run models to see what the upper atmosphere is like."

The researchers published this discovery in *Nature Astronomy* (bit.ly/Neptune-aurorae).

"This is the tantalizing starting point of really getting to understand Neptune."

A Neptunian Day

These JWST data were clear enough to trace aurorae to specific latitudes and longitudes, "producing the first map of the aurora at Neptune," Melin said.

What's more, the aurorae appeared at the exact longitudes in the southern hemisphere predicted by long-standing theories.

"This was not a given," Nichols explained, "since the length of the planet's day was determined more than 3 decades ago, and the uncertainty was such that we were supposed to have lost track of what the time is at any point on Neptune." (Uncertainty in planetary day lengths is pretty common.)

"But it appears as if it is more accurate than we thought!" Nichols added.

Later this year, the team will point JWST at Neptune several times over the course of a month to learn more about what drives its aurorae and how the planet's magnetosphere responds to different levels of solar activity.

"By studying the morphology of the aurorae and its changes over time, we can figure out what drives it," Melin said. The team needs more data to do that, "but this is the tantalizing starting point of really getting to understand Neptune."

By **Kimberly M. S. Cartier** (@astrokimcartier.bsky.social), Staff Writer

A Great Whale Conveyor Belt Transports Nutrients Across Oceans

Humpback and other baleen whales transport nutrients to breeding grounds. Credit: Elliott Hazen/NMFS/SWFSC/ERD/NOAA

Whalefalls—whale carcasses sinking to the ocean floor—bring a buffet of nutrients to the deep sea.

But whales don't have to be dead to be big movers of nutrients. Migrating baleen whales transport more than 3,700 tons of nitrogen and more than 46,000 tons of biomass each year from high-latitude feeding areas to warm, shallow breeding waters near the tropics, according to a recent study published in *Nature Communications* (bit.ly/nutrients-whales).

"In places like Hawaii or the Caribbean or the coastal waters of Western Australia, where nitrogen is often a limiting nutrient, migrating whales can have a big impact on the local biogeochemistry," said Joe Roman, lead author of the new study and a conservation biologist at the University of Vermont.

Roman and his colleagues found that in some breeding areas, the transport of nutrients like nitrogen can be as significant from whales as from nonbiological processes, such as nutrient-rich upwellings. In the Hawaiian Islands Humpback Whale National Marine Sanctuary, nitrogen brought in each day by migrating humpback whales can be 125%–175% that of nitrogen from abiotic processes during the breeding season.

Though whales move only a small portion of the total nutrients swirling through the oceans, they have a significant effect on the ecosystems in the breeding area, according to Matt Savoca, a marine ecologist at the Stanford University Hopkins Marine Station, who wasn't involved with the study. "It's a bit like adding fertilizer to a garden in New York City," he said. "On the scale of the entire city, any change is probably undetectable, but the garden is profoundly affected."

Nitrogen in Whale Pee

Roman and his colleagues used publicly available databases and whale sightings from ships and aerial surveys to estimate populations in feeding and breeding areas. They focused on gray, humpback, and right whales. (They avoided other baleen whales such as blue, fin, and minke because less is known about the migration patterns of these species.)

To calculate how much nitrogen migrating whales transport to breeding areas, the researchers turned to a perhaps unexpected animal: the northern elephant seal. "What makes northern elephant seals and baleen whales similar is that they are both capital breeders," Roman said. Capital breeders bulk up for part of the year while in their feeding grounds. Then, after traveling to their breeding areas, they gestate, give birth, and lactate, all while fasting. This behavior contrasts with that of income breeders, such as seabirds, which feed throughout the year.

Scientists have data on nitrogen levels in urine for only a few feeding and lactating species, and within that category, the elephant seal is the only capital breeding marine mammal for which data exists. The researchers used information on elephant seal urine and supplemented the calculations with limited existing measurements of urine from whales in feeding and breeding areas to estimate how much nitrogen whales transport. (They didn't include data on whale feces because adult baleen whales that are not feeding while in the breeding areas rarely defecate.)

Each year, whale species in the study may be adding more than 3,700 tons of nitrogen and more than 46,000 tons of biomass—which includes placentas released during births as well as carcasses of newborn and adult whales—to breeding areas. More conservatively, mothers and calves alone may transport more than 2,300 tons of nitrogen and 12,000 tons of biomass per year.

The Great Whale Conveyor Belt

Scientists still don't fully agree on why whales migrate, usually from cold, nutrient-rich waters in high latitudes to warmer, nutrient-poor tropical waters. Some baleen whales make tremendously long journeys. For example, gray whales can travel more than 11,000 kilometers from the waters around Sakhalin Island, Russia, to Baja California.

"This study helps us realize that whales are not only charismatic species, but they also provide vital ecosystem services by connecting environments separated by thousands of miles."

"Other mammals and birds also migrate long distances, but what makes baleen whales different is their size and the fact that they are capital breeders," Roman said. That means that "most of the waste generated by the whales in the breeding areas, from placentas to urine, introduces external nutrients into the ecosystems."

And baleen whales urinate a lot; a 2003 study estimated that one fin whale can produce almost a thousand liters of urine each day (bit.ly/whale-urine). Even whales that are fasting while in the breeding areas urinate copiously because they are breaking down stored fats and proteins to make milk for calves. Whale urine contains many elements, including phosphorus, magnesium, potassium, and nitrogen. The researchers were interested in nitrogen because it is a limiting nutrient in many marine ecosystems.

They estimate that the nitrogen that whales bring to an ecosystem could increase the amount of food available in breeding waters. Whale urine contains nitrogen mainly in the form of urea, which organisms such as phytoplankton can readily use to convert carbon dioxide into thousands of tons of biological carbon per year through photosynthesis.

Some uncertainty is unavoidable when researching large marine mammals that travel huge distances, Savoca said. "But the study provides data-driven estimates that are as good as it gets at this time."

"We are at the early stage of understanding how the nutrients, like nitrogen, that the whales bring in move through the ecosystems and the food chain," Roman said. This understanding is especially important as whale populations face various threats, including pollution and climate change.

"This study helps us realize that whales are not only charismatic species, but they also provide vital ecosystem services by connecting environments separated by thousands of miles," Savoca said.

By **Adityarup Chakravorty,** Science Writer

Cracks on Planetary Surfaces Hint at Water

This cracks in this rock slab on Mars known as "Old Soaker" may have formed from the drying of a mud layer. Credit: NASA/JPL-Caltech/MSSS

From cracking mud to thawing permafrost, fractured terrain is common on Earth and many planetary surfaces. The geometry of those fractures is influenced by the amount of water present and how long it's been around, according to researchers.

A team has now proposed a model to predict the evolution of fractured terrain through time. These new findings could be used to unravel the history of water on other worlds.

"From the moment that materials solidify, they start falling apart."

Since the 1960s, scientists have pored over hundreds of thousands of solar system images beamed back from spacecraft and landers. "The amount of data coming in is overwhelming, and it is mostly pictures," said Gábor Domokos, an applied mathematician at the Budapesti Műszaki és Gazdaságtudományi Egyetem in Hungary.

Many of those images show a process now known to be ubiquitous across the solar system: disintegration.

"From the moment that materials solidify, they start falling apart," said Doug Jerolmack, a geophysicist at the University of Pennsylvania in Philadelphia. The study that Domokos and Jerolmack and their respective graduate students Krisztina Regős and Sophie Silver recently published in the *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/planetary-cracks) reflects that sentiment in a poetic first line: "Things fall apart."

The researchers analyzed images of fractured terrain on Venus, Mars, and Jupiter's moon Europa and manually traced fractures visible in each. They focused on 15 images: 4 of Venus, 9 of Mars, and 2 of Europa.

From above, the fracture networks look like mosaics of convex polygons. Those polygons can be characterized by simple geometric properties, including their number of vertices and the number of cracks that meet at each of those vertices (or "nodes"). The team did just that, and there was nothing particularly complicated about that work, Domokos said. "We are just counting."

Of the more than 13,000 nodes that the researchers tabulated, more than 95% consisted of the meeting of two, three, or four cracks. Previous work in geomorphology has referred to those intersections as T, Y, and X junctions, respectively, on the basis of the letters that they often resemble.

Three Letters, Three Processes

T junctions were the most prevalent in the imagery. That result is consistent with investigations of fractures on Earth and is not surprising, Jerolmack said, because these junctions form from a basic process in which a newer crack runs into an older crack and stops. "This is the most common pattern of something that just breaks and breaks and breaks," Jerolmack explained. A mud plain that was once wet and then dried over time would be dominated by T junctions.

Y junctions, on the other hand, were less common and tended to occur in landforms that had experienced alternating periods of drying and wetting, the team showed. Laboratory results support that finding: In 2010, another research group published time-lapse photography of clay undergoing repeated cycles of drying and wetting and uncovered T junctions evolving into Y junctions.

The propagation of a crack through partially, but not fully, healed T junctions tends to produce rounded corners, said Lucas Goehring, a physicist at Nottingham Trent University in the United Kingdom and the lead author of the 2010 study. "Over time, that corner will be dragged into a shape that is like a Y."

Although Y junctions do not necessarily imply the presence of water—these features also form in basalt columns, for instance—they hint that a landscape might have experienced a sustained presence of water, according to the researchers.

X junctions proved to be the rarest of the three. The team spotted X junctions—in which a newer crack runs right through an older crack—only on Europa. "Normally, a crack cleanly separates two surfaces," Goehring said. But an X junction is evidence that a previous crack healed, thereby allowing a younger crack to propagate across it largely unimpeded. "It's behaving as if that old crack isn't there," Jerolmack said.

Water ice is one such material that heals itself, and Europa is known to be covered in a shell of the stuff. The existence of X junctions implies the presence of frozen water, the researchers concluded.

Making Movies

Domokos, Jerolmack, and their students next constructed a geometrical model of fracturing. The goal was to develop mathematical expressions encoding the physical processes involved in forming T, Y, and X junctions and then, on the basis of a single image of a planetary surface, model how an ensemble of fractures would evolve over time.

Playing such a movie back might reveal something about the geological processes underlying crack formation, Domokos said. That's powerful for understanding not only our own planet but other worlds as well. "We don't have these kinds of movies, not even on Earth."

"We don't have these kinds of movies, not even on Earth."

The researchers showed that their model could accurately reproduce the entire range of fracture mosaics they observed. That's critical to verifying the utility of this model, Jerolmack said. "We built a toy model of the universe of fracturing. The actual universe of crack patterns seems happy to comply."

Testing this model will require more experimental data showing how real fractures evolve, however, Goehring said. Collecting such data isn't technically challenging, but it can be laborious: Goehring and his team spent several months observing how clay fractured in response to 25 cycles of drying and wetting. "It's quite a tedious experiment to do," he said.

But such a model could shed important light on the solar system's past, said Nina Lanza, a planetary scientist at Los Alamos National Laboratory in New Mexico who was not involved in the research. For instance, getting a handle on whether water persisted somewhere for a long time says something about the geological environment, she said. "Now we're getting a more complex picture of a planet over time."

Domokos, Jerolmack, and their students analyzed all of their fracture mosaics manually. However, future investigations could rely on artificial intelligence and machine learning, which would make it possible to probe thousands of fracture mosaics rather than just a handful.

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

Have We Finally Found the Source of the "*Sargassum* Surge"?

A boat floats atop an inlet covered in brown Sargassum seaweed off the coast of Micoud, Saint Lucia. Credit: JD

Since 2011, massive mats of golden-brown seaweed—pelagic Sargassum—have repeatedly swamped the shores of the Caribbean, West Africa, and parts of Central and South America. These sprawling blooms have suffocated coral reefs, crippled tourism, and disrupted coastal life.

What caused this sudden explosion of seaweed in regions that had rarely experienced it before?

A modeling study published earlier this year in *Nature Communications Earth & Environment* offers one possible explanation (bit.ly/Sargassum-surge-cause). It links the start of this phenomenon to the 2009–2010 North Atlantic Oscillation (NAO)—a rare climatic event involving stronger-than-usual Westerlies and altered ocean currents.

According to the study, NAO conditions transported *Sargassum* from its historic home in the Sargasso Sea in the western North Atlantic into tropical waters farther south, where nutrient-rich upwellings and warm temperatures triggered the algae's explosive growth.

Migrating Macroalgae

Julien Jouanno, senior scientist at the Institut de Recherche pour le Développement and head of the Dynamics of Tropical Oceans team at Laboratoire d'Etudes en Géophysique et Océanographie Spatiales in Toulouse, France, led the modeling work behind the study.

"Our simulations, which combine satellite observations with a coupled ocean-biogeochemical model, suggest that ocean mixing—not river discharge—is the main nutrient source fueling this proliferation," Jouanno explained. The model incorporates both ocean circulation and biological processes like growth and decay, enabling the team to test various scenarios involving inputs such as ocean fertilization by rivers (such as the Amazon) or influxes of nutrients from the atmosphere (such as dust from the Sahara).

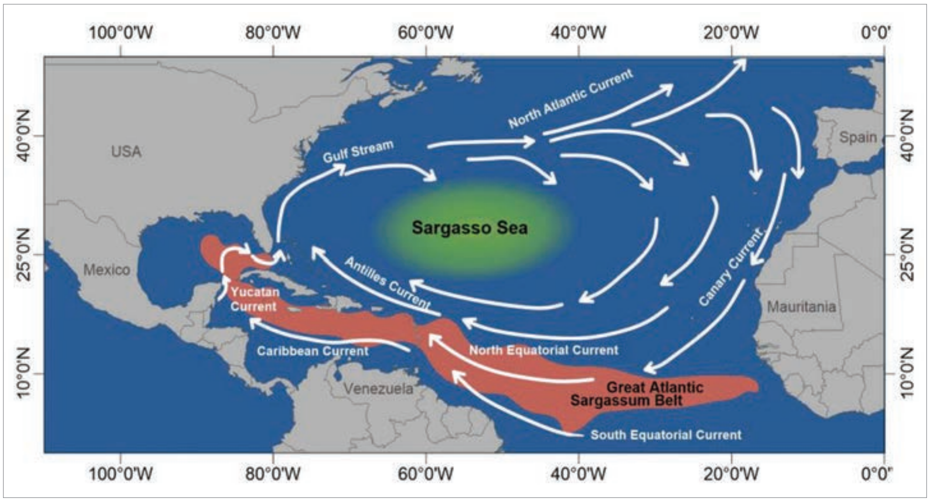
"Turning off river nutrients in the model only reduced biomass by around 15%," said Jouanno. "But eliminating deep-ocean mixing caused the blooms to collapse completely. That's a clear indicator of what's actually driving the system."

"When we exclude the ocean current anomaly linked to the NAO, *Sargassum* stays mostly confined to the Sargasso Sea," Jouanno said. "But once it's included, we start to see the early formation of what is now known as the Great Atlantic Sargassum Belt."

But not all scientists are convinced by the study. Some argue the truth is more complex, and more grounded in historical ecological patterns.

Was the Seaweed Already There?

Amy N. S. Siuda, an associate professor of marine science at Eckerd College in Florida



The Great Atlantic Sargassum Belt, first identified in 2011, is the largest macroalgae bloom in the world. The massive blooms sit below the Sargasso Sea and currents of the North Atlantic Ocean. Credit: López Miranda et al., 2021, https://doi.org/10.3389/fmars.2021.768470, CC BY 4.0 (bit.ly/ccby4-0)

and an expert in *Sargassum* ecology, critiqued the study's core assumptions. "The idea that the 2011 bloom was seeded from the Sargasso Sea doesn't hold up under scrutiny," she said.

The dominant form of *Sargassum* present in the early blooms in the Caribbean and elsewhere (*Sargassum natans var. wingei*), she explained, "hasn't been documented in the north Sargasso Sea at all, and only scarcely in the south."

Historical records suggest that the variety had long existed in the Caribbean and tropical Atlantic, however—just at such low concentrations that it was easily missed, Siuda said. She also cited research on population genetics that shows little physical mixing between *S. natans var. wingei* and other morphotypes through at least 2018 (bit.ly/algae-mixing).

"We were simply not looking closely enough," she noted. "Early blooms on Caribbean beaches were misidentified. What we thought was *S. fluitans var. fluitans*, another common morphotype, turned out to be something else entirely."

A *Sargassum* bloom can be difficult to model, Siuda explained. Models "can't distinguish whether *Sargassum* is blooming or simply aggregating due to currents. Field data, shipboard observations, and genetic studies tell a much more complex story," she said.

Donald Johnson, a senior research scientist at the University of Southern Mississippi, offered a different perspective. He agreed that *Sargassum* has long existed in the tropical Atlantic but said that he believed that the NAO may have also played a catalytic role in the blooms—just not in the way the original study claims.

"Holopelagic *Sargassum* has always been in the region—from the Gulf of Guinea to Dakar—as evidenced by earlier observations stretching back to Gabon," Johnson explained. "What changed in 2010 was the strength of the Westerlies. Drifting buoys without drogues showed unusual eastward movement, possibly carrying *Sargassum* from the North Atlantic toward West Africa."

"Modeling surface currents in the tropical Atlantic is extremely difficult."

He offered a crucial caveat, however: "There was never any clear satellite or coastal evidence of a massive influx [of *Sargassum*]. If the NAO did contribute, it may have done so gradually—adding to existing *Sargassum* in the region and pushing it over the threshold into a full-scale bloom."

In this view, the 2011 event was less about transport and more about amplification, described as an environmental tipping point triggered by a convergence of factors already present in the system.

More Than Just Climate

Both Siuda and Johnson agreed that multiple nutrient sources in the tropical Atlantic are likely playing a major role in the ongoing blooms:

- Riverine discharge from the Amazon, Congo, and Niger basins
- Saharan dust, rich in iron and phosphates, blown westward each year
- Seasonal upwelling and wind-driven mixing, particularly off West Africa and along the equator.

And, Johnson pointed out, persistent gaps in satellite coverage—caused by cloud cover and the South Atlantic Anomaly—mean we're still missing key pieces of the puzzle. "Modeling surface currents in the tropical Atlantic is extremely difficult," he said. "First-mode long waves and incomplete data make it impossible to fully visualize how *Sargassum* is moving and growing."

Ultimately, both researchers said that understanding these golden tides requires reconciling models with fieldwork, as well as recognizing the distinct morphotypes of *Sargassum*. "Each variety reacts differently to environmental conditions," Siuda explained. "If we don't account for that, we risk oversimplifying the entire phenomenon."

"There's a danger in leaning too heavily on satellite models," Johnson cautioned. "They measure aggregation, not growth. Without field validation, assumptions about bloom dynamics could mislead management efforts."

Jouanno, too, acknowledged the study's limitations. The model does not differentiate between *Sargassum* morphotypes and struggles with interannual variability, particularly in peak bloom years like 2016 and 2019. "This was likely a regime shift—possibly amplified by climate change—and while we can simulate broad patterns, there's still much we don't know about how each bloom evolves year to year."

"We're still learning," Jouanno said. "Our understanding of vertical mixing, surface stratification, and nutrient cycling in the tropics is incomplete—and the biology of different Sargassum types is another critical gap."

Ultimately, Jouanno said, "This is climate-driven. The NAO was a catalyst, and ongoing warming may be sustaining it. But without better field data and biological detail, we can't fully predict what comes next."

By **Sarah Nelson** (@SarahPeter3), Science Writer

Senior Scientists Must Stand Up Against Attacks on Research and Education

Massive cuts in federal funding of schools and science agencies, dogmatic calls to eliminate entire research areas, revocations of the visas of international students and scholars, and attacks on academic freedom, speech, and the value of education and expertise—all emanating from recent Trump administration actions—are damaging and reshaping U.S. higher education and scientific institutions. Furthermore, the country's withdrawals from international treaties (e.g., the Paris Agreement) and organizations (e.g., the Intergovernmental Panel on Climate Change and World Health Organization), and its weakening of programs promoting health, environmental protection, cultural exchange, and peace, diminish U.S. leadership and credibility globally and add to instabilities threatening lives, economies, and security around the world.

The surprising speed and breadth of the attacks and changes have left scientists, educators, and others confused, afraid, and grappling with how to respond. The environment of intimidation, uncertainty, isolation, and fear created by the administration has been compounded by the silence or outright capitulation of many leaders and institutions in the face of these threats, despite their having firm legal and constitutional protections. If sitting Republican senators like Lisa Murkowski (R-Alaska; bit.ly/Lisa-Murkowski), major universities, law firms, and private companies and foundations are afraid to speak out and defend their values, what can individuals do?

They can organize, and in so doing wield strength in numbers and identify leaders who are well-positioned to raise their voices to push reluctant institutions to act. Within science higher education, senior scientists can and should fill these roles.

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Standing Up and Standing Out

The risk calculations for many institutions and individuals in the face of the administration's swift, illiberal, and authoritarian actions have been clear: It is better to comply than to fight, because fighting risks funding losses, investigations, and lawsuits.

However, as the experiences of some universities—notably, Columbia—have demonstrated, submitting to administration demands has not spared institutions from further scrutiny. In Harvard's case, shortly after the school's president indicated willingness to engage with the administration about shared concerns, the scope of outrageous demands increased to infringe on its ability to make its own decisions on hiring, enrollment, curriculum, and values, leading the university to sue the administration.

> **Standing up and standing out are easier said than done, especially considering the very real risks to individuals' careers, livelihoods, and safety.**

Clearly, the balance of risk between compliance and standing up for core principles (not to mention the rule of law) has shifted. As the leaders of higher education and science institutions weigh how to respond to the shift, their employees, members, and constituent communities can speak up to shape these responses.

What is needed are courage, solidarity, and an intentional and strategic plan of action. Of course, standing up and standing out are easier said than done, especially considering the very real risks to individuals' careers, livelihoods, and safety. In science and academia, as elsewhere, these risks are greatest for those most vulnerable: students, early-career researchers, and immigrants and international scholars. Therefore, it is incumbent upon senior colleagues—who have outsize privilege, responsibility, and collective power in universities and professional societies—to lead the way.

Reframing the Message

With social media increasingly fueling the spread of misinformation and disinformation and the corporate consolidation and polarization (both real and perceived) of mass media, strategies used in the past to inform reasoned policy discussions no longer work. Scientists' rational, detailed, and evidence-based arguments used to be effective in influencing policy, but the current administration and its allies have largely disregarded experts and facts in making major decisions.

With this new reality, the messaging from scientists—especially senior scientists with privileged identities—must change.

The messaging must be direct and aimed at resisting ongoing actions that are dismantling U.S. scientific and education enterprises; harming students, universities and colleges, and federal research agencies; and degrading public health, foreign policy, the economy, and the rule of law. Simply put, these actions are leading to death and environmental destruction, and they are endangering the national economy.

The dismantling of federal support for HIV and AIDS research and prevention, for example, "will hurt people, will cause people to die, and will cause significant increased costs to all of us throughout the country," said a former Centers for Disease Control and Prevention official.

The numerous rollbacks of major EPA rules and environmental protections will dramatically degrade air and water quality and irreparably harm public health and ecosystems.

And the cuts to scientific research will directly affect our ability to advance medical, energy, transportation, space, communication, and infrastructure innovations, undermining the country's economic strength.

Influencing Institutional Leaders

In addition to speaking simply and clearly about the realities of such threats, scientists must come together within their own and across institutions to form united fronts. Senior scientists should be at the vanguard of these fronts, using their influence to protect students and more vulnerable colleagues, U.S. citizens and international scholars alike.

They should demand that their institutional leaders uphold core values of higher education and science, including inclusion, international cooperation, and ethical and evidence-based research. They should demand that leaders strengthen mutually beneficial ties among universities and professional societies, urging them, for example, to join mutual defense coalitions such as the Big Ten Academic Alliance and to sign on to the American Association of Colleges and Universities' "Call for Constructive Engagement," which rebuked the administration's attacks.

Senior scientists should be at the vanguard of these fronts, using their influence to protect students and more vulnerable colleagues.

And they should demand that instead of capitulating, their institutions bring and support litigation against attempts to suppress academic freedom, free speech, and freedom of association; to unlawfully cancel grants and revoke visas; and to infringe on universities' independence to develop their own curricula and academic policies. After all, executive orders are unilateral directives, not laws or legislation.

Furthermore, institutions should provide free legal counsel to imperiled international students and researchers and speak loudly and publicly about the meaning and value of academic freedom, the power of diverse and inclusive communities in driving societally valuable innovations, and the incredible returns of investing in modern research universities.

Though these demands should be made of our institutional leaders, senior scientists should also act on their own to help defend the higher education and scientific communities and their work from attacks meant to discredit and marginalize them.

Acknowledge and Activate

What can these scientists do? For starters, they can keep up-to-date about the shifting landscape of relevant federal, state, and institutional policies and responses. Many timely resources can help with this. I joined the chapter of the American Association of University Professors (AAUP) at the University of Michigan in Ann Arbor, where I work, for this purpose.

Senior scientists can support early-career colleagues and students by helping them, in turn, stay informed of policy developments. They can do this by actively listening to and understanding their colleagues' concerns, and by providing opportunities for career and community networking and professional development. Universities frequently offer mentoring resources and tool kits that can help, and multi-institutional programs can enable connections within and across peer groups.

Senior scientists can also support each other across campuses and seek allies in other disciplines, recognizing that attacks on the arts, humanities, and STEM (science, technology, engineering, and mathematics) fields are all connected.

Further, scientists should be contacting and meeting with local, state, and federal elected officials. Scientists should use those meetings to convey the impacts of funding cuts and attacks on students, scholars, research, and innovations, citing real examples from their home institutions.

At the University of Michigan, for example, scores of grants and contracts (including two of my own) have been canceled or not renewed, either because they did not comply with administration ideology on DEI (diversity, equity, and inclusion), health equity, or environmental justice or because of agency program eliminations and budget cuts. These cuts have directly halted student research experiences and led to layoffs and withdrawals of graduate admissions offers.

Although local and state officials cannot directly change federal policy, scientists can help focus their attention on the local impacts of federal actions. Moreover, officials' concerns often carry a different weight within political decisionmaking. A federal congressperson may respond differently to a state senator from their own political party than they would to the concerns of 10 scientists.

In addition, senior scientists can work with their professional societies and organizations to pursue litigation against unjust actions and provide programming (e.g., career counseling) and financial support (e.g., waived conference registration fees) for students and colleagues directly affected. If needed, they can push their professional societies to take stronger stances.

The powerful statement by the American Academy of Arts and Sciences offers a model that every nonprofit professional society should emulate (see bit.ly/AAAS-statement). Even if institutions or societies have adopted neutrality statements or are nonprofits prohibited from lobbying activities and whose memberships have diverse views, there is clear rationale to speak out and act against policy changes that directly affect their missions.

In short, senior scientists must acknowledge the severity of the threats to the scientific and higher education communities from the administration's actions and activate to support local and national efforts to counter the threats. Together with the leaders of their institutions and professional societies, they must defend these communities—particularly their more vulnerable members—and the value and integrity of the work they do.

The stakes are high: Lives and careers are being jeopardized, and brilliant scientists are being driven away. We must act to preserve the American partnership that created diverse, federally supported research universities before the damage is permanent.

By **Mark Moldwin** (mmoldwin@umich.edu), University of Michigan, Ann Arbor

Read the article at Eos.org

Winds of **Change**

Though winds may shift, science perseveres. And so do scientists. Whether change pushes them in new directions or strengthens their resolve, scientists find ways to keep doing important work.

The stories that follow highlight the journeys of scientists who have been blown off course, let the winds carry them, and stood tall in the breeze.

When, from the age of 11, one scientist knew she wanted to drive rovers on Mars, she made it happen.

When a young man saw his Narragansett community's concerns about the degradation of local landscapes and waters, that—along with his family's Traditional Knowledges—set him on the path to becoming a soil conservationist.

When an earthquake shook an aspiring actress's world (and her apartment), she enthusiastically asked how she could help.

When an atmospheric scientist pushed through her childhood fear of storms, she found a career studying extreme weather.

Along the way, all of the scientists profiled here connected communities, made discoveries, and had some wild adventures. May their inspiring stories help you weather whatever comes your way.

—The Editors

Glasshouse Images/The Image Bank via Getty Images

Wendy Bohon

Quelling Fears and Sparking Geoscience Joy

This earthquake enthusiast and science communicator wants you to know that a "whole ecosystem" of scientific careers exists outside of academia.

LIKE MANY YOUNG WAITRESSES IN LOS ANGELES, Wendy Bohon once dreamed of an acting career—that is, until the 1999 magnitude 7.1 Hector Mine earthquake shook up her plans (and her fourth-floor apartment).

"My surfboard fell on my head," Bohon recalled. "I was like, 'This is amazing.'"

The next day, she showed up at the U.S. Geological Survey office in Pasadena and asked to volunteer. They said no, but she persisted.

Eventually, Bohon helped design a public lecture series about earthquake science, which led to a job at the Pasadena office doing outreach and education.

Two decades later, she's the branch chief for seismic hazards and earthquake engineering at the California Geological Survey, where she manages scientists who help keep people safe from earthquake hazards.

Tens of thousands of people know of Bohon for something else: science communication. Through social media, talks, and more, she shares the joy of understanding our planet with audiences that otherwise might never have taken a second look at a rock.

> *"You're not lost. You're just taking a different path, and your science knowledge goes with you wherever you go."*

During grad school, Bohon experimented with how best to share science online. After earning her Ph.D. in geology in 2014, she managed communications for organizations such as Incorporated Research Institutions for Seismology (IRIS; now part of EarthScope) and NASA Goddard and even started her own science communication company. Outreach isn't part of her current job, but she continues doing it in her free time.

"I care a lot about people, and I have anxiety," Bohon said. "I know that earthquakes induce a lot of anxiety in people."

Quelling anxiety isn't her only goal. She also wants to inspire. Among other pursuits, she's an ambassador for IF/THEN, an initiative that highlights women role models in science, technology, engineering, and mathematics (STEM) fields.

Bohon wants aspiring scientists to know that there's a "whole ecosystem of science careers." She especially dislikes the "leaky pipeline" metaphor that people use to describe the tendency of women to leave academia at higher rates than men, especially after becoming parents.

Bohon was 7 months pregnant when she defended her Ph.D. And after taking a hard look at what an academic career would mean for her family, she decided it wasn't for her. So she took her expertise and infectious enthusiasm elsewhere.

"They're implying that if you don't follow this very narrow path, that you're leaking out, that you're lost," Bohon said. "You're not lost. You're just taking a different path, and your science knowledge goes with you wherever you go."

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

Wendy Bohon is a geologist and science communicator. Credit: IF/THEN Collection

Tanya Harrison

Roving on Mars

This planetary geologist has worked on nearly every Mars rover while connecting government, universities, the private sector, and the public.

WHEN NASA DEPLOYED A SMALL SIX-WHEELED ROBOT named Sojourner on Mars in 1997, space-obsessed 11-year-old Tanya Harrison was watching.

"When NASA released the little animated GIF of Sojourner driving onto the surface, I thought, 'I want to work on Mars rovers,'" she said. "I was laser focused on that goal from there out."

A bad experience getting a master's degree soured her on academia. To keep connected to the world of research, she looked for jobs that used her data analysis skills.

"I started emailing people who had written the papers that I read for my [master's] thesis and saying, 'Hey, do you need somebody to crunch data for you?'" Harrison said. Those emails led to a job at Malin

Space Science Systems, which gave her experience operating cameras on the Mars Reconnaissance Orbiter. But she realized she wanted more, which meant going back for a Ph.D. in geology and planetary science.

With doctorate in hand, Harrison fulfilled her dream of being directly involved with the Opportunity rover, along with planning the Curiosity and Perseverance rover missions. "I was on the teams advocating for both Gale and Jezero [craters], so we went to all the places that I was hoping we would go!" she said.

Meanwhile, she made a splash posting about her life as a scientist on Twitter (now X), which led to the media's seeking her out as an expert on all things Martian. "It hit me that I could make a bigger difference by inhabiting that role in the community than if I were just a scientist," she said.

Today Harrison works as an independent consultant for space companies based in her native Canada. She served on AGU's Board of Directors and still works on its Finance Committee. Her current life means less Mars work but more essential Earth observation research focused on climate change.

"My underlying goal is really to get all pieces of the larger space sector working together and benefiting each other."

"My underlying goal is really to get all pieces of the larger space sector working together and benefiting each other," she said, referring to academia, government, and private industry. "Forty percent of the Canadian landmass is in the Arctic, so we have a vested interest in being a leader in climate research."

Tanya Harrison, shown here driving the Canadian Space Agency's Mars Exploration Science Rover, wanted to work with rovers since she was a child. Credit: Eric Pilles

By **Matthew R. Francis** (@BowlerHatScience.org), Science Writer

Stacey Hitchcock

From Fearing Storms to Seeking Them

This atmospheric scientist digs into the details of storms to help keep people safe.

Stacey Hitchcock releases a weather balloon in Argentina. Credit: Russ Schumacher

STACEY HITCHCOCK REMEMBERS BEING TERRIFIED of storms as a child. (It didn't help that her neighbor's house was struck by lightning three times.) But today she is an atmospheric scientist studying extreme weather at the University of Oklahoma in Norman.

Hitchcock's younger self conquered her fears of the weather by asking lots of questions. "I remember at some point asking my dad to explain radar to me," she said.

Hitchcock first learned that studying the weather could be a profession when she took a tour of a university in Indiana while visiting to play in a tennis tournament. "I didn't know it was a career," she said.

As an undergraduate, Hitchcock helped with research on climate and snow. But extreme weather was always her passion. "I kept coming back to storms," she said. And she pushed on when she encountered adversity. Some of her classmates said she wouldn't make it professionally as an atmospheric scientist, but Hitchcock knew she was doing good work.

"If you feel like you're succeeding, don't let naysayers tell you that you're not," she said. "That's advice that I try to give to students."

Hitchcock uses both observations and simulations in her research. She is working to better understand the structure of storms that produce intense rainfall and the challenges of forecasting multiple storms that occur in close succession. She credits her wide-ranging research interests to her willingness to try out projects and develop new collaborations.

"A lot of the best things that have happened to me in my career happened because I had an interesting opportunity and I said yes," she said.

"If you feel like you're succeeding, don't let naysayers tell you that you're not."

For instance, Hitchcock spent 4.5 years in Australia as a postdoctoral researcher.

The professional connections she made abroad led to investigations of how turbulence in the atmosphere caused by storms translates into bumpy flights. Hitchcock is still involved in that field.

It's a somewhat fitting line of work, Hitchcock admits, because she used to be a queasy flyer.

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

Hermínio Ismael de Araújo Júnior

Savvy Planning Can Get You Far

The biologist turned paleontologist has been organized and nimble, and he jumped at opportunities as they arose.

On an expedition to the Lajinhas Paleontological Site in Brazil, Hermínio Araújo Jr. and his colleagues excavated megafauna fossils, including this vertebra. Credit: Hermínio Araújo Jr.

WHEN HERMÍNIO ISMAEL DE ARAÚJO JR. started his undergraduate degree in biology in 2006, the culture at Universidade Federal do Rio Grande do Norte, in northeastern Brazil, was that students got involved in research as early as possible. So at the end of Araújo's first semester, he joined an animal physiology project and studied how local plants affected diabetic mice.

"But I've always liked paleontology better," he said, so much so that his lab adviser introduced him to paleontologist Kleberson Porpino.

"We talked a lot, and I realized paleontology was really what I wanted to do," Araújo recalled. From that moment on, he thought his professional path was clear: After graduation, he would get his master's and doctorate at the Universidade Federal do Rio de Janeiro (UFRJ), just as Porpino had done not long before.

Araújo was interested in taphonomy, or the study of how bones become fossils. Being a taphonomist is like doing forensics,

> *The most interesting thing about paleontology "is to be able to give life to something that will never have life again."*

Araújo said. "We can understand how an animal died, how it got buried, the [geological] processes that happened after that… until the moment we find it."

The most interesting thing about paleontology "is to be able to give life to something that will never have life again," he said.

Halfway to finishing his bachelor's degree, Araújo looked closely at the selection requirements for a master's degree in geology at UFRJ. In Brazil, students can enroll in a master's only after coursework for a bachelor's degree is completed and their diploma has been conferred, which can take some time after their final semester.

"I didn't want to wait a year after graduation to start my master's," he said.

So he finished his last year of courses a semester early so he could squeeze in a thesis defense and an enrollment in the master's program in the same year.

Years later, as Araújo was pursuing his Ph.D., a faculty position opened at the Universidade do Estado do Rio de Janeiro (UERJ). Deciding to go for it, he again fast-tracked his degree work, defending his thesis a semester earlier than the official deadline so that he could assume the teaching position he currently holds.

Araújo said these sharp planning skills were inspired by his parents, who could not access higher education themselves but always encouraged their children to study. "My father is really organized—he does nothing without prior planning," Araújo said. "My parents are so methodic that up to this day they still go to the supermarket [every week] at the same day and time," he said, chuckling.

> *"I've been working to help open more space for women and other minoritized groups at the university."*

Araújo is currently president of the Brazilian Society of Paleontology and the graduate coordinator of the geosciences program at UERJ. In these positions, he engages in education programs against harassment and discrimination. "I've been working to help open more space for women and other minoritized groups at the university," he said. "It is something I really like and am very proud of."

By **Meghie Rodrigues** (@meghier.bsky.social), Science Writer

Phoebe Lam

Embracing the Ocean's Complexities

A generalist at heart, this geochemist is unraveling the mysteries of the ocean's chemical cycling.

PHOEBE LAM'S SCIENCE CAREER STARTED when she looked up at the stars. Her father, a theoretical physicist, explained the movements of Earth, the Moon, and planets, and Lam developed an appreciation for the natural world.

Today Lam works below the stars as a marine geochemist at the University of California, Santa Cruz, studying the role particles play in the cycling of carbon, iron, and other elements in the ocean.

Early on, it was hard for Lam to fit her love for nature into the confines of a scientific discipline. As an undergraduate at the Massachusetts Institute of Technology (MIT), she enjoyed all her classes—calculus, physics, chemistry, biology—almost equally.

Lam saw her peers joining research labs and did the same. She dove into oceanographic work with scientists at MIT and the Woods Hole Oceanographic Institution. An adviser predicted that Lam would be a "great generalist someday," Lam said. "I wasn't super focused—I was trying little things there, little things here. I think that still characterizes my brain."

"I realized I like the messiness of the real world."

Drawn to work that integrated different disciplines, she joined an oceanography lab at Princeton University to study the trace metal requirements of phytoplankton. But dealing only with tightly controlled variables felt limiting. "I realized I like the messiness of the real world," she said.

Frustrated, Lam joined the world of environmental policy—a "rebound relationship," she said. While enrolled in a policy-focused master's program, she took a class on carbon cycles, and found her way back to oceanography, eventually earning a Ph.D. from the University of California, Berkeley.

The twists and turns of Lam's academic journey "made me understand…that there are a lot of ways to do science," she said. She counsels prospective undergraduate and graduate students to think about how they might feel satisfied by their research.

For Lam, that satisfaction comes from putting together the complex puzzle of the ocean's chemistry—from knowing there are so many different questions she can ask of the ocean.

By **Grace van Deelen** (@gvd.bsky.social), Staff Writer

Phoebe Lam monitors the deployment of equipment on the deck of the icebreaker Nathaniel B. Palmer *in the Amundsen Sea. Credit: Sofia Moutinho*

Susanne **Maciel**

Marrying Mathematics and Geology

A geophysicist brings math down to Earth and reaches a rural audience.

SUSANNE MACIEL'S PATH INTO GEOPHYSICS was not straight.

After finishing high school, Maciel was drawn to math because of a description she read in a Universidade de Brasília (UnB) student guide. "It was so beautiful," she recalled. "It said math is, at the same time, a philosophy, a science, and an art."

> *"This course keeps me rooted in reality."*

As she advanced toward her bachelor's degree, the description proved true. "But I wanted to solve real-life problems, to go somewhere I could apply all I had learnt," she said. At a career fair, Maciel learned about geology and realized geophysics was "the marriage between mathematics and geology." Coming from a family of mostly visual artists, that educational choice was a point out of the curve.

After completing a master's degree in geology at UnB, Maciel went on to pursue a doctorate at the Universidade Estadual de Campinas, in São Paulo state. She worked with seismic wave monitoring during her Ph.D., and now, 15 years after returning to Brasília, she works at UnB's Seismological Observatory.

Maciel studies the slight tremors that happen every day. "We study environmental noise; a vibration caused by cars passing or wind blowing is different from that [caused] by landslides or mudslides," she said. Maciel does a lot of signal processing work looking at data from seismometers spread across Goiás state.

"We're trying to catch specific seismic signatures of landslides before they happen," she said. "That can help civil defense evacuate risk areas before disasters hit."

Maciel is also a math professor in UnB's education department, where she teaches undergraduate students from rural areas and traditional communities near Brasília. The training focuses on the realities and needs of the countryside, she said. Geophysics helps her bring real-life examples of math to her classes.

At the end of the day, teaching is a win-win, Maciel said. Her students "know the rocky outcrops and formations of their regions, and I learn a lot from them. We exchange views on nature but also affection. This course keeps me rooted in reality."

By **Meghie Rodrigues** (@meghier.bsky.social), Science Writer

Susanne Maciel realized that geophysics was the marriage of math and geology. Credit: Elisa Elsie/Instituto Serraphilheira

Jeff **Massey**

Atmospheric Science Meets the Private Sector

Expertise in weather modeling has applications in business, this atmospheric scientist found.

A SKI RACER BY THE AGE OF SIX, Jeff Massey has been searching for snow nearly his whole life. "I was tracking snowstorms and nor'easters much more than a first grader should," he said. When he was in elementary school, his mother took him to visit a local TV meteorologist, who explained how weather forecasting worked.

"After that, I knew that's what I wanted to do," Massey said.

As an undergraduate at Cornell University, Massey studied atmospheric science, then went on to complete a Ph.D. at the University of Utah, studying the impacts of dust events on snow and completing a dissertation focused on weather modeling. He helped other researchers with projects related to snow, too.

After graduate school, Massey mulled over whether he should stay in academia or work in industry. He chose a role supporting a weather data platform for farmers run by the Climate Corporation, an agricultural technology company. He was pleased to find that what he loved about academia—the opportunity to produce original, unique research—was part of the job there, too, with the added benefit that his research had a direct application to farmers' operations.

> *"I've done agriculture, I've done drone delivery, and now I'm doing finance. It's interesting how related it all is."*

Massey then moved into roles at Amazon, where he used his weather modeling expertise to inform the company's supply chain operations and, later, to build a new weather modeling infrastructure for Amazon's drone delivery service.

Now he wields his atmospheric science skills to project how weather might affect

Jeff Massey's lifelong love of snow sparked a career in atmospheric science. Credit: Courtney Massey

certain energy and commodity markets for Squarepoint Capital, an investment firm.

"I've done agriculture, I've done drone delivery, and now I'm doing finance," he said. "It's interesting how related it all is—it's all just different applications of weather data, machine learning, and programming."

Businesses will need more weather expertise as climate change progresses and the economic impacts of extreme weather add up, he added. "Weather is still one of those variables you can't control."

By **Grace van Deelen** (@gvd.bsky.social), Staff Writer

Kate Mulvaney

Bringing Human Dimensions to Water Resources

From small coastal towns to international ocean treaties, this EPA scientist has helped integrate social science into how people study and protect natural water resources.

AS A SOCIAL SCIENTIST, Kate Mulvaney researches the intersection of coastal water quality and human populations and behavior.

"People are affected by environmental problems, and people are ultimately going to have to protect the environment or improve the environment," she said.

After earning her undergraduate degree in marine biology, Mulvaney joined the U.S. Peace Corps as a coastal management resources volunteer in the Philippines.

"It was an exciting position," she recalled. "We did a lot of snorkeling, diving, reef surveys, and fish counting—the work that a lot of people dream they're going to do [as] a marine biologist when they grew up."

She soon realized that the data she and her team were collecting would be more powerful in the hands of people and communities who could use them to inform and enforce more environmentally conscious practices.

"That's where I started to springboard into human dimensions work," she said.

Mulvaney earned a master's degree in marine affairs, a field at the intersection of marine science and marine policy, after which she took a fellowship at the U.S. State Department. There, she learned more about high-level decisionmaking that affects international ocean treaties and policies, which helped contextualize some of the local impacts she had seen earlier in her career.

Both in small Filipino fishing towns and at the State Department, "there was this consistent call for more social science data in [the] environmental governance space, but there weren't very many people doing it," Mulvaney said.

> *"There was this consistent call for more social science data in [the] environmental governance space, but there weren't very many people doing it.*

That led her to pursue a doctorate in natural resources social science studying fisheries and climate change on the Great Lakes. Mulvaney joined the U.S. EPA more than a decade ago and was the third social scientist ever hired by EPA's Office of Research and Development.

Kate Mulvaney is a social scientist working on water issues at the EPA. Credit: Kate Mulvaney

Over time, Mulvaney has witnessed other fields increasingly recognize the need to consider the human aspects of environmental science and governance.

"That's been a slow, slow burn," she said, but it has been rewarding to see her field become more mainstream within the science community.

She's also experienced that recognition firsthand. In early January 2025, she became the first EPA social scientist to win the Presidential Early Career Award for Scientists and Engineers.

That acknowledgment "felt like a collective win" for environmental social scientists, she said. "I think it says a lot about the evolution of thinking across disciplines."

By **Kimberly M. S. Cartier** (@astrokimcartier.bsky.social), Staff Writer

Lucia Perez Diaz

Expressing Earth with Art

A geoscientist and illustrator finds artistic inspiration in plate tectonics and geodynamics.

Lucia Perez Diaz finds artistic inspiration in the Earth sciences. Credit: Ryan Cowan

LUCIA PEREZ DIAZ ALWAYS NEEDED A CREATIVE OUTLET. She studied music from an early age and played the piano through her teens. She was always the one to be scolded for doodling in class.

Wary that the hustle required by a professional career in music might be challenging and inspired by an influential Earth systems teacher, Perez Diaz chose a geology degree over a music degree when attending the Universidad de Oviedo in Spain. She then completed a master's degree and Ph.D. in geodynamics at Royal Holloway, University of London, investigating the geologic formation and evolution of the South Atlantic Ocean.

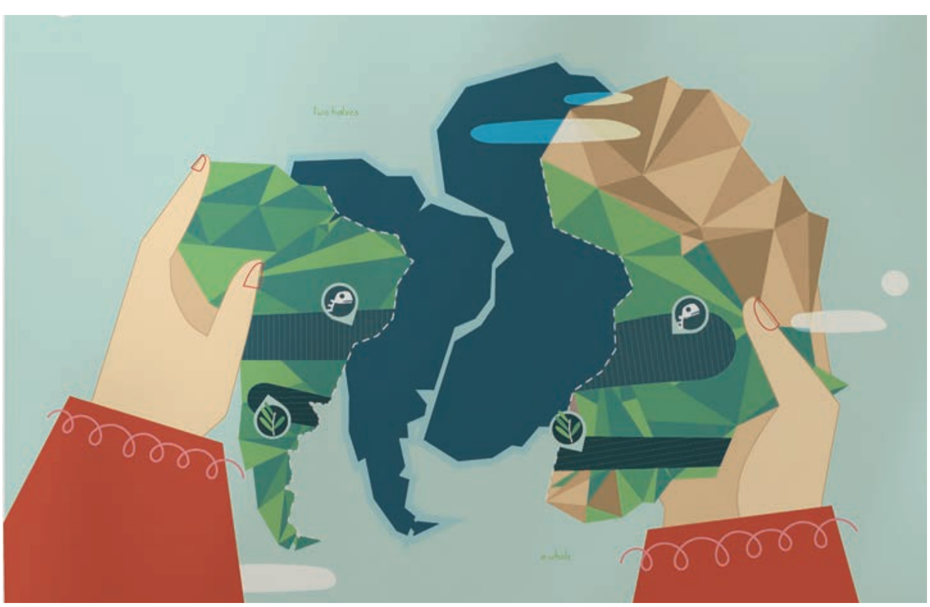
> *"Science is full of inspiring stories."*

But Perez Diaz never let go of her creative side. After years of producing intricate illustrations for her own presentations, a pandemic-era refocusing spurred her to grow her illustration business. Now she's a published children's book author: Her first book, *How the Earth Works*, hit the shelves earlier this year.

"Science is full of inspiring stories," she said. "Art is a really great vehicle to tell them."

Perez Diaz also works as a computational geodynamicist at Halliburton. Learning to program didn't feel natural to Perez Diaz initially, and she required a lot of support from her peers. But the fact that she eventually succeeded and built a career using those skills motivated her to take on new, unfamiliar projects—like book publishing—with zeal.

"People often ask me, 'How did you manage to make a book?'" she said. "I'm like, 'Honestly, because I thought, What's the worst that could happen?'"



Perez Diaz's artwork includes a geosciences poster series. Credit: Lucia Perez Diaz

> *"It's rarely about having all the skills—it's more about giving ourselves space to learn and time to get there."*

She hopes to use what she's learned to help others explore their own creativity. She hosts workshops to show aspiring illustrators that creating art isn't as daunting as it may seem. "Often we look at others' achievements and they make us feel like we don't have their talent or their skills," she said. "It's rarely about having all the skills—it's more about giving ourselves space to learn and time to get there."

By **Grace van Deelen** (@gvd.bsky.social), Staff Writer

Jess Phoenix

Curiosity Unfettered

After leaving her Ph.D. program, this geologist leaned into saying yes when exciting new opportunities arose.

JESS PHOENIX'S CAREER AS A VOLCANOLOGIST and science consultant has taken her around the world. She earned a bachelor's degree in history from Smith College in Northampton, Mass., and a master's in geology from California State University, Los Angeles.

"I was definitely a latecomer to the geo-party, but I dove in wholeheartedly," Phoenix said.

She moved to Australia seeking a geology doctorate from Queensland University of Technology, but she fell out with her adviser and left without finishing her dissertation.

Leaving the program for which she had uprooted her family was terrifying, she said. But she soon realized that doctor or not, her geology education had provided her with a very marketable set of skills. (It was also around that time that she got the first of her many tattoos.)

"Geology is literally everywhere," she said. "With the skill set you gain, even if you haven't done the most terminal degree possible, you still have a very solid core of skill sets—pun intended." Whether it's making a detailed rock description (important in many industries), analyzing macro- and microscale problems, writing reports, or understanding the scientific method, "those are, fundamentally, extremely valuable skills," she said. "Once you have them, no one can take them away from you."

"As long as you maintain that curiosity, that flexibility, that willingness to interrogate your own assumptions and beliefs, you're going to be OK."

Phoenix's wide-ranging career has taken her from the depths of the sea to fields of flowing lava. She wrote a memoir, consults on TV shows and documentaries, and appears as a subject matter expert on international news networks. She cofounded the environmental nonprofit Blueprint Earth, is a fellow of The Explorers Club, and ran for U.S. Congress in 2018.

"By allowing my curiosity to be pretty much unfettered, it's given me a lot of opportunities to just try things and say yes," Phoenix said. "You've got to be willing to take in new information and update your worldview constantly with your own career as well as your scientific interest. As long as you maintain that curiosity, that flexibility, that willingness to interrogate your own assumptions and beliefs, you're going to be OK."

Phoenix also emphasized how crucial staying connected with other scientists has been in her career. "Support their work and be their cheerleaders, and they'll do the same for you."

She was an ambassador for the Union of Concerned Scientists for 2 years and has recently returned to freelance science consulting, leading field research expeditions, and personally advocating for science.

"I'm in my own period of shifting and change," Phoenix said, "but the rocks are always solid beneath my feet."

By **Kimberly M. S. Cartier** (@astrokimcartier.bsky.social), Staff Writer

Jess Phoenix stands in front of the world's largest acid lake in the crater of Kawah Ijen Volcano in Java, Indonesia. Credit: Jess Phoenix

Cassius Spears Jr.

Conserving the Living Soil

This soil scientist braids the Traditional Ecological Knowledge of his ancestors with modern soil conservation practices to help Rhode Island's farmers and land stewards.

CASSIUS SPEARS JR.'S LIFELONG PARTNERSHIP with the living soil is rooted in the Narragansett Indian Tribe's cultural ties to the land and subsistence way of life.

Spears grew up on his family's ancestral land in what is now Rhode Island, hunting, foraging, and learning the traditional place knowledge of his ancestors. As a teenager, he attended community meetings in which Narragansett people discussed concerns about degradation across important landscapes and waters and how it affected harvesting practices and ways of life.

"Witnessing that firsthand concern, as well as witnessing my family's traditional knowledge of place and what that looks like within landscapes and waterways, inspired me to go down the road of conservation," he said.

Spears studied environmental conservation at the University of Rhode Island in South Kingstown and the University of Notre Dame in Indiana. In school, he frequently encountered scientific concepts that clashed with what his people's ecological knowledge holds true.

"Early in my education, I was taught to think about soil in physical, taxonomical, or inert ways, which ran [in] conflict with traditional knowledge of soil as living or life-giving," he said.

On soil and many ecological concepts, Spears said that he has seen a greater acceptance in scientific understanding. "Now soil health concepts have aligned with Traditional Ecological Knowledge and perceive soil as a vital living ecosystem," he said.

In his career as a soil conservationist with the U.S. Department of Agriculture's Natural Resources Conservation Service office in Rhode Island, Spears has worked to deepen the understanding between these sources of ecological knowledge. He said that local farmers and other land stewards have been especially receptive to incorporating Traditional Ecological Knowledge into their practices.

"When you live with the land, you inherently build a relationship."

"When you live with the land, you inherently build a relationship," Spears said. "Many farmers understand this; connecting with natural processes every season creates a tangible bond with the land and a sense of responsibility to manage it in a good way."

Spears takes great pride in the relationships his team has developed with local communities, partnering on projects that improve agricultural soil conservation, restore habitats, and fix riparian forest buffers. He said that having trust and patience, as well as immersing yourself in a community, is the key to building long-lasting and successful collaborations.

"Change doesn't happen overnight, and it's essential to listen to and engage with community members genuinely," he said. "Seeing our local communities lead conservation work inspires me and fills me with hope for future generations."

*Cassius Spears Jr. holds a piece of Asháppock, commonly known as Indian hemp (*Apocynum cannabinum*). This culturally significant plant is harvested for its fibers, which can be used to create nets and various items essential to lifeways of the coastal Narragansett people. Credit: Cassius Spears Jr.*

By **Kimberly M. S. Cartier** (@astrokimcartier.bsky.social), Staff Writer

Alex Teachey is an actor-turned-astronomer in Taipei, Taiwan. Credit: Alex Teachey

Alex Teachey

Elevating Astronomy with the Arts

This actor-turned-astronomer found success researching exomoons. Now he's ready for another career change.

ALEX TEACHEY DIDN'T TAKE A SINGLE SCIENCE CLASS in college. At least, not the first time.

A few years after getting a theater degree, Teachey started a casual blog surrounding his interest in astronomy. It gained a surprising number of followers, enough for him to consider being a science teacher. So he went back to school for physics and worked as a research assistant in astrophysics at the American Museum of Natural History.

"That's where I just got hooked," he said.

Teachey now has a Ph.D. in astronomy and astrophysics but still considers his theater background an influential part of his career. He contributed regularly to the *Weekly Space Hangout* podcast and for years cohosted Astronomy on Tap in New York City.

"Communication is a huge part of our field," Teachey said. Like a tree falling in the woods, "if you don't get the word out, it might as well not have happened."

As a grad student, Teachey led work on the first possible detection of an exomoon. The project netted significant media coverage, and his background in the performing arts prepared him to speak with the press.

> *"Communication is a huge part of our field. If you don't get the word out, it might as well not have happened."*

He continued prioritizing science communication while searching for exomoons as a postdoc at Academica Sinica in Taipei, Taiwan. He launched the Taiwan chapter of Astronomy on Tap and led popular sessions on performance techniques for scientists.

Having moved across the world for his postdoc, Teachey now plans to shift careers again to stay in Taipei. He might work in coding. Or maybe science communication. But he'll always be an astronomer, he said, just like he'll always be an actor.

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

Teachey launched an Astronomy on Tap satellite location in Taipei after cohosting the event in New York City for several years. Credit: Alex Teachey

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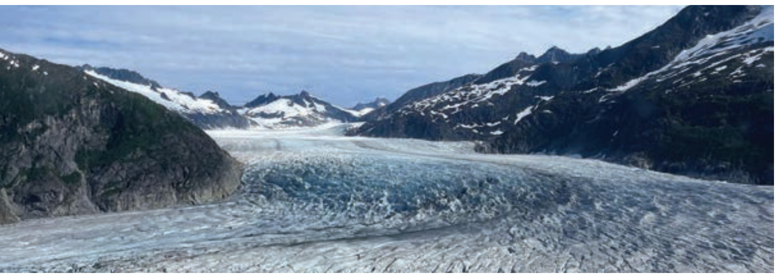
Glaciers Offer Clues about Fossil Fuel Pollution



New research examines the sources of carbon in glaciers, such as those exported from Mendenhall Glacier in Alaska. Credit: Amy Holt

Glaciers provide unique opportunities for researchers to measure levels of atmospheric carbon deposition. Unlike other terrestrial ecosystems, these slow-moving rivers of ice do not hold large reservoirs of soil or vegetation that might obscure how much carbon they receive from the atmosphere.

In most terrestrial ecosystems, dissolved organic matter comes from plants and soil and can contain both organic carbon and black carbon (the sooty black product from wildfires and burning fossil fuels). In glaciers, organic matter is predominantly derived from in situ microbial production and atmospheric deposition. Both can contribute to downstream food webs and broader biogeochemical cycling.

Understanding how glaciers get their carbon, including how much comes from atmospheric deposition, can help scientists understand how human activity affects the glacier carbon cycle and ecosystems.

Holt et al. investigated dissolved organic matter in meltwater from 10 glaciers across Alaska, Switzerland, Kyrgyzstan, and Ecuador. By examining dissolved organic carbon and black carbon isotopes, as well as the molecular-level composition of these materials, the researchers found that anthropogenic pollutants significantly influenced the composition of dissolved organic matter in glaciers and that this influence varied by region.

The researchers collected samples from glacier outflow streams from each glacier and determined the ages and sources of the dissolved organic carbon they contained. Whereas younger samples might originate from wildfire material and microbial activity on the glacier surface, older material more likely originated from ancient carbon sources, namely, fossil fuels.

Each region displayed different amounts of dissolved organic carbon linked to anthropogenic atmospheric pollution, ranging from 12% to 91%, with a median of 50%. Carbon from fossil fuels was most prevalent in the dissolved organic matter of the Alaskan glacier. In Ecuador, the researchers observed a higher relative contribution of carbon from biomass burning, such as wildfires, and in situ microbial activity.

The exact sources, ages, and makeups of dissolved organic carbon and dissolved black carbon varied among different glaciers' outflows. But overall, the researchers say, it's clear that fossil fuels are affecting the carbon content in glacier outflow globally, with implications for the ecosystems that depend on them. (*Global Biogeochemical Cycles*, https://doi.org/10.1029/2024GB008359, 2025) **—Rebecca Owen,** *Science Writer*

Solar Power Shortages Are on the Rise

The use of solar power is growing rapidly, especially in developing regions in the tropics, as countries work toward meeting carbon neutrality goals. But according to new research, solar power use is also accompanied by solar power shortages, or "droughts," when demand exceeds supply for at least 3 consecutive days. Such shortages can leave millions without access to cooling or cooking abilities.

Lei et al. analyzed global supply and demand for solar power from 1984 to 2014, looking for instances of these 3-day shortages and the conditions under which they occur. Over that time, the western United States, eastern Brazil, southeastern Asia, and much of Africa each experienced at least five solar power droughts per year, and solar power droughts increased by an additional 0.76 shortage per decade.

Solar power droughts are driven by a combination of soaring temperatures that increase demand for cooling and inclement weather or light-blocking pollution that suppresses power generation, the researchers found. Low solar power generation typically becomes a problem during periods of high cooling demand—precisely when power is most needed to keep people comfortable and safe.

Solar power droughts can be driven by weather extremes such as clouds, rain, and extreme heat, as well as by light-blocking pollution and periods of extremely high demand. Credit: Michalis T./Flickr, CC BY-ND 2.0 (bit.ly/ccbynd2-0)

The researchers also modeled how the frequency and severity of solar power droughts could change under different emissions scenarios, assuming modern infrastructure. Under Shared Socioeconomic Pathway 2-4.5, a theoretical medium-emissions pathway used in projections by the Intergovernmental Panel on Climate Change, the researchers projected that by the 2090s, solar droughts will become 7 times more frequent and 1.3 times more severe than those in the historical period. In lower-emissions scenarios, solar power droughts peak in the 2060s and then decrease because lower emissions mean fewer heat waves.

The findings illustrate the importance of adopting mitigation measures and clean energy sources to lower emissions, the authors say. Doing so, they add, could result in a "cooler and cleaner future." (*Geophysical Research Letters*, https://doi.org/10.1029/2024GL112162, 2024) **—Rebecca Dzombak,** *Science Writer*

Matching Magma Dikes May Have Different Flow Patterns

Hundreds of millions of people live in areas that could be affected by volcanic eruptions.

Fortunately, eruption precursors observed at the surface, such as earthquakes and ground deformation, can indicate movement of magma underground, including within dikes—sheets of magma that cut across layers of rock. Scientists can use these clues to make potentially lifesaving predictions of eruptions, but there is room for improvement in their approaches.

Most models of volcanic systems used to inform earthquake predictions treat magma as a simple Newtonian fluid whose viscosity stays constant under stress. However, mineral crystals and gas bubbles in magma make it more likely to behave as a non-Newtonian fluid whose viscosity decreases under greater stress (a trait known as shear thinning). That tendency is especially true as it approaches the surface.

Lab experiments by *Kavanagh et al*. reveal new insights into the potential dynamics of non-Newtonian magma flow in dikes that could ultimately help improve eruption prediction strategies.

To mimic magma dikes, the researchers injected various fluids into a translucent and elastic solid gelatin material representing Earth's crust. The injected fluids contained suspended tracer particles that could be illuminated by laser light, allowing the researchers to track each fluid's flow within the forming dike as it traveled up from the injection site to the surface, where it "erupted" from the gelatin. They compared the behaviors of two non-Newtonian shear-thinning fluids, hydroxyethyl cellulose (a thickener often found in cosmetics) and xanthan gum (a thickener often added to foods), to those of water, a Newtonian fluid.

The experiments showed that the flow patterns of the non-Newtonian fluids were very different from the flow patterns of water. However, all fluids formed dikes with a similar shape and speed as they approached the surface.

These findings suggest that the primary information currently used to predict impending eruptions—such as the shape and speed of magma dikes—does not necessarily correlate with information about magma flow dynamics within the dikes. This result is significant because flow dynamics depend on magma characteristics that can affect how explosive an eruption will be or how quickly or how far the lava will travel.

Further research could help link these findings to real-world geological evidence and explore how they might help to improve eruption forecasting, the researchers say. (*AGU Advances*, https://doi.org/10.1029/2024AV001495, 2025) **—Sarah Stanley,** *Science Writer*

A deeper understanding of magma flow within dikes could lead to earlier, more accurate predictions of volcanic eruptions, such as this 2021 eruption in Iceland. Credit: Janine Kavanagh

Isotopes Unearth History of Earthquakes in the Apennines

Identifying long-term seismic activity patterns is crucial for understanding how fault systems evolve, as well as for estimating the probabilities of future earthquakes. But seismic records date back only hundreds of years—1,000 years at the most—not long enough to fully understand any given fault's history. Furthermore, because faults can experience times of high activity alternating with quiet periods lasting millennia, seismic forecasts extrapolating from short time spans may greatly over- or underestimate a fault's rate of activity.

One approach for studying longer-term seismic activity on a fault, chlorine-36 (^{36}Cl) cosmogenic dating, is used to recover histories that can span more than 10,000 years. As slip along a fault progressively exposes rocks, cosmic radiation interacts with carbonate rocks on the fault surface to form atoms of ^{36}Cl, an isotope of chlorine. Concentrations of the isotope reveal approximately how long different rocks have been exposed, a proxy for when an earthquake happened.

Sgambato et al. used ^{36}Cl cosmogenic dating to assess seismic activity over millennia on three faults in Italy's southern Apennines, where some of the country's strongest earthquakes have occurred. They then compared the data with other paleoseismic estimates derived from excavating trenches along a fault and tracing markers to measure its displacement. The researchers also calculated slip rates and related annual earthquake probabilities.

The authors found that all three faults experienced periods of both high seismic activity and dormancy in the past 30,000 years and that estimates of earthquake activity from trenching generally agreed with those derived from ^{36}Cl dating. They noted that their results may help show whether these faults are connected to others in the region.

Their research further indicates that slip on a single fault can account for all of the regional extension in a given year. This may indicate that strain can be localized to individual faults at certain times. Because their work uncovered a longer record of the clustering of earthquake activity along these faults, it also has implications for seismic hazard forecasting. (*Tectonics*, https://doi.org/10.1029/2024TC008529, 2025) **—Nathaniel Scharping,** *Science Writer*

Teaming Up to Tailor Climate Education for Indigenous Communities

Shown here is Monument Valley Navajo Tribal Park in Arizona. Credit: Pexels

Research shows that communities are best able to mitigate the effects of climate change when they can work alongside scientists on adaptation plans. *Hanson et al.* recently extended this finding to Indigenous communities in the Colorado Plateau, including members of the Navajo Nation, Hopi Tribe, and Ute Mountain Ute Tribe.

To learn more about the qualities that make climate education most accessible to these groups, the researchers conducted a series of listening circles, interviews, and consultations with Indigenous peoples and Westerners with extensive experience working in Indigenous communities. They collaborated with members of The Nature Conservancy's Native American Tribes Upholding Restoration and Education, or NATURE, program, which aims to equip Indigenous college students with natural resources management skills.

Several themes emerged. Indigenous students are most likely to engage in climate education when they're actively recruited for a program, when mentors are willing to learn from students as well as teach them, and when a program emphasizes the value of integrating Traditional Knowledges with Western science, for instance. Small class sizes and ample one-on-one instruction also keep students engaged.

On the basis of these findings, the researchers created a climate module that can be taught as part of a broader college-level environmental science curriculum, for example, as part of a program like NATURE. The module is "menu style," meaning that instructors and students can choose the activities they find appealing from an array of options. One option is classroom lessons on issues that are relevant to the Colorado Plateau, such as water conservation and cattle management. Another involves field trips, such as a day trip down the Colorado River, during which guides provide insights into how climate change is altering the landscape.

Indigenous students are "uniquely positioned to engage in environmental restoration" because they have deep connections with natural systems, the researchers wrote. This collaboratively designed program could help students achieve this potential, they say. (*Community Science*, https://doi.org/10.1029/2023CSJ000054, 2025) **—Saima May Sidik**, *Science Writer*

Seeping Groundwater Can Be a Hidden Source of Greenhouse Gases

Researchers recently assessed greenhouse gas emissions from groundwater seeps in the Farmington River watershed, located in Connecticut and Massachusetts. Credit: Ashley Helton

Scientists know that streams and rivers can contribute significant quantities of greenhouse gases to the atmosphere. One way these bodies of water come to contain greenhouse gases is via groundwater, which picks up carbon and nitrogen as it seeps and flows through rock and sediment.

Much research into greenhouse gas emissions from rivers assumes that before being released into the atmosphere, the gases in this groundwater mix with the currents of rivers and streams. But during low-flow conditions, groundwater can seep out along stream banks at or above the river surface, creating a pathway for greenhouse gases to escape directly from groundwater.

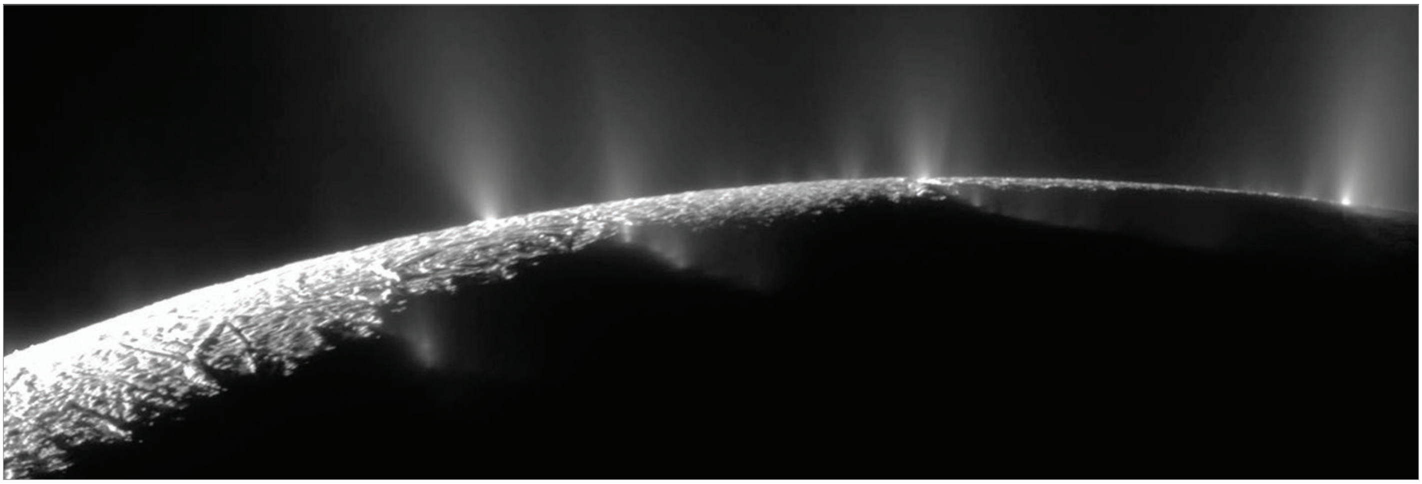
Bisson et al. set out to estimate the magnitude of emissions from groundwater discharging directly at the surface. They measured greenhouse gas emissions along riverbanks at three locations in the Farmington River watershed in Connecticut and Massachusetts, concentrating on areas that had groundwater discharge above the waterlines during a typical summer flow season.

At each stream, the team used handheld thermal infrared cameras to identify stream banks with and without areas of exposed groundwater discharge. Once these stream banks were located, the team measured fluxes of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O), and methane, as well as groundwater discharge rates along the stream banks. They also collected subsurface groundwater and analyzed it for concentrations of dissolved organic carbon, oxygen, and nitrogen.

At one site, the researchers found that CO_2 concentrations were 1.4–19.2 times higher in groundwater discharge than in surface water and N_2O concentrations were 1.1–40.6 times higher. In comparison, stretches of stream with no groundwater seeps acted as N_2O sinks. They also found that groundwater emissions of CO_2 and N_2O were 1.5 and 1.6 times higher, respectively, than surface water emissions. On average, 21% of emissions from the groundwater seeps were released into the atmosphere before they could mix with surface waters.

The authors note that their work shows that exposed groundwater discharge along stream banks can be a significant, often unaccounted-for, source of river corridor greenhouse gas emissions. They add that more work should be done to better understand potential emissions from river corridors where groundwater discharge is abundant. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2024JG008395, 2025) **—Sarah Derouin**, *Science Writer*

Using Algorithms to Help Find Life on Icy Ocean Worlds



Detecting potential life on bodies such as Saturn's moon Enceladus is challenging, because probes and spacecraft often take measurements only from hundreds to thousands of kilometers away. Credit: NASA/JPL-Caltech/Space Science Institute

Scientists have long thought that our solar system's ocean worlds, such as Jupiter's moon Europa and Saturn's moon Enceladus, may harbor extraterrestrial life in the form of microbes.

But detecting it is a challenge, because missions to ocean worlds have relied on probes, not landers.

Probes pass only through a planet's or moon's atmosphere, kilometers or more away from the surface and interior. Spacecraft such as Europa Clipper (like Cassini before it) are designed to stay even farther away, not even entering the moon's exosphere.

To meet this challenge, *Clough et al.* describe a method for detecting biochemical signatures using samples from wisps of gas escaping such worlds. The approach uses mass spectrometry to measure levels of isotopes produced during metabolic processes such as photosynthesis and methanogenesis. Machine learning techniques then assess whether those levels indicate the presence of life below.

To train the algorithm, the researchers needed examples of these exospheric conditions with and without life present. In the lab, they concocted brines with chemistry similar to that of Europa and Enceladus. To some brines, they added the sulfate-reducing bacterium *Desulfotomaculum thermocisternum*, which may bear a resemblance to life on ocean worlds.

Measuring gases in the headspaces of the bottles of brine gave researchers examples of the potential composition of the exospheres of ocean worlds and how microbes change that composition.

Drawing inspiration from images taken by the Voyager, Galileo, and Juno spacecrafts and recognizing how little we know about Jupiter's icy moon Europa, research scientist Bethany Theiling painted Meditations on Europa. *Credit: Bethany Theiling*

Geochemistry unrelated to the presence of life will also influence isotopes in these types of samples, so the researchers varied the ingredients in their brines to capture a range of possible scenarios. By training their model on these samples, they created a diagnostic tool that can disentangle signatures of life from other types of chemistry with a low potential for false positives.

The researchers note that the model requires further testing, including with different microbes, adding that it could become a valuable tool for future space missions. (*Earth and Space Science*, https://doi.org/10.1029/2024EA003966, 2025) **—Saima May Sidik,** *Science Writer*

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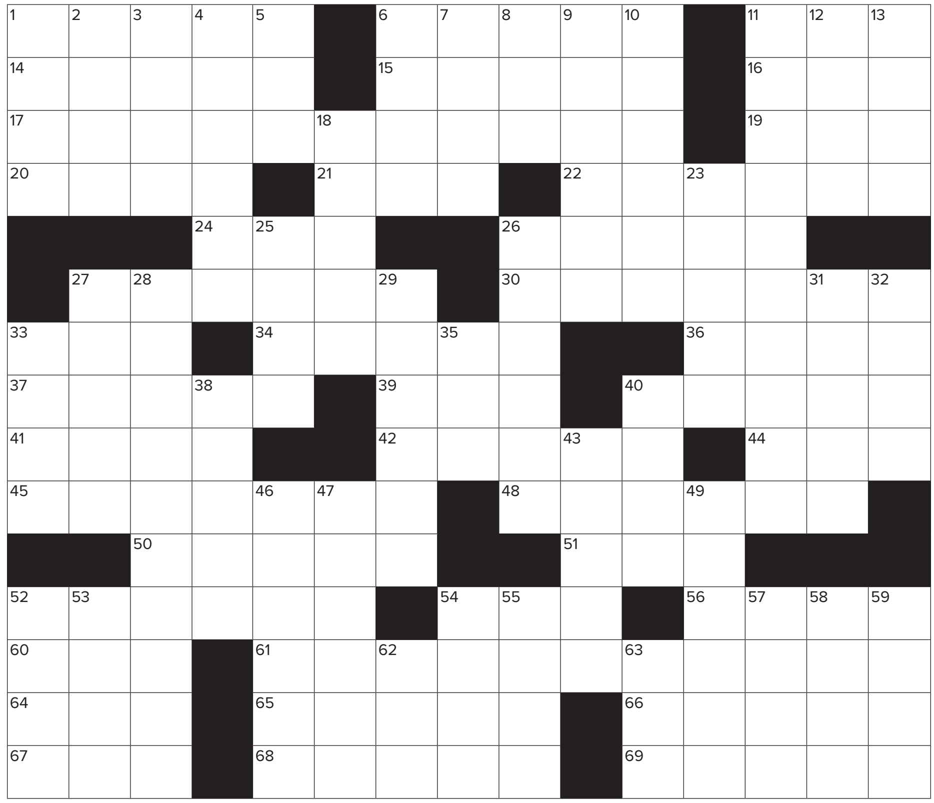
What's Missing (from My Career)?

By Russ Colson, Minnesota State University Moorhead



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16 Start for "-tus" or "-watha"
17 Tenure under a tutor, say
19 *Earth science field of employment (with 51-across)
20 Stun, as in "The officer threatened to _____ him"
21 "Same" prefix
22 Pre-raisins
24 "Don't worry, it's in the _____"
26 Friendly thief?
27 Name for a Canadian province or city
30 *Earth science field of employment (with 56-across)
33 Wordplay joke
34 Boat or macramé
36 Name for a city, lake, and canal
37 Contract agreements or periods of service
39 Leafy drink, and something missing from 52-down
40 "Double-stranded" genetic material (abbr.)
41 Width × length
42 Parquetry process
44 Fantasy tree being
45 *Earth science job (with 1-down)
48 Not unstable
50 Quaking _____, an American tree
51 Unit of work, and something missing from 19-across
52 Admired special something, as in "She has a certain _____"
54 Ending for can, pay, or cray
56 Steel component, and something missing from 30-across
60 A volcanic _____ spot may create a chain of islands
61 Be greater in number, as in "The better adapted species will often _____"
64 Cenozoic epoch ender
65 Observable expression of cultural ethos
66 Radiating, as in "Their faces were _____ with excitement"
67 Hematite streak color
68 Cowboy heel stars
69 Managed spy, or stock

See p. 31 for the answer key.

DOWN

1 Essence, as in "I got the _____ of it," and something missing from 1- and 45-across
2 What's needed for many making a short-term U.S. visit, or "this" in Spanish
3 The burden of responsibility is _____ _____ (either two words or one, both correct)
4 "The mother _____ _____ hidden in them hills, matey!"
5 Canis ending for coy
6 Cave critters
7 The Sun _____ Rises
8 "Well, _____-di-dah!"
9 DC universe villain, or mathematical start for -ometry
10 Off-the-cuff acting or music
11 Tended sheep
12 Earthly extraction site and something missing from 57-down
13 Childhood game, "Simon _____"
18 Name for a river or country in West Africa
23 Pinnacles
25 Do-re-mis, one-two-threes, _____
26 Steel, aluminum, and copper
27 Initial letter to an editor or agent
28 Not expunged (e.g., from a document)
29 Charged atom, and something missing from 62-down
31 Silly person
32 Udder component
33 Egyptian god of creation and craftmanship
35 Groundwater-fed wetland
38 Grassy wetland
40 Color worker
43 Top squad
46 Golden-wooded African trees, or the middle of "pyrope pestle"
47 Speak or act explosively
49 Plural ending for pack, band, or mess
52 *Earth science job (with 39-across)
53 Top notch, or a steak sauce
54 Scent
55 Opposite of gain
57 *Earth science field of employment (with 12-down)
58 Native Nebraskan
59 Semiaquatic salamander or former Speaker Gingrich
62 *Earth science field of employment (with 29-down)
63 Plant growth horm.