VOL. 104 | NO. 11
NOV–DEC 2023

Eos

SCIENCE NEWS BY AGU

AGU
ADVANCING EARTH
AND SPACE SCIENCES

Wide. Open. Science.

With our annual year-end double issue, *Eos* marks the Year of Open Science with a grand tour of the ways researchers are increasing the depth and breadth of Earth and space sciences.

First, we consider how open science is redefining cultural approaches to academia. Our Mexico City bureau chief, Humberto Basilio, masterfully outlines the myriad ways in which Latin American scientists are developing innovative cultures of scientific achievement that do not rely on the traditional norms of the Global North in "Raising the Visibility of Latin American Science" on page 60. In "There is no JOIDES in Mudville," (p. 26) Damond Benningfield provides a melancholy valedictory for the *JOIDES Resolution* as well as a short list of alternate opportunities for research at sea. (Heads up: Keep your eyes on Japanese research vessels.) Finally, from fieldwork to lab work, alternates to the familiar burden of overwork are explored in "Academia's Hidden Price Tag," (p. 48) by scientist and author Katherine Kornei.

Our next set of articles scrutinizes the ways in which researchers are using the schemas of open science to make data more accessible. Ge Peng dives deep into balancing the findability, accessibility, interoperability, and reusability of data sets (and the manner in which they are shepherded) in the Opinion "Finding Harmony in FAIRness" on page 22. Artificial intelligence and machine learning could also help strike a chord, argue Nathan E. Sanders and Rose Hendricks in "AI Could Reshape Climate Communication" (p. 19), suggesting that large language model–based programs could help the public regain trust in science and scientists. The dizzying array of data that open science makes available necessitates coherent and nimble management, and research scientists Kaylin Bugbee, Deborah Smith, Stephanie Wingo, and Emily Foshee characterize this in the "Art of Scientific Curation" on page 42.

The multidisciplinary nature of open science demands collaboration, the focus of our last set of articles. Building on the theme of curation, Kimberly Blaeser, Dwight Owens, Sarah Zhou Rosengard, Kathryn Semmens, and Mika Tosca explore "Why—and How to—Engage Artists in Science" on page 34. Shifting from art to politics, Adam S. Ward and Adell Amos's Opinion "The Supreme Court Is Bypassing Science—We Can't Ignore It" (p. 15) makes the case for scientists engaging more proactively with policymakers. Finally, Eric M. D. Baer, Karen M. Layou, R. Heather Macdonald, and Sharon L. Zuber incorporate principles of equitability and accessibility in "Strategies for Successful Collaborative Writing" on page 54.

Layered between our thought-provoking articles is our beautiful centerfold poster, from our own Kimberly Cartier and Mary Heinrichs. "Layers of Climate Change: Issues and Solutions from Sky to Sea" introduces a particularly relevant set of challenges and opportunities suggested by open science.

We hope the diversity and depth of the articles in this issue encourage you to return to them again and again, for inspiration, interpretation, and innovative ideas.

Wide. Open. Science.

Caryl-Sue

Caryl-Sue Micalizio, Editor in Chief

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.

Submit your article proposal or suggest a news story to *Eos* at bit.ly/Eos-proposal.

Views expressed in this publication do not necessarily reflect official positions of AGU unless expressly stated.

Janice Lachance, Interim Executive Director/CEO

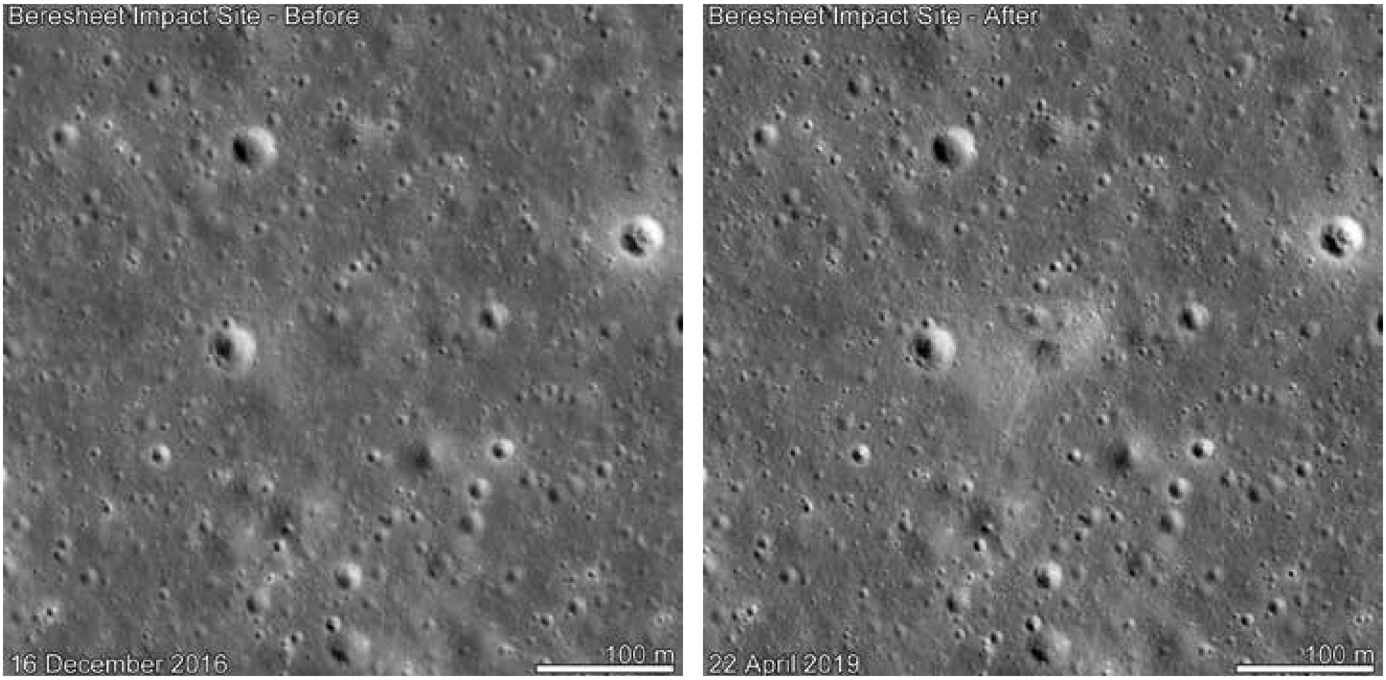
This issue includes FSC-certified paper.

On the Cover
Credit: Stefan Liebermann/Alamy

Features

Columns

A Lunar Mission Spots Its Fallen Brethren



Images from NASA's Lunar Reconnaissance Orbiter (LRO) reveal the impact site of Israel's Beresheet lander. Credit: NASA/GSFC/Arizona State University

India's Chandrayaan-3 mission landed a spacecraft near the south pole of the Moon on 23 August 2023. The lander, Vikram, and an accompanying rover collected valuable data from the lunar surface for nearly 2 weeks.

That successful landing was far from assured. Just a few days earlier, Russia's Luna-25 spacecraft crashed trying to land in the same region, the latest in a spate of recent lunar missions that have ended in failure.

To better understand what can go wrong with a lunar mission, scientists and the public alike have pored over data collected by NASA's Lunar Reconnaissance Orbiter (LRO) to pinpoint the precise locations of recent crashes. They've spotted clear evidence that several spacecraft landed not so gently on our nearest celestial neighbor.

All of the Moon, Every Month

Since 2009, LRO has been returning a treasure trove of data about the Moon's topography, mineralogy, and water resources. The truck-sized orbiter is currently cruising roughly 100 kilometers above the surface of the Moon. The Lunar Reconnaissance Orbiter Camera (LROC)—actually a suite of cameras consisting of two Narrow Angle Cameras and one Wide Angle Camera—images most of the lunar surface every month.

Data from the Narrow Angle Cameras are particularly valuable for spotting minute changes in the Moon's landscape over time, said Robert Wagner, a planetary geologist at Arizona State University in Tempe and a member of the LRO team. "It's great for finding small features," he said. The Narrow Angle Cameras return some of the highest-resolution imagery of the Moon's surface collected to date from orbit—each pixel corresponds to roughly 50 centimeters.

And LROC data aren't used by just professional scientists: About every 90 days, a trove of new data are released to the public. (The 55th data release occurred on 15 September.) Thousands of unique users access the observations in a typical month, said Nick Estes, the Science Operations Center manager of LROC at Arizona State University in Phoenix. "[They're] definitely in use out there," he said.

Shanmuga Subramanian, a mechanical engineer in Chennai, India, and a space aficionado, is one such user. In 2019, Subramanian learned that India's space agency had lost contact with an earlier Vikram. The lander, which was roughly the size of a desk, had been slated to touch down on the Moon as part of the Chandrayaan-2 mission. Subramanian had experience working with computer code, and he knew about the high-resolution images of the Moon's surface captured by LRO. Perhaps those data could be used to pinpoint Vikram's crash site, Subramanian hypothesized.

Data from the Narrow Angle Cameras are particularly valuable for spotting minute changes in the Moon's landscape over time.

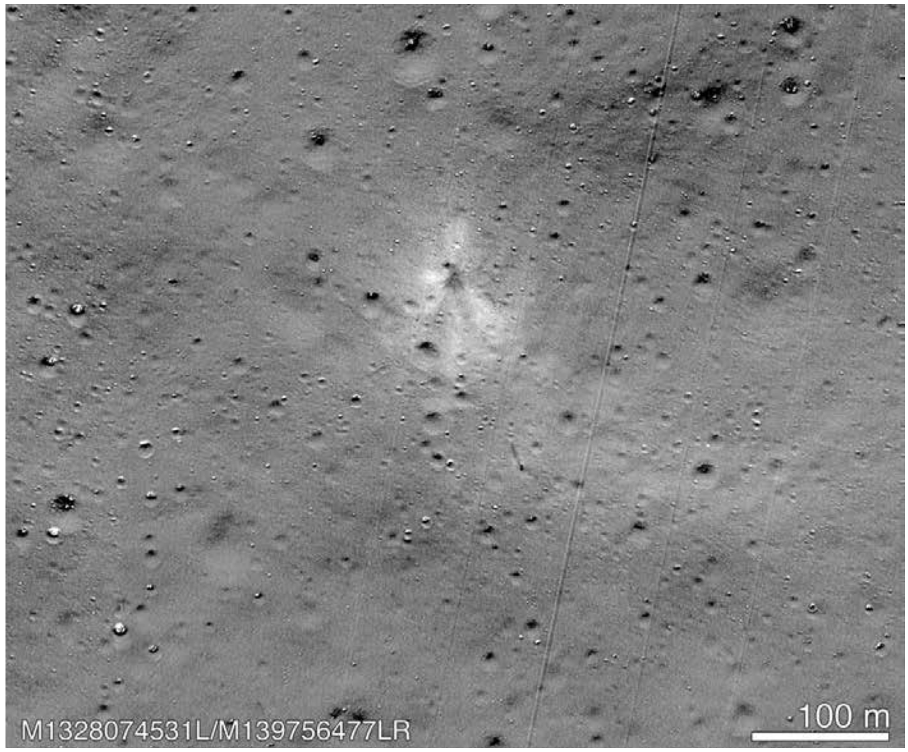
A Meticulous Search

Subramanian downloaded an image obtained by LRO on 17 September 2019, 10 days after Vikram's purported crash. He compared it with images of the same region taken months earlier. Subramanian was looking for minute changes in the 2- × 2-kilometer images—anything that might correspond to debris from the 600-kilogram lander or a crater excavated by its crash. It was labor-intensive work, he said. "I started searching pixel by pixel."

But his meticulous sleuthing paid off: After about 2 days of searching, Subramanian noticed one anomalously bright pixel in the 17 September image that was conspicuously absent in the earlier images. "It was a very tiny little white speck," Subramanian said.

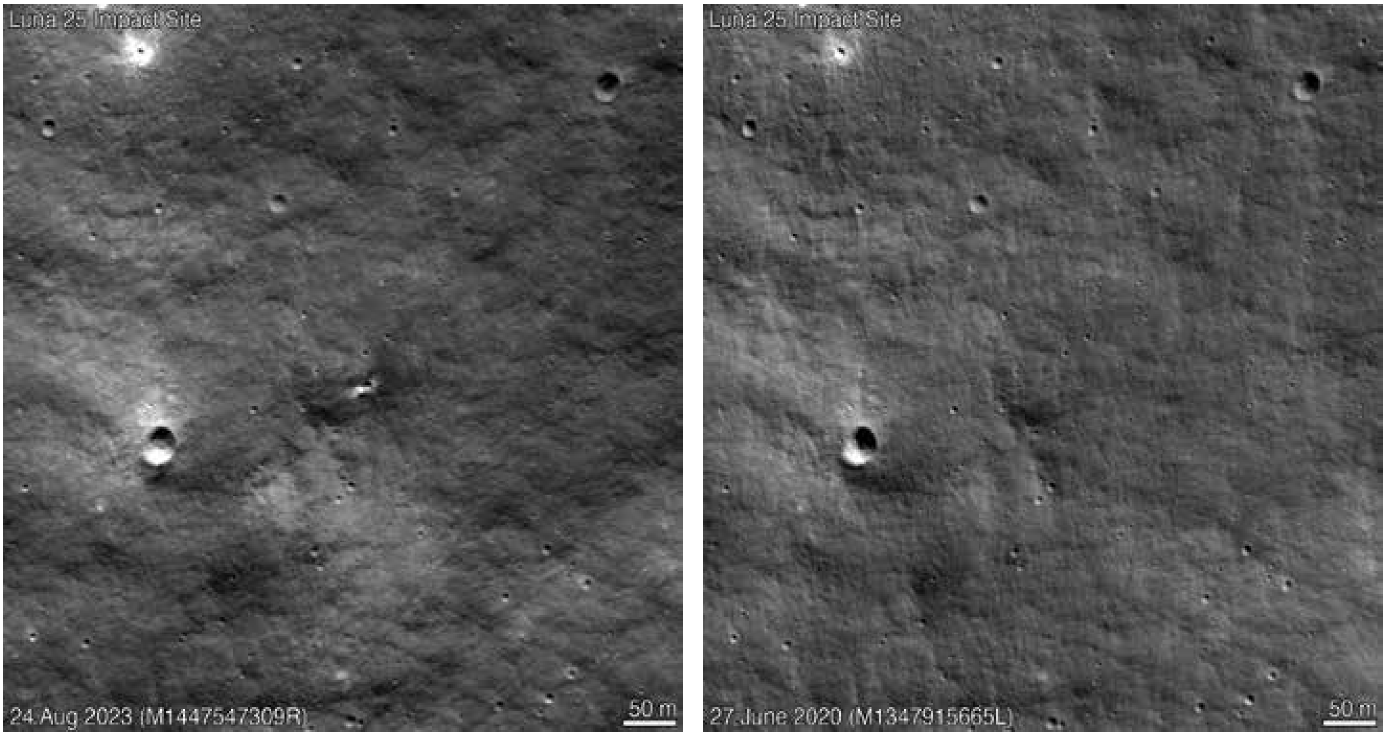
He alerted the LRO team, who started searching in the same vicinity. Wagner, who often processes LRO data, assembled pairs of images obtained before and after Vikram's crash and enlisted the help of his colleagues. "We had at least half a dozen people here in the office going through a large pile of little before-after blink images I had made," Wagner said. In these, before and after images alternate swiftly, allowing viewers to identify differences easily.

The team confirmed Subramanian's discovery and identified more than 10 additional pieces of debris strewn over an area of roughly 5 square kilometers. Subramanian's tip was instrumental in finding Vikram, Wagner said, and the mechanical engineer



A combined before-and-after ratio image from LRO shows a halo of disturbed soil on the Moon's surface around the dark impact site where Chandrayaan-2's Vikram crash-landed. Credit: NASA/Goddard/Arizona State University

LRO, shown here in an artist's rendering, has been returning high-resolution images of the Moon's surface since 2009. Credit: NASA/GSFC



LRO images show a fresh impact feature presumed to be from Russia's Luna-25 lander. Credit: NASA's Goddard Space Flight Center/Arizona State University

was duly credited in NASA's announcement that the lander had been spotted (bit.ly/Vikram-found).

Missing Lander? Call LRO

LROC data have also revealed the final resting places of other crippled spacecraft.

Israel's Beresheet lander was attempting to land in the Sea of Serenity on 11 April 2019 when personnel at the mission's command center in Yehud lost contact with the spacecraft. Images captured by LRO 11 days later revealed a crash site. They showed that the roughly washing machine–sized lander had struck the rim of a small crater and excavated a roughly 100-meter-long swath of lunar regolith.

Earlier in 2023, Japan's Hakuto-R Mission 1 lander also crashed on the Moon. The lander, designed and built by the company ispace, would have been the first private spacecraft to land on the Moon. On 26 April, 1 day after mission control in Tokyo lost contact with the lander, the LRO team acquired several images around the spacecraft's intended landing site near Atlas crater. By comparing those images with data taken previously, the team homed in on what appeared to be at least four pieces of debris scattered around a roughly 50- × 100-meter site.

And when Russia's Luna-25 hit the Moon on 19 August, just a few days before the successful landing of Chandrayaan-3, LRO once again played a starring role in pinpointing the crash site.

"We had at least half a dozen people here in the office going through a large pile of little before-after blink images I had made."

Estes noticed something that resembled a fresh impact in data collected 5 days after the crash. The feature was enough of a visual oddity that he first spotted it without having to compare it with before-crash imagery. "I saw something that looked plausible," he said.

The LRO team later confirmed Estes's discovery and determined that Luna-25 had crashed roughly 400 kilometers from its intended landing site. The impact excavated a crater roughly 10 meters in diameter that showed up in LRO data as a brighter-than-normal spot. "It was this very, very spectacular brightness change," Wagner said. "Once we did a ratio between the before and after images, it just popped out as this spray pattern of ejecta."

After 14 years, LRO's data archive now includes more than a petabyte of observations and accompanying metadata, Estes said. And just this year NASA launched an interactive map featuring LRO data (bit.ly/LRO-map). Scientists and the public can compare LRO images with observations of the Moon made in the 1960s by five NASA spacecraft that orbited the Moon to spot changes in the lunar surface.

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

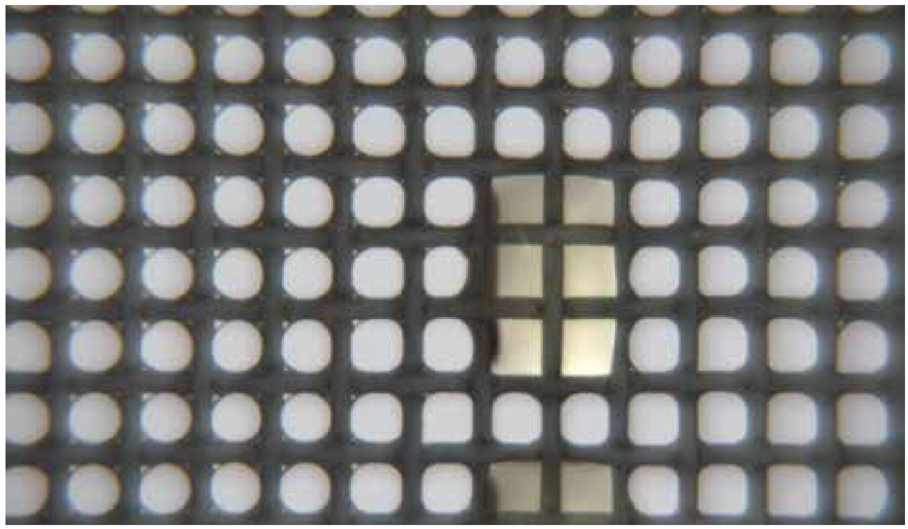
Read the latest news at Eos.org

Low-Tech, Energy-Free Tool Collects and Cleans Fog Water

Communities in some regions of the world lack easy access to clean freshwater due to remote locations, insufficient or damaged infrastructure, or changing climate conditions. People in these regions often rely on alternate methods of collecting freshwater, such as harvesting rain, dew, vapor, and fog—but that water can be polluted and dangerous to use.

Now, an innovative update to a tried-and-true method of harvesting fog water can purify it, too. Researchers developed and tested how well a polymer-based coating on a metal mesh collected water that had been contaminated with organic pollutants. They found that not only did the coated mesh outperform existing fog harvesters, but also the coating purified the water by 91% without requiring any power.

"We would not recommend it directly for drinking because we couldn't reach up to 100% [purification]," said lead researcher Ritwick Ghosh, a scientist at the Max Planck Institute for Polymer Research in Mainz, Germany. "But, of course, this can be used for your vegetation or for any other water uses that we need every day, like for your washroom."



During laboratory tests, the researchers placed polymer-coated mesh in a spray of contaminated water vapor. The mesh collected and purified the polluted water. Credit: Ritwick Ghosh, ETH Zurich

Out of Thin Air

Where freshwater access is scarce, various collection devices are used to harvest water from the atmosphere. Rain barrels collect rain, radiative cooling surfaces condense dew, and meshes collect fog. Passive devices that use no power are especially useful in areas that lack electricity.

Fog harvesters are particularly effective in dry, mountainous areas with low rainfall, like Chile's Atacama Desert and the Namib Desert along the southwestern African coast. Fog harvesters installed in Chile, Eritrea, Ethiopia, Guatemala, Morocco, and Nepal record daily harvests of thousands of liters of water.

But there is no guarantee that this water is usable. Air pollution is easily trapped in fog droplets, so fog-harvested water is often contaminated, especially near pollution centers such as fossil fuel plants and manufacturing zones.

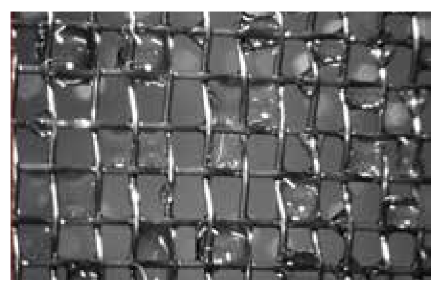
Harvest and Clean, Simultaneously

Ghosh's experiment was inspired by a series of poor air quality incidents around the Indian capital that some dubbed "the Great Smog of Delhi." So much smog was in the air that the polluting aerosols were being trapped in fog droplets. Fog harvesters around Delhi were collecting the polluted water, which spurred Ghosh and his team to think of ways to passively rid this water of contaminants.

Ghosh and his colleagues tested new ways to help cleanse collected fog water of contaminants through a chemical process called photocatalysis, wherein metal is exposed to certain wavelengths of light. This causes some metal oxides to become chemically active, allowing them to break down other molecules.

In their experiments, the researchers coated a fine mesh made of metal with a nanoscale-thin layer of a titanium dioxide (TiO_2) polymer. When activated by sunlight, the TiO_2 reacted with the organic pollutants trapped in fog before the freshwater ran off into a collector.

Laboratory and field tests demonstrated that the polymer-coated mesh collected water as well as or better than uncoated meshes that have been deployed in the past, at a rate of about 8% collection efficiency. Moreover, the coated mesh simultaneously purified the water of organic contaminants without the coating sloughing off into the collected water. The harvester produced water cleansed of up to 91% of organic contaminants, as well as treating it for diesel and bisphenol A (BPA), in just over an hour.



Uncoated wire mesh, like this, can easily harvest fog water but can't purify it for drinking. Credit: Ritwick Ghosh, ETH Zurich

What's more, "the titanium dioxide gets activated by the sunlight, so the good thing is, you don't need any energy," Ghosh added. "And an interesting thing that we saw is that this effect can stay even after the sunlight is gone." The coating on the mesh remains activated and can purify water even when it is overcast, as is common in foggy areas. This research was published in *Nature Sustainability* (bit.ly/water-harvest-treatment).

Serving Foggy, Polluted Areas

The researchers “have presented a groundbreaking design in this field, introducing a fog collector that can store photocatalytic power on sunny days and release it for water purification during fog collection,” commented Zuankai Wang, lead researcher of the nature-inspired engineering lab at Hong Kong Polytechnic University. Wang was not involved with the research. Both the harvesting efficiency and the organic contaminant removal efficiency meet or exceed levels achieved by current technologies, he added.

“I believe that the fog harvester holds tremendous value, particularly in regions where fog is frequent and air pollution is heavy.”

“I believe that the fog harvester holds tremendous value, particularly in regions where fog is frequent and air pollution is heavy,” Wang said. “This device has the potential to serve as a source of clean water for local communities by enabling concurrent fog collection and decontamination.... After all, in today’s increasingly severe air pollution, it is difficult to guarantee the quality of the fog.”

Ghosh said future experiments aim to shorten the time it takes to collect and purify water from fog by testing other photocatalysts to improve the purification efficiency and to retain the photocatalytic “charge” for longer periods of time. The researchers also hope to scale up the experiments to larger swaths of mesh to see how the device performs in conditions closer to real-world scenarios.

Wang hopes to see future iterations of the device use a more powerful photocatalyst to speed up the purification process. Regardless of whether that happens, he said, the technology is “a small step toward device improvement but a significant leap forward for practical applications.”

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

Natural Floodplains Are Quickly Vanishing

When rivers overflow their banks, they flush freshwater, nutrients, and sediment onto surrounding lowlands. These nutrient-dense floodplains attract agriculture and development, but when humans encroach on these areas, the risk of floods and damage to wetland ecosystems rises.

In a new study published in *Scientific Data*, researchers found that the world has lost 600,000 square kilometers of floodplains in 27 years (bit.ly/altered-floodplains).

“As development and growth happen, intentional and unintentional encroachments onto floodplains happen,” said Raghu Murtugudde, an Earth systems scientist at the Indian Institute of Technology Bombay and the University of Maryland who was not involved in the study.

To figure out how much area has been lost, a team of scientists developed a new global data set of floodplain development between 1992 and 2019. The records were culled from a map of floodplains (GFPLAIN250m) created from NASA’s Shuttle Radar Topography Mission (bit.ly/floodplains-map), land use maps from the European Space Agency, and maps of major river basin extents. With a resolution of 250 meters, the data illuminate how individual floodplains were altered.

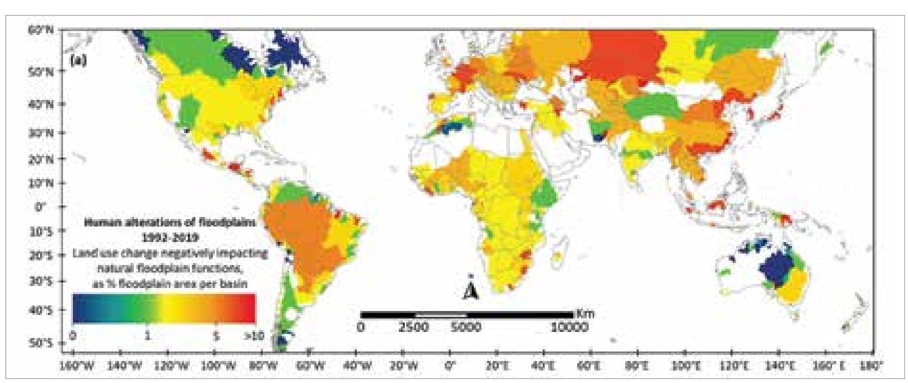
The researchers found that people have converted 460,000 square kilometers of floodplain to agricultural land and developed an additional 140,000 square kilometers. That’s a land area larger than Madagascar.

“It’s like losing a whole country,” said Adnan Rajib, a civil engineer at the University of Texas at Arlington and lead author of the study.

Floodplains have historically been used for human settlement and food production, uses that compromise the ability of floodplains to provide other ecosystem services such as clean water and flood control, said Ellen Wohl, a fluvial geomorphologist at Colorado State University who was not involved in the study.

“The rapid loss of naturally functioning floodplains in some regions of the world should provide the impetus to protect existing floodplains in these regions and restore floodplain functions where possible.”

Earlier studies document a rise in population and development in floodplains around the world (bit.ly/anthropocene-floodplains). However, scientists didn’t know how much had occurred relative to areas outside of floodplains. The current



This map displays the degree of floodplain alteration as a percent of floodplain area. Credit: Rajib et al., 2023, https://doi.org/10.1038/s41597-023-02382-x, CC BY 4.0 (bit.ly/ccby4-0)

study showed that floodplains were 1.75 times more affected than areas outside them, according to Rajib. The data underscore that floodplains should be considered separately from other landscapes in policy decisions, he opined.

"The study is a nice global mapping of the loss of floodplains, which is very useful for adaptation and land use planning," Murtugudde said, adding that the scale of the study gave him greater confidence in its findings.

The rate of floodplain loss was highest in Asia. Policy frameworks and floodplain protection initiatives are either relatively underdeveloped or nonexistent in many Asian countries, Rajib said. Large populations and their corresponding demand for food, shelter, and jobs lead to unplanned development in floodplains, he added. Floods in Delhi this past summer—the worst the city has seen in 4 decades—were caused by severe encroachment on floodplains, for example.

One third of floodplain wetland losses occurred in North America, and nearly 60% of urbanization in global floodplains occurred in Europe, Rajib added. "The importance of this study is that it calls attention to the ubiquity of floodplain losses on a global scale, as well as providing region-specific information," Wohl said.

Mapping Loss

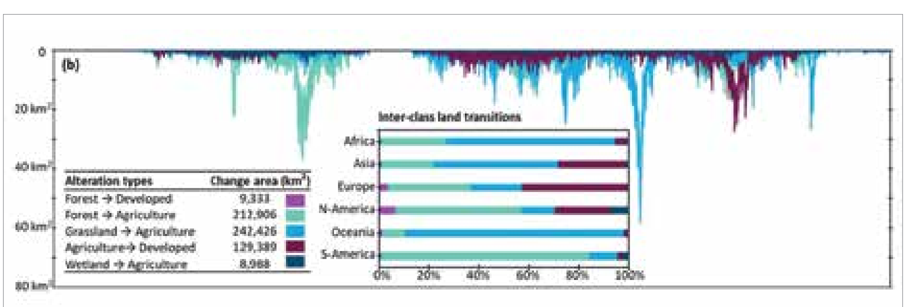
The authors took a closer look at the dominant alterations in major basins and found that changes in land use varied. In the Great Lakes Basin in North America, for example, forested floodplains were urbanized, whereas in the Nile Basin, grasslands were converted for agricultural use.

Different land uses provide different habitats and ecosystem services, so having this detail is important, Wohl said. Land use conversions can also alter the effects of floods and change a floodplain's carbon storage potential.

Policymakers and those concerned about United Nations Sustainable Development Goals can use this information to see where and how change is happening at a granular level, Rajib said. "They can see what the driver of the change is—is it agricultural land becoming cities, or forests becoming agriculture?"

The researchers developed and made public tools to explore and analyze individual basins. The data can inform policies to prevent or reverse floodplain alteration and invest in restoration to reduce risk to lives, livelihoods, and the environment, Rajib said.

The findings emphasize and reinforce previous work, Wohl said. "The rapid loss of naturally functioning floodplains in some regions of the world should provide the impetus to protect existing floodplains in these regions and restore floodplain functions where possible."



Around the world, the most common land use changes in and around floodplains have been for agriculture. Credit: Rajib et al., 2023, https://doi.org/10.1038/s41597-023-02382-x, CC BY 4.0 (bit.ly/ccby4-0)

By **Deepa Padmanaban** (@deepa_padma), Science Writer

Illegal Fossil Export Is More Than an *Irritator* to the Global South

Researchers are requesting that a German museum return to Brazil the fossilized skull of a 110-million-year-old Irritator challengeri *dinosaur. Credit: Kabacchi/Flickr, CC BY 2.0 (bit.ly/ccby2-0)*

In 1995, British paleontologist David Martill and his German colleague Eberhard "Dino" Frey looked closely at the skull of a 110-million-year-old dinosaur fossil found in northern Brazil and noticed something curious. A computerized tomography (CT) scan revealed that the animal's snout had been elongated, presumably to fetch a better price.

Irritated with the situation, Martill and Frey named the new species *Irritator challengeri*.

Frustration with the fossil, now part of the collection of Germany's State Museum of Natural History Stuttgart, didn't stop there.

Today more than 2,000 paleontologists and other supporters have signed an open letter requesting the fossil's repatriation to Brazil (bit.ly/irritator-letter). In September of this year, they sent the letter to Petra Olschowski, minister of science, research, and arts for Baden-Württemberg, the state where the museum is located.

"The *Irritator* is one of the most important fossils from Brazil because it is the best-preserved skeleton of a rare group of dinosaurs worldwide," said Aline Ghilardi, a paleontologist at the Federal University of Rio Grande do Norte in Brazil, who is helping to lead the repatriation effort.

The reparation request is based on Brazilian legislation enacted in 1942 declaring that fossils found in the country are the state's property and cannot be traded or exported without authorization. A 1990 law also mandates that any holotype (a fossil representing a new species) remain in the country.

"Basically, we want the Brazilian law to be respected," Ghilardi said. "Unfortunately, there is this general impression that the countries from the Global South are some sort of an amusement park for researchers from the North, who can come here, take our fossils, and put them in their museums to get academic prestige. This is neocolonialism."

Ethical Statement

Irritator got the attention of academia in May of this year after a new analysis of the skull was published in *Palaeontologia Electronica* (bit.ly/irritator-skull).

The publication contained an ethical statement acknowledging "the possibly problematic status" of the fossil, raising significant criticism about how the museum had acquired it. According to the authors, a German dealer likely purchased the fossil from local collectors and took it out of Brazil before 1990. The museum bought the specimen from the dealer in 1991.

The study's lead author, paleontologist Serjoscha Evers of the University of Fribourg, wrote in an email to *Eos* that he recognized that he and his colleagues did "a poor job on the statement," calling it an *ethics* statement, when, according to him, the issue with the fossil is instead a legal claim.

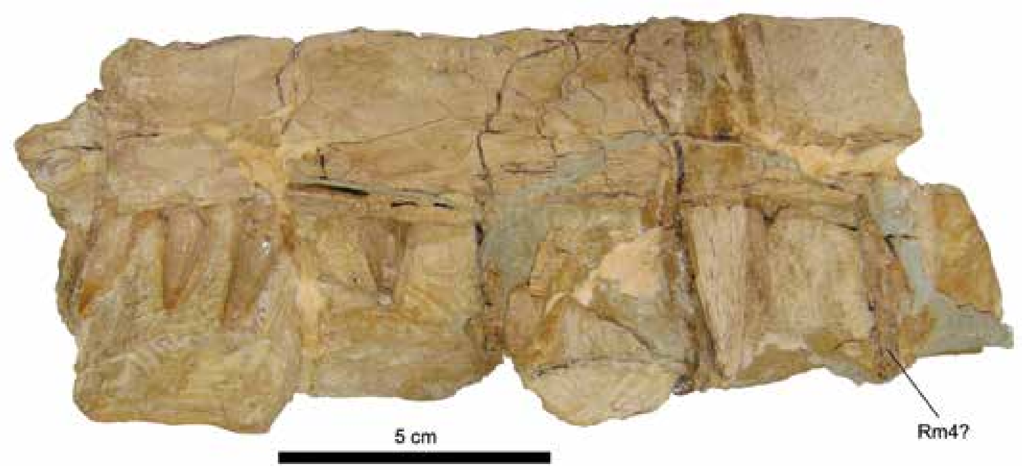
"Unfortunately, there is this general impression that the countries from the Global South are some sort of an amusement park for researchers from the North."

Evers, who has signed the letter supporting the *Irritator* repatriation, decided to halt his work on other Brazilian fossils until there is legal clarification about their origin or unless the research is done under the leadership of a Brazilian colleague.

"I am more aware of provenance issues than before—just because a fossil is in a museum and thus available for study, it is not always fair or ethical to work on it," Evers wrote. "I think that everything shown to be illegal should, of course, be returned."

Evers's paper on the *Irritator* was taken down for 2 days while *Palaeontologia Electronica* assessed the matter. Matúš Hyžný, one of the journal's executive editors, wrote in an email to *Eos* that the journal's editorial board decided to keep the article available, as they found no wrongdoing from the authors.

Michael Rasser, deputy head of the Department of Paleontology of the State Museum of Natural History Stuttgart, wrote



The Irritator challengeri *fossil has been studied by several researchers. Shown here is a detail of an artificially detached fragment of* Irritator challengeri*'s right upper jaw and teeth. Credit: Sales and Schultz, 2017, https://doi.org/10.1371/journal.pone.0187070, CC BY 4.0 (bit.ly/ccby4-0)*

in an email that the institution "takes the open letter and the demand for the return of the fossil seriously" and is working with the Ministry of Science, Research and Arts of Baden-Württemberg to clarify all facts and reach a legal assessment.

Not an Isolated Case

The *Irritator* case follows a successful campaign from paleontologists in Latin America who requested that another German museum in Baden-Württemberg return the fossil of a different dinosaur to Brazil. The *Ubirajara jubatus* fossil left the country illegally sometime in the 1990s or 2000s and was described by Martill and Frey in a 2020 paper in *Cretaceous Research*.

In June, the *Ubirajara* fossil became the first dinosaur fossil to be repatriated to Brazil. Editors retracted the *Cretaceous Research* paper (bit.ly/Ubirajara-paper), and the director of the State Museum of Natural History Karlsruhe, where the fossil had been held, resigned.

"These cases are not isolated but [are] the consequence of a systematic scientific colonialism that persists in the field of paleontology to this day," said Juan Cisneros, a paleontologist at the Federal University of Piauí in Brazil and one of the leaders of the repatriation campaigns.

In a 2022 study, Cisneros, Ghilardi, and their colleagues analyzed all research on new fossil species from two important geological formations in northeastern Brazil and Mexico published in the past 3 decades

"Just because a fossil is in a museum and thus available for study, it is not always fair or ethical to work on it."

and found that 80% of them did not disclaim whether the authors had permission to collect or export the specimens, a statement requested by both nations (bit.ly/colonial-practices). In the Brazilian case, about 90% of the specimens were described by foreign researchers, even though the country prohibits the export of holotypes.

Currently, Ghilardi and her colleagues are compiling a list of more than 500 holotype fossils in museums in Germany, Japan, and the United States that may have been illegally taken from Brazil.

Recognizing the issue, paleontological societies in Argentina, Brazil, Chile, Ecuador, Mexico, and Peru formed a consortium to work together in future repatriation cases and help fight scientific colonialism. One of the group's first actions was to publish an article in *PaleoAmerica* suggesting that journals require authors to disclose the origin of fossils and include fossil permits in the "materials and methods" sections of academic papers (bit.ly/paleontology-colonialism).

"Journals have an important role in blocking scientific colonialism," said Hermínio Araújo Júnior, president of the Brazilian Society of Paleontology.

Martill, a paleontologist at the University of Portsmouth in the United Kingdom, said that museums are justified in buying pieces from sellers who acquired them illegally if the purchase helps preserve the fossil for academic study. "All paleontologists all over the world should be grateful to curators, because they bought those fossils and stopped them from going into private collections where they are available to nobody," he said.

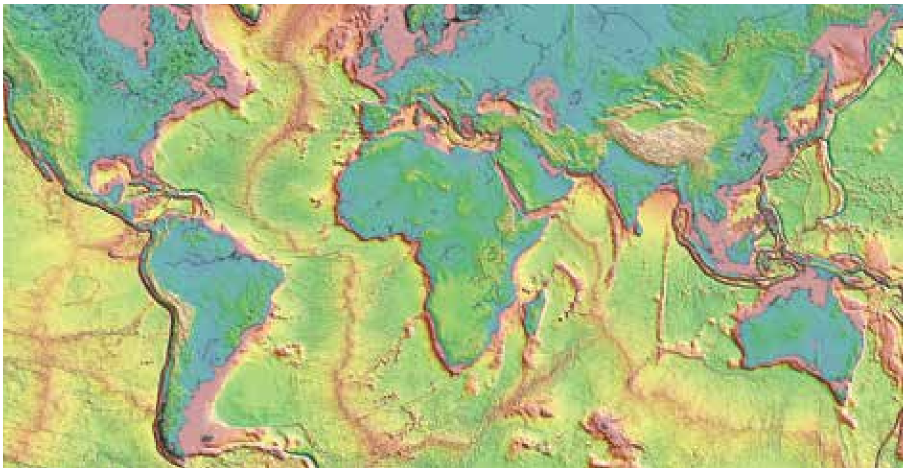
Martill has criticized national laws, such as Brazil's, that don't allow such sales. Still, he said he supports the repatriation of the *Irritator* fossil.

The return of fossils is more than just a legal issue, Ghilardi explained; it is also an ethical imperative. Repatriation can help socioeconomically disadvantaged communities in the Global South.

"It is also cultural violence to take these fossils from these people," Ghilardi said. She hopes the return of the *Irritator* fossil to Brazil's Araripe region, where it was found, will help foster the local economy via paleontological tourism and inspire a new generation of scientists. "Through fossils, we can transform a place."

By **Sofia Moutinho** (@sofiamoutinhoBR), Science Writer

A New, Underground Atlas of Subduction Zones



Submap is a user-friendly tool that allows anyone with an Internet connection to create quick, custom maps of subduction zones. This map shows bathymetry, or landforms below sea level, along with world topography. Credit: submap.fr

Subduction zones are complex, but mapping them is now as simple as cropping a family photo.

That's thanks to Submap, an online resource hosted by the Université de Montpellier in France. The latest version was intentionally designed for a wide audience, suitable for students, teachers, and professional researchers. The fast, free service incorporates dozens of data sets and makes mapping available to anyone with an Internet connection.

"Everything is public. Everybody can use it," said Serge Lallemand, a marine geodynamicist at the Université de Montpellier who helped develop the resource.

Graphic Design Meets Geoscience

Some of the deadliest disasters in recent history have occurred around subduction zones, including the 2004 Indian Ocean tsunami and the 2011 Tōhoku earthquake. But scientists are still distinguishing the phenomena that cause these catastrophes. The slow scrape of subducting plates occurs deep underground. Visualization tools like Submap can illuminate the process by creating maps and cross sections from multiple areas and angles.

The first version of Submap appeared online in 2009 (bit.ly/submap-fr). In the years since, Lallemand and his research group have steadily published public data sets to improve the project. This past spring, they went a step further and completely overhauled the website to make it more widely accessible. The new version debuted in June.

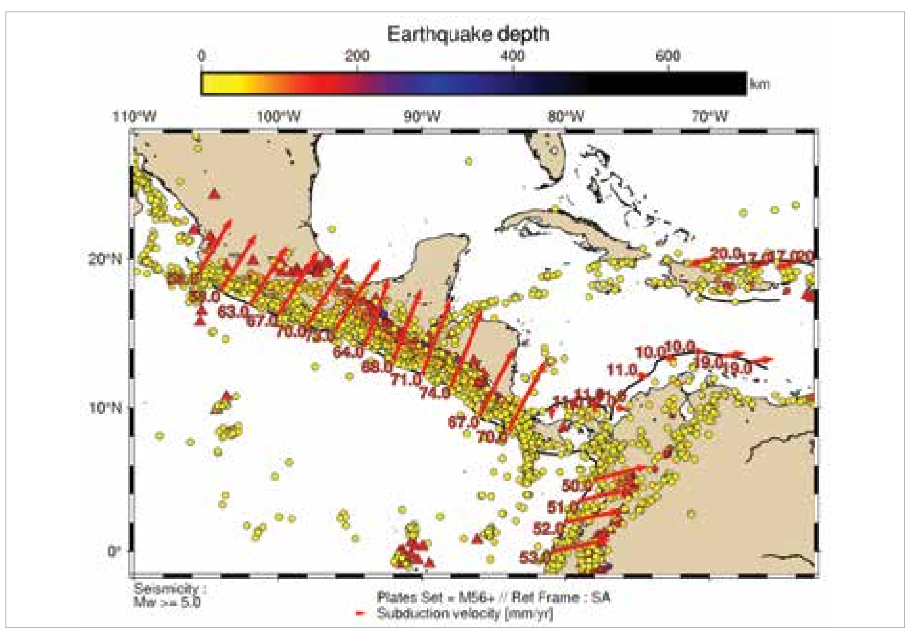
Submap has always been a public resource, said Lallemand. His lab group regularly adds and updates their findings and boosts the site with public data sets published by others. The modules include parameters that factor into the formation of giant tremors, like sediment thickness and seafloor roughness.

The user-friendly design was intentional, he said. The Submap team includes geoscientists, computer engineers, and a graphic designer. Although other mapping tools exist, Submap is unique in its user-friendly appearance, Lallemand said. The tools also include options for readers who are color-vision deficient, following inclusive recommendations from a 2020 *Nature Communications* perspective (bit.ly/color-science-comms).

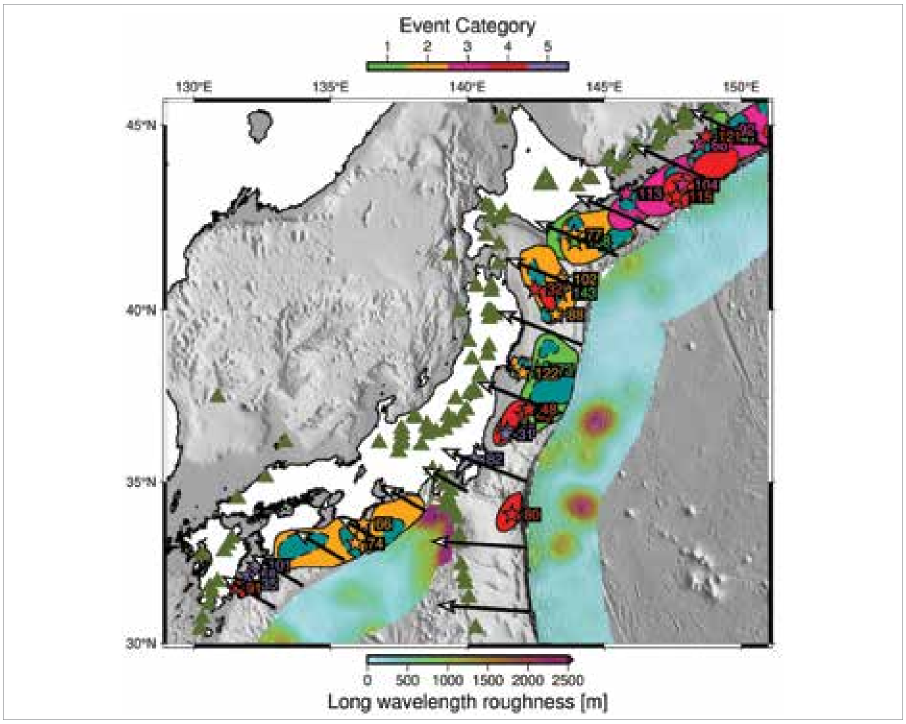
How to Map a Subduction Zone

The Submap website features four tools, including MAP-Geodyn. The mapping service lets users simply drag and drop the corners of a square over a map of the world just like they're cropping a photo.

Users decide what parameters to visualize, like seafloor age or topobathymetry. They can pepper their map with volcanos, earthquake epicenters, and subduction velocities.



MAP-Geodyn creates fast and free maps of subduction geodynamics using public data. This map of Central America shows the epicenters and depths of all recorded earthquakes rated magnitude 5 or higher as yellow circles and volcano locations as red triangles, as well as the velocity and direction of the Cocos plate as it subducts beneath the Caribbean plate. Credit: submap.fr



MAP-Subquake visualizes seafloor roughness and earthquake locations. This MAP-Subquake graphic shows the epicenters and rupture areas of all subduction earthquakes rated magnitude 7.5 or higher off Japan since 1900. Arrows indicate the direction of the Pacific plate (right) subducting beneath the Okhotsk (north) and Philippine (south) plates, green triangles identify volcano locations, stars identify epicenters of quakes, and colored patches indicate rupture areas. Credit: submap.fr

Users click "generate map," and seconds later, Submap produces a custom graphic ready to download in multiple file formats.

The other three Submap tools are equally visual. SECTION-Geodyn creates cross sections of Earth's crust up to 1,800 kilometers long. MAP-Subquake maps seafloor roughness against sites of major subduction earthquakes. Sub-DATA supplies parameters for trench transects around the world.

"It's very, very thoughtfully designed," said Margarete Jadamec, a geodynamicist at the University at Buffalo not involved in the project. The tools combine a user-friendly layout with actual quantitative data, she said, which meets the needs of several audiences. The program is a valuable teaching tool for students, a vital time-saver for researchers, and an important avenue for science communication.

"Submap is done in such an intuitive way that it has the ability to reach beyond just the scientific community and to really reach the broader public," she said.

Although the Submap site is active and ready to use, Lallemand and his colleagues continue to add to and enhance the data. Lallemand is currently researching kinematic parameters for areas with multiple microplates. His students are examining variations among arc volcanoes. Any results will be published open-access and added to the project.

For now, Lallemand wants researchers to try the tools, get ideas, and deliver feedback. Comments are welcome, he said. Every suggestion and contribution improves the project and increases the public understanding of these potentially catastrophic rupture sites.

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

The Supreme Court Is Bypassing Science—We Can't Ignore It

The United States has a strong tradition of investing in and trusting the best available science to inform regulations that govern natural resources protection, restoration, and management. Lately, however, the Supreme Court seems to have other ideas. In two recent decisions, the court, with environmental protections seemingly in its crosshairs, has sidestepped the checks and balances in our customary lawmaking process and cut sound science—and scientists—out of the equation.

In its May 2023 decision in *Sackett* v. *Environmental Protection Agency (EPA),* the court scaled back protections for wetlands under the Clean Water Act (CWA) to their smallest in decades (bit.ly/Sackett-EPA). The majority opinion invented out of whole cloth a new and narrow test to determine which wetlands are protected, ignoring scientific consensus and even the explicit intent of Congress when it wrote the law. To conform with the *Sackett* decision, the EPA has now amended the science-based rule it finalized earlier this year, replacing it with the high court's restrictive interpretation.

Similarly, in its 2022 decision in *West Virginia* v. *Environmental Protection Agency,* the majority opinion curtailed the ability of the EPA to address atmospheric carbon dioxide under the Clean Air Act (CAA) (bit.ly/WV-EPA). The decision was made not on the basis of scientific expertise but, rather, by invoking the so-called major questions doctrine, which, as Justice Elena Kagan noted in her dissent, the court has never explicitly invoked.

With a silent Congress and an activist court, environmental protections are evaporating as federal rules designed by scientists are overridden.

Involving scientists has traditionally been a hallmark of crafting and implementing successful environmental legislation. However, with a silent Congress and an activist court, environmental protections are evaporating as federal rules designed by scientists are overridden. This troubling trend endangers not only public and environmental health but also the perceived value and role of science in environmental management. Moreover, cutting science and scientists out of rulemaking undermines trust in scientists working to better understand our environment and our impacts on it.

We contend that scientists, as part of their personal commitment to scientific advancement, must pay attention to how their research and insights are—or are not—being reasonably applied by governing institutions that so heavily influence how we all live in the world. And we encourage them to get involved in the policymaking process to ensure that science is central in environmental legislation.

Trusting the Best Available Science

In 1972, Congress explicitly set an objective for the CWA to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters," empowering the EPA and the U.S. Army Corps of Engineers to use the best available science as the basis for promulgating rules and enforcing the law. Similarly, in 1970, when Congress directed the EPA to regulate air pollution via the CAA, it allowed the agency's scientific experts to define which pollutants were most problematic and develop an approach to their regulation.

The EPA has robust and well-established mechanisms by which it gathers the best available science. The agency employs scores of scientists who work to understand the environment and synthesize knowledge to guide policymaking and enforcement, and it analyzes and deploys research conducted by other agencies and scientists around the world. At Congress's direction, the EPA also convenes a Science Advisory Board to provide external input and an independent review of science, and it welcomes written commentary and feedback at public meetings and listening sessions as part of the required public comment process.

These mechanisms are not without limitations. If Congress realizes its intent with a law was unclear or thinks an agency has gone too far with its rulemaking, it can amend the law, or the agency can be challenged in court. In fact, the CWA and the CAA have been challenged many times, with each instance generating new guidance about enforcement.

The question of which waters, and particularly which wetlands, are protected by the Clean Water Act has been among the most litigated environmental issues at the Supreme Court.

When those challenges occur, the courts have a long tradition of deference to the scientific and technical expertise that exists in the agencies tasked with day-to-day implementation of laws. This deference has typically strengthened modern environmental regulations, allowing the best available science to inform policies. Courts must be mindful, though, to distinguish responsible deference to scientific and technical expertise from deference to political positions.

Idaho's Priest Lake is at the center of a new Supreme Court decision. Credit: Pecky Cox/Wikimedia, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

The CWA and *Sackett* v. *EPA*

The question of which waters, and particularly which wetlands, are protected by the CWA has been among the most litigated environmental issues at the Supreme Court. A series of back-and-forth decisions has yielded shifting enforcement. Although debates have been contentious, two principles have held: (1) Scientists and agencies have been central in the rulemaking process, and (2) the courts have exercised judicial restraint and respect for scientific judgment. Unfortunately, these did not persist in the *Sackett* decision, which abandons both judicial precedent and scientific consensus.

In *Sackett,* the plaintiffs began filling a wetland on their property near Priest Lake, Idaho, with gravel in preparation for construction of a home without first obtaining a permit to fill the wetland. The EPA ordered work halted, claiming the unpermitted work was a violation of the CWA.

In a decision in 2021, the U.S. Court of Appeals for the Ninth Circuit ruled that the wetland in question, roughly 90 meters from the lake and separated from it by a berm, was protected by the CWA and required a permit to fill. The Ninth Circuit's perspective was consistent with several past rulings by the Supreme Court, recent rulemaking efforts, and enforcement decisions that have been in place since 1986. The ruling was also consistent with scientific understanding, which indicates that wetlands provide innumerable benefits to the physical, chemical, and biological health of nearby waters based on their connectivity not only on the surface but also through the subsurface (e.g., via groundwater flowing under a road or a berm).

However, the majority opinion this year, authored by Justice Samuel Alito, invents the requirement of "adjoinment" for protection of a wetland under the CWA, stating that a wetland must share a "continuous surface connection" with a stream, river, lake, or other surface water that is broadly understood to be protected. This contrasts with the earlier precedent that a wetland need only be adjacent to (and likely to affect the water quality of) a larger body.

The standard established in *Sackett* set stricter bounds for protection than those in rules proposed by the Obama, Trump, and Biden administrations. And in no prior agency rule, scientific report, opinion from a scientific agency, or recommendation from the Science Advisory Board has the notion of adjoinment been proposed.

In concurring opinions, several justices agreed that the CWA's jurisdiction is not unlimited but disagreed with the wholesale reimagining of the test for protection. These concurring opinions argued that the majority's interpretation does not meet the plain language reading of the law and pointed out that the court could have issued a much narrower decision that gave relief to the Sacketts but kept the system of deference to agency scientific and technical expertise in place.

Thus, the majority's decision appeared less motivated by science and more by political desires to dismantle protections afforded under the CWA.

And dismantle, it does.

Sackett's Environmental Implications

In the wake of this decision, federal protections for America's wetlands are at their smallest and weakest in decades. Federal rules are the only protections for wetlands in about half of the states, leaving a substantial portion of the United States' remaining wetlands—and the benefits they produce, such as flood control, aquatic habitat, and improved water quality—vulnerable to destruction.

Just how many wetlands might be affected by the new decision and rule? The federal government has declined to make estimates at the national scale, but some data exist and offer glimpses regionally. In one recent study of New York's wetlands, for example, researchers found that fewer than half are located within 100 feet (~30 meters) of waterways (bit.ly/NY-wetlands). And in a study of the extensively drained midwestern Wabash River Basin, only about 17% of current wetlands (or about 3% of the historical wetland acres in the region, where 80% have been lost since Europeans arrived) are within 100 feet of waterways (bit.ly/Wabash-River).

In both studies, 100 feet was used as the narrowest interpretation of prior CWA rules, although this interpretation was still much broader than the Sackett criterion for adjoinment via a continuous surface connection. With the more stringent requirement, only a fraction of these wetlands are left with federal protections, representing the largest loss of wetland protections since they have been federally regulated.

West Virginia and the Emerging Major Questions Doctrine

At issue in *West Virginia* was the EPA's proposed regulation, under the CAA, of greenhouse gas emissions from power plants as part of a set of Obama era rules called the Clean Power Plan (CPP). The CPP included a combination of "within the fence" requirements (i.e., processes deployed at power plants to limit emissions) and "beyond the fence" requirements (i.e., requirements to shift production to alternative energy sources). The case centered not on the science of climate change or the basic ability of the EPA to regulate greenhouse gas emissions (already established in *Massachusetts* v. *Environmental Protection Agency* (bit.ly/MA-v-EPA)) but, instead, on Congress's perceived intent in adopting the CAA.

The EPA contended—and dissenting justices agreed—that the agency was explicitly directed in the CAA to implement the "best system of emission reduction" from power-generating plants and stationary sources. Yet the plaintiffs, including several states and coal companies, won the day, arguing that the EPA was overreaching. As a result, the EPA's tool kit to regulate greenhouse gas emissions has been substantially reduced, at a time when climate change effects are more apparent and the need for action is more urgent than ever.

In the wake of the *Sackett* decision, federal protections for America's wetlands are at their smallest and weakest in decades.

In addition to mitigating carbon emissions, the CPP would have reduced related sulfur dioxide and nitrous oxide emissions, and it was projected to prevent thousands of premature deaths each year and yield billions of dollars in net benefits. In siding with the plaintiffs, however, the court's majority sidestepped technical expertise and scientific consensus supporting the need for increased regulation of emissions, applying a broad interpretation of the major questions doctrine to the EPA's regulation of greenhouse gases from power plants.

The major questions doctrine is an emerging judicial principle positing that federal agencies must have clear congressional authorization to implement rules or make major decisions that will have major political or economic effects. The doctrine suggests that although the courts and Congress may defer to agencies for less significant decisions, laws should not be interpreted to presume the same deference for major decisions, unless Congress grants an agency that power using "exceedingly clear language."

This approach stands in stark contrast to the Chevron doctrine (established in 1984 in *Chevron U.S.A. Inc.* v. *Natural Resources Defense Council, Inc.* (bit.ly/Chevron-NRDC)), in which deference is given to agency interpretations of congressional laws like the CAA and CWA.

The emergence of the major questions doctrine as a response to the standard of agency deference creates a political vehicle for major cutbacks in environmental protections and the roles of scientific information and expertise in driving those protections. In *West Virginia* and *Sackett,* despite well-established laws and regulations seemingly within the scope of those laws, the court rolled back proposed regulations (*West Virginia*) or created a new test with no basis in science or in the legislation (*Sackett*).

In *Sackett* especially, the court failed to follow its own directive under the major questions doctrine, neglecting the exceedingly clear language that Congress *did* use when it explicitly added mention of "adjacent wetlands" to the CWA's protections in 1977.

Scientists Must Be at the Table

Lacking a clear definition of what might constitute a "major question" and with our present polarized Congress unlikely to implement comprehensive updates of federal environmental regulations to clarify their intents—even as we face emerging threats not conceived of when the regulations were drafted—additional environmental protections may be on the chopping block.

We need Congress to end its steadfast silence on the CWA and CAA and on the erosion of environmental protections. In doing so, it can reassert that scientists must play roles in the design and implementation of environmental regulations. Without congressional action, we expect replication of the court's line of thinking, further divorcing these regulations from the best available science and endangering the health of communities and ecosystems.

So what can scientists do?

Scientists' primary role remains knowledge production. Americans invest in science through federal agencies, public universities, and taxpayer-funded research to expand our understanding of the world. Implicit in the agreement is that this science provide reliable, trustworthy, unbiased information upon which regulatory decisions on how best to manage natural resources sustainably and improve lives should be based.

In addition to producing knowledge, scientists can further serve society by more directly supporting decisionmaking. The *Sackett* and *West Virginia* cases offer powerful examples of why scientists need to understand how their research is (or isn't) being put to good use and why we need a culture shift toward engagement with the policy process.

Helping members of Congress understand potential consequences of—and how legislators' intent may not be reflected in—judicial decisions is one path to change. Scientists can ensure that Congress has access to the best available science by, for example, writing white papers and reaching out to representatives to provide briefings on the current state of the science related to key issues. These briefings may be most effective when legislation is being proposed or debated, providing expertise when it is most timely.

We also encourage scientists to engage with their professional organizations on policy work. Recent court decisions and agency rulemaking have prompted joint statements from a host of scientific organizations, providing intellectual weight and clear, unified positions on issues that may have more influence than a collection of individually authored statements.

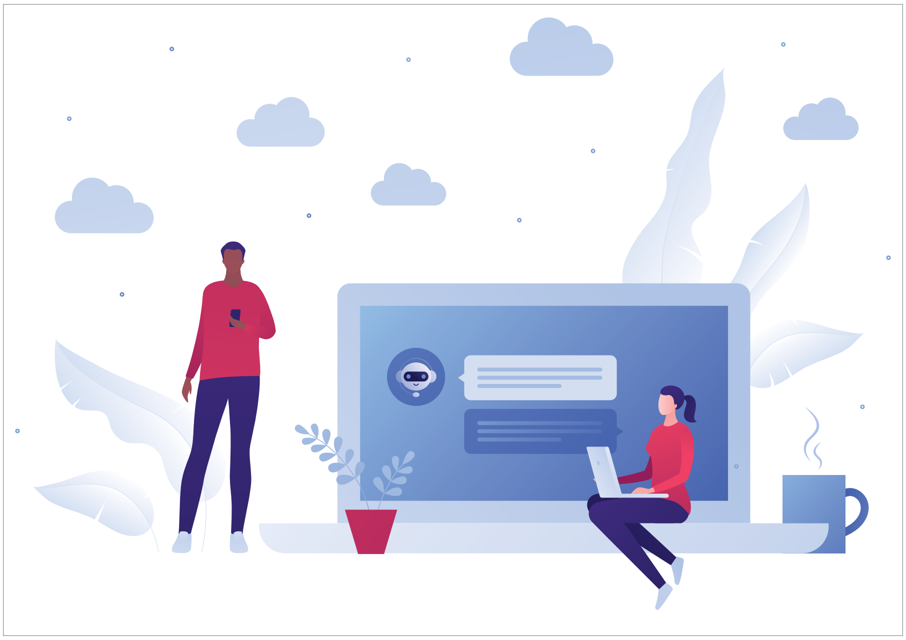
Examples of ways to get involved include through society policy programs, collaborating on amicus briefs authored on behalf of scientific organizations (e.g., an amicus brief filed by 12 national and international scientific societies in *Sackett* (bit.ly/WOTUS-brief)), and working with professional societies to brief communities on critical issues (e.g., the Society for Freshwater Science's resource page created during the 2019–2020 rulemaking to revise the definition of waters of the United States (bit.ly/SFS-resources)).

Another avenue for involvement is the EPA's Science Advisory Board, which has a host of committees and panels that provide scientific input on a broad range of topics. These committees enable direct engagement between scientists and the EPA, and they regularly weigh in on proposed rules and decisions.

The U.S. public expects scientists to be at the table when environmental regulations are being drafted and enforced. Lately, the Supreme Court has bypassed this vital role and prioritized political goals over environmental and public health. The court's sweeping decisions have emphasized the urgency for scientists to engage in environmental policy and regulation at local, state, and federal levels.

By **Adam S. Ward** (adam.ward@oregonstate.edu), Department of Biological and Ecological Engineering, Oregon State University, Corvallis; and **Adell Amos,** School of Law, University of Oregon, Eugene

AI Could Reshape Climate Communication



Confidence in science has become increasingly fragmented in the United States across our polarized political spectrum. And overall, the American public is showing declining trust in experts and institutions, including scientists and universities, especially with people "doing their own research" on issues ranging from COVID-19 to climate change. Such self-guided research typically amounts to seeking out and cherry-picking information or viewpoints that support preconceived opinions. Could artificial intelligence (AI) provide a pathway to change these trends?

Scientists have used AI and machine learning tools for decades to help analyze data and answer research questions. What's new in the past few years is the rapid advance of large language model (LLM)–based chatbot systems that can generate responses to natural language prompts and carry on conversations with impressive sophistication.

Today AI can often answer scientific questions as well as credentialed experts can. As AI capabilities continue to improve, it's getting harder to tell whether a human or a chatbot is answering your question. OpenAI recently reported that in the few months between the public releases of its GPT-3.5 and GPT-4 LLMs, in November 2022 and March 2023, respectively, the system improved its ability to answer AP Physics 2 exam questions accurately from 25% to 70% [*OpenAI*, 2023]. And with OpenAI claiming the fastest growing tech userbase of all time, the public has demonstrated its eagerness to use these capabilities.

In a future in which AI has Ph.D.-level command of scientific knowledge and reasoning, everyone will be able to access this expertise. Although there is dramatic potential for spreading misinformation, the democratization of expertise through generative AI also has great potential to improve people's understanding of science and ease strain between the scientific enterprise and the public it serves.

Chatbots as Expert Interlocutors

Consider the ways in which AI could supplement climate change communication. Historically, expertise in climate science has been siloed in research institutions that are accessible to relatively few people. In contrast, chatbots can give virtually anyone unlimited access to a digital expert to answer their questions—a feat that never will be possible with human expertise.

To be sure, broadening access to evidence and expertise is not a panacea for fixing the problems of trust in science and dispelling unscientific beliefs. Information is not enough. In many cases, distrust or skepticism about scientific issues or consensus stems not from a lack of knowledge but from the perception that the kinds of actions most aligned with the evidence (e.g., transitioning from fossil fuels to clean energy) conflict with one's cultural identity or values [*Kahan et al.*, 2012; *Hilgartner et al.*, 2021].

In such cases, discourse can help. Reflective discussion can pull people back from polarized extremes [*Brader and Tucker*, 2018]. And early evidence from studies of the latest generation of chatbots has shown that exposure to AI agents representing different policy views can meaningfully shift users' perspectives [*Jakesch et al.*, 2023]. Users also may be willing to ask chatbots questions that they are too uncertain of or insecure about to ask a human expert or to ask a chatbot questions that clarify information they've heard from human communicators.

In addition, a chatbot may be better equipped to talk to someone at their current level of understanding and thinking about climate change. For inspiration, we may look to other fields, such as medicine, where complex and technical concepts must routinely be communicated to broad and diverse audiences.

Chatbots can give virtually anyone unlimited access to a digital expert to answer their questions—a feat that never will be possible with human expertise.

For example, a doctor or other medical professional may need to explain a complicated medical scenario to a colleague one minute and to a patient with no medical training the next. The doctor must incorporate and answer questions and be responsive to feedback from each of them. Researchers are actively considering using the current generation of AI tools to fulfill these communication tasks in the near term [*Abrardi et al.*, 2022].

Whereas human communicators may be pressed for time or attempting to engage with a number of individuals at once, there is no time limit on engagement with a chatbot. Climate experts may also struggle to explain concepts as a result of the "curse of knowledge"—that is, they understand something so well they forget that others do not and thus neglect to share foundational information with their audience [*Bohren*, 2019]. A chatbot, on the other hand, can tailor its responses to, and share the information most relevant for, a single user—including not just what is known but also how it is known.

Like any good human communicator, for example, an AI chatbot can report that climate disruption can increase hurricane risks, explain how attribution science works, and even offer links to specific research results relevant to a user's home region. Chatbots such as YouChat, Perplexity, and Microsoft's Bing Chat (based on OpenAI's GPT-4 model) have been designed with dedicated abilities to cite real sources.

Further, whereas people, as invested and emotional beings, may get impatient or frustrated when communicating about an issue like climate change with someone who is skeptical or has a different perspective, AI can be programmatically instructed to maintain an even tone.

Context, Interpretation, and Application

Polling has suggested that most Americans are skeptical of using chatbots in sensitive contexts, such as for making medical decisions, but we also know that many Americans are skeptical of human scientists and human climate communicators. If they are built in a trustworthy fashion, AI chatbots could allow users to interrogate evidence for climate change in a way that feels more objective to them than talking to humans they may perceive as biased.

A chatbot can tailor its responses to, and share the information most relevant for, a single user—including not just what is known but also how it is known.

A specialized AI model could talk a user through how to interpret a highly complex geospatial-temporal climate model, making it more accessible than a scientific paper or even an interactive data visualization tool could.

Interacting with a chatbot also could allow users to ask questions about what climate change will mean for their local community and get rapid, personalized, and accurate answers with contextualization that even renowned experts could not provide instantly. OpenAI's GPT-4 model, a general-purpose LLM system with no specialized training in climate change communication, has impressive abilities to answer questions about data and even to generate new graphs, with poetic flair.

Recent demonstrations have shown how GPT-4 can generate data visualizations from tables provided by users, iteratively improving them in response to user questions [*Bubeck et al.*, 2023]. As a flex, GPT-4 will even explain scientific concepts in Shakespearean rhyme, an example that demonstrates the technology's potential to tailor information to individual needs and communication styles [*Livemint*, 2023].

Chatbots also may enable people to use their scientific knowledge—gained from interacting with AI or elsewhere—to benefit themselves and their communities. For example, polls have shown that a large portion of the American population is concerned about climate change, but very few act on their concern by doing things like contacting elected officials or even talking to their friends and family about the issue.

One commonly cited reason for inaction is that it is challenging to know what can be done. A chatbot could provide many ideas for meaningful action, even customizing suggestions to an individual's interests, skills, and resources. If someone wants to write to an elected official or submit a public comment on proposed legislation, a chatbot could suggest key points capturing that person's point of view and even help in articulating those points. If a user wants to join an advocacy group, it could identify local options.

The Human Element in Artificial Intelligence

For all their remarkable potential, we don't expect or want chatbots to replace human communicators entirely. People will remain essential messengers for many circumstances, audiences, and messages.

For example, people can introduce the topic of climate change in contexts where it otherwise might not be salient. Think of how meteorologists who report on climate change in local news effectively increase their audiences' understanding of local climate impacts [*Myers et al.,* 2020]. In addition, climate communicators have opportunities to engage with different audiences in a wide range of settings, from schools and state fairs to local and national newspapers, initiating conversations where a chatbot could not. Humans also may be better at that initiation because they can connect over shared interests and values and demonstrate empathy.

To remain up-to-date and effective, chatbots also will require continual high-quality inputs of information, which human communicators will be uniquely suited to provide. Even as AI assistive tools are starting to make climate research more efficient, the research itself will continue to be led by humans.

We don't expect or want chatbots to replace human communicators entirely.

And, of course, it is humans who must work to keep debugging AI tools. The latest AI chatbots "hallucinate" nonfactual answers and even cite fake sources [*Alkaissi and McFarlane,* 2023]. The current class of language models will gladly generate a web link or a paper DOI (digital object identifier) that doesn't really exist because it thinks that that fragment of text will satisfy a human user's expectations [*Armstrong,* 2023]. Chatbots sound confident even when they shouldn't be. As a result, they have the counterproductive potential both to generate and to perpetuate misinformation.

What's more, chatbots, powered as they are by algorithms with billions of parameters and huge quantities of data, use energy and hardware resources at prodigious rates and thus carry their own climate and environmental costs. And we face the specter of political polarization among AI systems that mirrors polarization among humans [*Thompson et al.,* 2023]—these remain tools built by and trained on text generated by people, after all.

These issues must be addressed before AI can be used confidently to support public engagement with and trust in scientific evidence.

Climate scientists and AI developers and researchers should look for opportunities to collaborate with each other to design and test AI tools with climate communication in mind.

What's needed next is experimentation. We must test these strategies for public engagement, education, and activation with new generations of AI chatbots. And we need to develop and experiment with custom-trained LLMs and AI applications that have specialized capabilities in domains like climate.

Surely the giants of the field, such as OpenAI, Microsoft, and Google, will develop tools catering to the scientific and education markets, but we need not wait for or rely on them. Rapid innovation among the open-source community—with help from, yes, big tech—has made it possible for small research groups, companies, and agencies to build and customize their own chatbots and integrate LLMs into their own applications. Climate scientists and AI developers and researchers should look for opportunities to collaborate with each other to design and test the effectiveness and reliability of LLMs and other AI tools with climate communication in mind. Government should play a role here, too; there should be a "public option" for AI [*Schneier and Sanders,* 2023].

Despite the hurdles to overcome in developing well-trained and trustworthy chatbots, the urgency with which we must address climate change requires that we consider opportunities to work alongside AI in ways that will engage as much of the public as possible in pursuing solutions as quickly as possible. More broadly, as AI assistive tools improve in their understanding of science, perhaps they can help all of us do the same.

If used appropriately, ethically, and sustainably, these tools could usher in a shift in how diverse publics engage with science topics like climate change, medicine, and more and, in turn, how they form opinions, build trust, and incorporate scientific information into their own decisionmaking.

References

Abrardi, L., C. Cambini, and L. Rondi (2022), Artificial intelligence, firms and consumer behavior: A survey, *J. Econ. Surv., 36*(4), 969–991, https://doi.org/10.1111/joes.12455.

Alkaissi, H., and S. I. McFarlane (2023), Artificial hallucinations in ChatGPT: Implications in scientific writing, *Cureus, 15*(2), e35179, https://doi.org/10.7759/cureus.35179.

Armstrong, K. (2023), ChatGPT: US lawyer admits using AI for case research, BBC News, 27 May, bbc.com/news/world-us-canada-65735769.

Bohren, C. F. (2019), The curse of knowledge, *Eur. J. Phys., 40*(3), 030201, https://doi.org/10.1088/1361-6404/ab1202.

Brader, T., and J. A. Tucker (2018), Unreflective partisans? Policy information and evaluation in the development of partisanship, *Polit. Psychol., 39*(51), 137–157, https://doi.org/10.1111/pops.12480.

Bubeck, S., et al. (2023), Sparks of artificial general intelligence: Early experiments with GPT-4, arXiv.2303.12712, https://doi.org/10.48550/arXiv.2303.12712.

Hilgartner, S., J. B. Hurlbut, and S. Jasanoff (2021), Was "science" on the ballot?, *Science, 371*(6532), 893–894, https://doi.org/10.1126/science.abf8762.

Jakesch, M., et al. (2023), Co-writing with opinionated language models affects users' views, arXiv.2302.00560, https://doi.org/10.48550/arXiv.2302.00560.

Kahan, D. M., et al. (2012), The polarizing impact of science literacy and numeracy on perceived climate change risks, *Nat. Clim. Change, 2,* 732–735, https://doi.org/10.1038/nclimate1547.

Livemint (2023), Twitter user asks Chat GPT-4 to explain climate change in Shakespearean style; results leave netizens shocked, *Mint,* 20 March, bit.ly/chat-GPT4-Shakespeare.

Myers, T. A., et al. (2020), Impact of the Climate Matters program on public understanding of climate change, *Weather Clim. Soc., 12*(4), 863–876, https://doi.org/10.1175/WCAS-D-20-0026.1.

OpenAI (2023), GPT-4 technical report, arXiv.2303.08774, https://doi.org/10.48550/arXiv.2303.08774.

Schneier, B., and N. E. Sanders (2023), Build AI by the people, for the people, *Foreign Policy,* 12 June, foreignpolicy.com/2023/06/12/ai-regulation-technology-us-china-eu-governance/.

Thompson, S. A., T. Hsu, and S. L. Myers (2023), Conservatives aim to build a chatbot of their own, *New York Times,* 22 March, nytimes.com/2023/03/22/business/media/ai-chatbots-right-wing-conservative.html.

By **Nathan E. Sanders** (nsanders@cyber.harvard.edu), Berkman Klein Center for Internet & Society, Harvard University, Cambridge, Mass.; and **Rose Hendricks,** Association of Science and Technology Centers, Washington, D.C.

Read the article at Eos.org

Finding Harmony in FAIRness

How do you define fairness? Well, who's doing the defining?

About a decade ago, data scientists began developing guiding principles meant to ensure that digital data sets are fair—or, rather, FAIR. FAIR stands for findability, accessibility, interoperability, and reusability, the four qualities related to scientific data management and stewardship on which the FAIR principles focus. The overarching purposes of making data FAIR are to support open science and maximize reuse of digital data.

Fifteen FAIR Guiding Principles cover three unique high-level entities, or categories: "data (or any digital object), metadata (information about that digital object), and infrastructure" (Table 1). Specifically, these principles aim to optimize data sharing in a machine-friendly environment across systems, disciplines, and regional boundaries by laying out a set of the behaviors that digital data objects should exhibit [*Wilkinson et al.*, 2016, 2022].

The rapid uptake and adoption of the FAIR Guiding Principles by policymakers (e.g., in Australia and the European Union (EU)), funders such as the EU Commission, professional organizations, and research data communities worldwide have resulted in the creation of substantial data stewardship and compliance requirements for publicly funded projects and research data repositories. However, even with the desired behaviors enumerated, assessing how well data sets align with the FAIR principles—that is, defining FAIRness—remains a challenge. The principles themselves were not originally intended to be used in evaluating whether a digital data object is FAIR [*Mons et al.*, 2017], and in an attempt to be technology and discipline neutral, they do not prescribe mechanisms to achieve the desired behaviors [*Wilkinson et al.*, 2022].

To address needs for evaluating FAIRness, a range of useful FAIR assessment frameworks have been developed recently. However, these frameworks have different focuses and use different criteria and indicators, so their results are often inconsistent or not directly comparable. This difficulty with comparability has motivated the creation of a set of uniform, or harmonized, indicators of FAIRness.

Assessing how well data sets align with the FAIR principles—that is, defining FAIRness—remains a challenge.

Table 1. The 15 Original FAIR Data Guiding Principles, as Established by *Wilkinson et al.* [2016], Covering Three Unique Entities, or Categories: Data, Metadata, and Infrastructure

Principle Number	Principle ID	Description	Data	Metadata	Infra-structure
1	F1	(Meta)data are assigned a globally unique and eternally persistent identifier	✓	✓	
2	F2	Data are described with rich metadata (defined by R1 below)	✓	✓	
3	F3	Metadata clearly and explicitly include the identifier of the data they describe	✓	✓	
4	F4	(Meta)data are registered or indexed in a searchable resource	✓	✓	✓
5	A1	(Meta)data are retrievable by their identifier using a standardized communications protocol	✓	✓	✓
6	A1.1	The protocol is open, free, and universally implementable			✓
7	A1.2	The protocol allows for an authentication and authorization procedure, where necessary			✓
8	A2	Metadata are accessible, even when the data are no longer available		✓	
9	I1	(Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation	✓	✓	
10	I2	(Meta)data use vocabularies that follow FAIR principles	✓	✓	
11	I3	(Meta)data include qualified references to other (meta)data	✓	✓	
12	R1	(Meta)data are richly described with a plurality of accurate and relevant attributes	✓	✓	
13	R1.1	(Meta)data are released with a clear and accessible data usage license	✓	✓	
14	R1.2	(Meta)data are associated with detailed provenance	✓	✓	
15	R1.3	(Meta)data meet domain-relevant community standards	✓	✓	

Variation Among Frameworks

Two prominent FAIR assessment frameworks are those developed by *Wilkinson et al.* [2019] and by the Research Data Alliance (RDA) [*RDA FAIR Data Maturity Model Working Group*, 2020; *Bahim et al.*, 2020]. As an example of how these frameworks vary and why they may not provide comparable assessments, let's consider how each treats the original four FAIR principles related to accessibility (i.e., FAIR-A) as defined by *Wilkinson et al.* [2016] (Table 1), which include the following:

A1. (Meta)data are retrievable by their identifier using a standardized communications protocol.

A1.1. The protocol is open, free, and universally implementable.

A1.2. The protocol allows for an authentication and authorization procedure, where necessary.

A2. Metadata are accessible, even when the data are no longer available.

"Protocol" in this context refers to the mechanism or infrastructure for requesting and retrieving digital information (e.g., hypertext transfer protocol secure, or HTTPS, for securely exchanging information across the Internet), and an "identifier" is a unique string of characters that identifies a given

iStock.com/tzahiV

digital object (e.g., the digital object identifier, or DOI, of a scientific study).

Wilkinson et al. [2019] provide a set of 15 machine-interoperable FAIRness metrics, or maturity indicators (MIs). These indicators do not cover all the original principles, but recognizing that assessing FAIRness has different requirements in different communities [*Mons et al.*, 2017], the developers also establish a system allowing users to create "domain-relevant community-specific MIs."

The framework's MIs—for the FAIR-A principles, for example—tend to be infrastructure-centric (Table 2, top). In addition, data and metadata are not separated in MI definitions; for example, Gen2_MI_A1.1 asks whether data and metadata are retrievable using an open-source and royalty-free protocol. In practice, though, the protocols used to retrieve data and metadata may not be the same, so it is beneficial to assess the openness of each separately.

The *RDA FAIR Data Maturity Model Working Group* [2020], aiming to allow direct comparison of assessment results, makes the first systematic attempt to provide a common set of core FAIR MIs [*Bahim et al.*, 2020]. This framework, the most comprehensive so far, contains 41 indicators. (The FAIRsFAIR project used a subset of 17 of these to create an automated tool to evaluate the FAIRness of data sets.)

However, some subjective interpretations that are outside the scope of the original FAIR Guiding Principles have been embedded in the RDA indicators set. For example, it includes additional requirements for human accessibility of data and metadata (e.g., RDA-A1-02D and RDA-A1-02M; Table 2, bottom), whereas the FAIR principles explicitly focus on ensuring the abilities of computers to act autonomously [*Mons et al.*, 2017].

Table 2. Two Examples of FAIRness Assessment Frameworks and Their Indicators for FAIR-Accessible (FAIR-A) Principles

***Wilkinson et al.* [2019]**	
Principle ID	**Description**
Gen2_MI_A1.1	Open protocol for (meta)data retrieval
Gen2_MI_A1.2	Protocol supports authentication/authorization
Gen2_MI_A2	Policy for metadata persistence
***RDA FAIR Data Maturity Model* [2020]**	
Principle ID	**Description**
RDA-A1-01M	Metadata contain information to enable the user to get access to the data
RDA-A1-02M	Metadata can be accessed manually (i.e., with human intervention)
RDA-A1-02D	Data can be accessed manually (i.e., with human intervention)
RDA-A1-03M	Metadata identifier resolves to a metadata record
RDA-A1-03D	Data identifier resolves to a digital object
RDA-A1-04M	Metadata are accessible through a standardized protocol
RDA-A1-04D	Data are accessible through a standardized protocol
RDA-A1-05D	Data can be accessed automatically (i.e., by a computer program)
RDA-A1.1-01M	Metadata are accessible through a free access protocol
RDA-A1.1-01D	Data are accessible through a free access protocol
RDA-A1.2-01D	Data are accessible through an access protocol that supports authentication and authorization
RDA-A2-01M	Metadata are guaranteed to remain available after data are no longer available

Furthermore, the RDA FAIR MIs tend to be (meta)data-centric compared with the original principles. For example, the subject of the original A1.1 and A1.2 principles is "the protocol," whereas the subject of the corresponding MIs (RDA-A1.1-01M, RDA-A1.1-01D, and RDA-A1.2-01D) is either "data" or "metadata." In addition, the elements of a protocol being "open" and "universally implementable" spelled out in principle A1.1 are not included in the corresponding RDA MIs.

The details of these two sets of FAIR-A assessment indicators, as captured in Table 2, clearly reveal their variation not only from the original FAIR principles but also from each other. Thus, although each framework is useful and beneficial, it is very difficult to cross compare their resulting assessments directly.

Such observations are not limited to these two FAIRness frameworks. Indeed, it has been noted that different interpretations of the FAIR principles tend to lead to different assessment models [*Bahim et al.*, 2020], resulting in vastly different assessment results [*Peters-von Gehlen et al.*, 2022; *Wilkinson et al.*, 2022].

Different interpretations of the FAIR principles tend to lead to different assessment models, resulting in vastly different assessment results.

Therefore, there is an urgent and practical need for a complete set of harmonized indicators that adhere to the original FAIR Guiding Principles and can be used as fundamental building blocks of any FAIRness assessment framework. Such indicators, if broken down to the most granular level, will be beneficial to data stewards and repositories when they are developing their own FAIRness evaluation workflows or reporting FAIR compliance. And they will be essential in creating a consistent, standardized means of documenting, sharing, and integrating FAIRness evaluation outcomes across tools and systems.

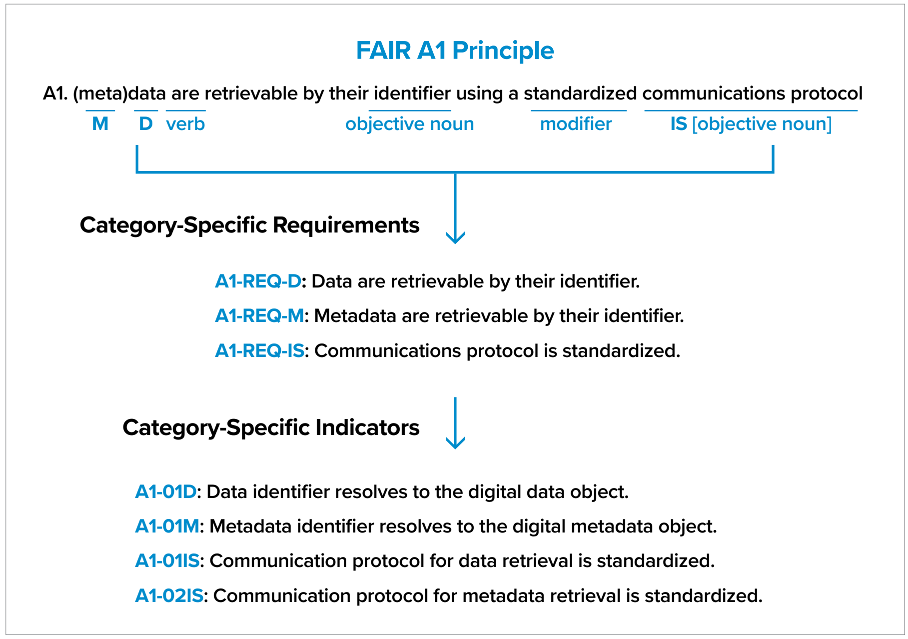


Fig. 1. This diagram shows the process of grammatically decomposing the original FAIR-A1 guiding principle into category-specific requirements (REQ) and indicators associated with data (D), metadata (M), and infrastructure (IS).

Deriving Harmonized Indicators

So how do we craft a set of fundamental, harmonized FAIRness indicators? One possible approach, which I am developing and briefly describe here, involves grammatically decomposing the original 15 FAIR Guiding Principles.

First, the relevant categories in each principle are determined: data (D), metadata (M), and infrastructure (IS; Table 1). This breakdown results in a total of 29 expected FAIR behaviors, or category-specific requirements, with 12, 13, and 4 requirements in the D, M, and IS categories, respectively. The category-specific requirements are then decomposed further into new category-specific indicators by identifying the objective noun(s) and any verb or object modifiers in the original guiding principles.

The process is outlined in Figure 1, using the FAIR-A1 principle as an example. In this case, all three categories are relevant, resulting in three category-specific requirements. Identifying the objective nouns ("data identifier," "metadata identifier," and "communications protocol") and modifiers ("standardized") then leads to the following four indicators:

A1-01D. Data identifier resolves to the digital data object.

A1-01M. Metadata identifier resolves to the digital metadata object.

A1-01IS. Communication protocol for data retrieval is standardized.

A1-02IS. Communication protocol for metadata retrieval is standardized.

In total, this approach results in a complete set of about 80 basic indicators that together decompose the 15 FAIR principles to the most granular level possible and introduce nothing outside the scope of the additional principles. Some of the indicators, although consistent with those in existing frameworks, offer subtle differences. For example, A1-01D (A1-01M) above is almost identical to RDA-A1-03D (RDA-A1-03M; Table 2), but the slight clarification in the article ("the" versus "a") denotes the requirement in this case for the data (metadata) identifier to resolve specifically to *its* corresponding digital data (metadata) object.

Ultimately, these category-specific indicators are intended to be systematic and consistent with the definitions of the original FAIR principles, as well as granular and modular. These qualities mean they can be used to develop FAIRness assessment workflows for any unique application or perspective while still allowing direct comparison of assessment results from each indicator for different digital data objects regardless of the workflow.

A harmonized set of fundamental indicators that work across fields and applications is urgently needed.

Adding Extensions

Even with an approach to decomposing the FAIR Guiding Principles fully and consistently, nuances require additional consideration. Of note, several concepts, including "rich metadata," "qualified references," and "relevant attributes," are mentioned but not explicitly defined in the original FAIR principles because of their disciplinary dependency (Table 1). For example, principle 2 under findability (F2) stipulates that "data are described with rich metadata," and principle 1 under reusability (R1) stipulates that "(meta)data are richly described with a plurality of accurate and relevant attributes."

Ultimately, individual research disciplines or communities may each need to find their own consensus on the appropriate meaning of these terms. However, the concepts can still be included in a harmonized approach to evaluating FAIRness. Because they are not explicitly defined, the relevant indicators can be classified as "FAIR extension indicators."

Regarding the mention of "rich metadata" in F2, for example, in addition to assessing whether the metadata associated with a data object include the data usage license and data provenance, I recommend using extension indicators that assess whether the metadata include attributes that support discovery, data retrieval, and data access. Similarly, for R1, I recommend using extension indicators that assess whether metadata include attributes describing past or potential uses of a data set as well as other contextual information and information about data processing (i.e., all information that improves data reusability and reproducibility of results).

The specific attributes desired in each case might vary by discipline or application but could include, for example, links to the metadata records of previous releases of a data product, which help preserve these records even if the previous releases are taken offline. Other relevant attributes may include data quality flags and uncertainty estimates, which can be critical to downstream applications.

Meeting an Urgent Need

Given the growing demand for consistently assessing the FAIRness of digital data sets and resources, along with the evident differences among existing assessment frameworks, a harmonized set of fundamental indicators that work across fields and applications is urgently needed. Systematically decomposing the original FAIR Guiding Principles is an effective approach to producing granular and widely adaptable indicators. With a uniform assessment framework at hand, institutions and individuals who produce or manage data will have the tools they need to meet their obligations to ensure and demonstrate that their data are, indeed, as findable, accessible, interoperable, and reusable as possible.

Acknowledgments

G.P. is supported by NASA through the Marshall Space Flight Center (MSFC) Interagency Implementation and Advanced Concepts Team (IMPACT) project under a cooperative agreement with the University of Alabama in Huntsville (NASA grant NNM11AA01A). For more detailed information about decomposing the FAIR principles into harmonized indicators and for a complete list of the indicators, please visit bit.ly/FAIR-indicators or contact the author. Generation 2 (Gen 2) MIs from *Wilkinson et al.* [2019] are considered in this article. A GitHub page offers more information about these MIs (bit.ly/FAIR-maturity), and an online FAIRness evaluation tool based on these MIs is available (bit.ly/FAIR-evaluation). The version of the Research Data Alliance's FAIR Data Maturity Model considered here is the one released in June 2020.

References

Bahim, C., et al. (2020), The FAIR Data Maturity Model: An approach to harmonise FAIR assessments, *Data Sci. J., 19*(1), 41, https://doi.org/10.5334/dsj-2020-041.

Mons, B., et al. (2017), Cloudy, increasingly FAIR; revisiting the FAIR data guiding principles for the European Open Science Cloud, *Inf. Serv. Use, 37*, 49–56, https://doi.org/10.3233/ISU-170824.

Peters-von Gehlen, K., et al. (2022), Recommendations for discipline-specific FAIRness evaluation derived from applying an ensemble of evaluation tools, *Data Sci. J., 21*(1), 7, https://doi.org/10.5334/dsj-2022-007.

RDA FAIR Data Maturity Model Working Group (2020), FAIR Data Maturity Model: Specification and guidelines, Res. Data Alliance, Zenodo, https://doi.org/10.15497/rda00050.

Wilkinson, M. D., et al. (2016), The FAIR Guiding Principles for scientific data management and stewardship, *Sci. Data, 3*, 160018, https://doi.org/10.1038/sdata.2016.18.

Wilkinson, M. D., et al. (2019), Evaluating FAIR maturity through a scalable, automated, community-governed framework, *Sci. Data, 6*, 174, https://doi.org/10.1038/s41597-019-0184-5.

Wilkinson, M. D., et al. (2022), Community-driven governance of FAIRness assessment: An open issue, an open discussion [version 1; peer review: approved with reservations], *Open Res. Europe, 2*, 146, https://doi.org/10.12688/openreseurope.15364.1.

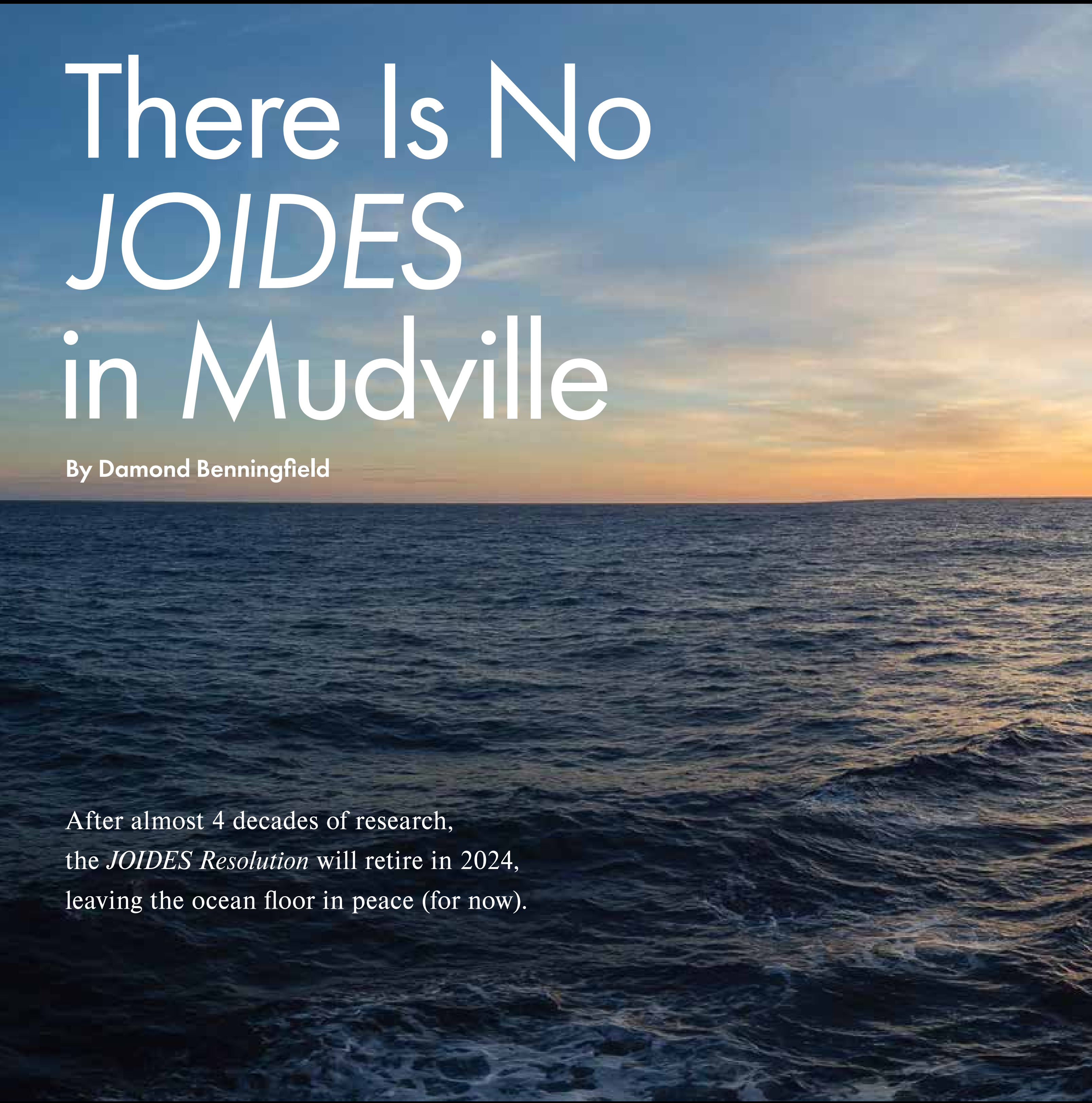
By **Ge Peng** (ge.peng@uah.edu), Earth System Science Center, University of Alabama in Huntsville

Read the article at Eos.org

There Is No *JOIDES* in Mudville

By Damond Benningfield

After almost 4 decades of research, the *JOIDES Resolution* will retire in 2024, leaving the ocean floor in peace (for now).



Sunset from the ocean drilling communitiy's scientific workhorse, the Joides Resolution *(JR), which is scheduled to be retired in September 2024. Credit: Tim Fulton, IODP JRSO*

For Kaustubh Thirumalai, a 2-month cruise aboard the research vessel *JOIDES Resolution* was "an experience that changed my life." Now an assistant professor of geosciences at the University of Arizona, Thirumalai was one of 30 scientists aboard the ship on a 2014 expedition that was drilling into sediments at the bottom of the Bay of Bengal to learn about the history of the South Asian summer monsoon.

Thirumalai worked 12-hour shifts 7 days per week as a sedimentologist on Expedition 353, nicknamed the "iMonsoon." He examined the core segments that plopped on deck every 45 or so minutes—"the best job on the cruise," he said.

"It's penny-wise and pound-foolish. It's not a tremendous amount of money, and the return on investment is huge."

The people he worked with "became like a family," celebrating the holidays with Christmas carols and a New Year's dance party and marking Thirumalai's birthday by wearing false mustaches to match his impressive 'stache. "The whole thing was like science camp, and that was awesome," he said.

Kaustubh Thirumalai, then a graduate student, holds a crushed core liner during JR *Expedition 353, in 2014. Credit: Kate Littler and IODP,*

The awesome experiences are about to come to an end. The National Science Foundation (NSF), which funds scientific ocean drilling, announced in March 2023 that *JOIDES* (*Joint Oceanographic Institutions for Deep Earth Sampling*) *Resolution* (JR) will retire in September 2024. The agency said a budget crunch, the end of an international agreement, and the pending expiration of the ship's current environmental impact statement left NSF with little choice.

"It's clear to us that the current model of U.S. scientific ocean drilling lacks international support, so we need a new model," said James McManus, director of NSF's Division of Ocean Sciences, during a 6 July 2023 virtual town hall meeting. "It's imperative that we start planning for the next phase of scientific ocean drilling now, because any plans will take time to fully realize."

Some scientists, however, have complained that NSF hasn't prepared for any real transition. It has no plans to build or acquire a replacement ship, and although the agency said it supports the idea of paying to lease drilling platforms for specific projects, it hasn't produced any specifics on how much it can spend on those efforts or when they might begin. In the town hall, McManus said that it's up to the scientists to tell the agency what they want and need.

"Pulling the plug without a plan for the future cuts us off at the knees," said Beth Christensen, who chairs the Department of Environmental Science at Rowan University in Glassboro, N.J. "To quote an old saying, it's penny-wise and pound-foolish. It's not a tremendous amount of money, and the return on investment in the science is huge."

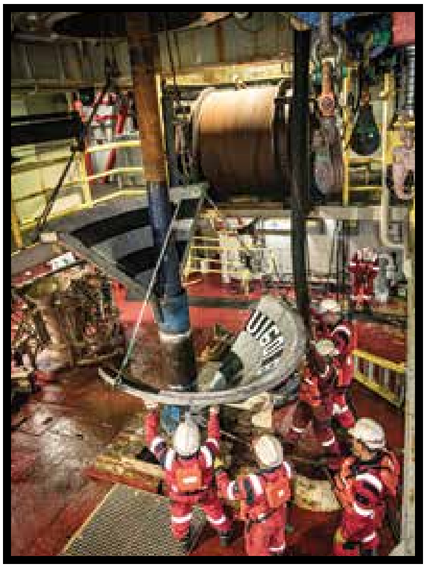
A Geology Department at Sea

JOIDES (pronounced JOY-deez) *Resolution,* which is a modified commercial oil exploration platform, made its first scientific expedition for NSF in January 1985. In the 4 decades since, the 143-meter ship has conducted research in every ocean, from the Arctic to the Antarctic. It can operate in waters up to almost 6 kilometers deep and drill cores up to 2 kilometers long, which can record hundreds of millions of years of Earth's history.

"Ocean sediments are relatively undisturbed," said Thirumalai. "They're shel-

"You can walk off the ship with a lot of data. With 800 meters of core, everyone finds something they like."

tered from rain, wind, rivers, and other processes, so we tend to get pristine records that we're just not able to get on land. We're looking into Earth's history book, and we have a much more complete book in the oceans."



Technicians work on the JR's drilling rig. Credit: Kelly Eric Bravo, IODP JRSO, CC BY 4.0 (bit.ly/ccby4-0)

"The *JOIDES* has honed and fine-tuned the ability to recover pristine core material in immensely complex environments, such as deep-sea locations, or to efficiently handle high core recovery," said Anna Joy Drury, a research fellow at University College London, who is studying the history of Earth's oceans and climate during the Mesozoic and Cenozoic periods.

Drury sailed on Expedition 363, in 2016, to the Western Pacific Warm Pool in the Indian and Pacific oceans. "I was part of the night shift, or sunrise shift, and my favorite time of day was to have my lunch on deck watching the Sun come up, before the majority of the ship woke up and swung into action," she said.

JR is equipped with labs that allow mission scientists to examine and process the cores, take thin slices for microscopic analysis, and conduct other experiments.

"It's possible to do a lot of analyses at sea," said Susan Q. Lang, an associate scientist at Woods Hole Oceanographic Institution who earlier this year was co-science leader of Expedition 399, "Building Blocks of Life." The ship journeyed to the Atlantis Massif, a region that's home to a large hydrothermal vent field at the Mid-Atlantic Ridge. The mission extended an existing borehole to a depth of about 2,000 meters and drilled a shallower one at a second location to provide insights into the chemistry that could have given rise to microbial life in the region.

Although most of the analysis begins months after the expedition, when core samples are parceled out to team members, "you can walk off the ship with a lot of data," Lang said. "With 800 meters of core, everyone finds something they like."

Although it was Lang's first trip on the JR, it was a melancholy experience, she said, because it was the first cruise after the retirement announcement. "Even boarding the ship, someone said, 'Oh, my goodness, this is the last time I'll be able to walk up the JR gangplank.'"

"It's like being in a geology department at sea," said Kenneth Miller, distinguished professor of Earth and planetary sciences at Rutgers University and a member of NSF's *JOIDES Resolution* Facility Board. "Everybody's working very hard, 24/7, in 12-hour shifts. After 30 or 40 days you're a little shell-shocked, but everybody's still working together very well."

Upending Conventional Wisdom

Ocean drilling has allowed scientists to probe many topics, from climate change to the evolution of life on Earth.

"A lot of what we know about Earth really comes from ocean drilling," said

Susan Lang takes a water sample directly from the core liner on the rig floor. Credit: Erick Bravo, IODP JRSO, CC BY 4.0 (bit.ly/ccby4-0)

Christensen, who has sailed on three JR expeditions. “Plate tectonics, rapid climate change, evidence for fast glacial advance and retreat, changes in ocean circulation, the pace of sea level rise and fall—I’ve wanted to sit down with a college textbook and a highlighter and highlight how much of environmental science or oceanography or geology is driven by ocean drilling. It’s almost incredible how much we’ve delivered to the citizens of Earth in terms of the understanding of our planet.”

“The whole realm of paleoceanography and paleoclimatology would not exist as it does now without ocean drilling,” said Lawrence Krissek, an emeritus professor of Earth sciences at The Ohio State University and chair of the JR Facility Board. “If you want a record of more than a million years ago, and a continuous record through time, that comes from the ocean floor.”

Contributions have included a better understanding of high–carbon dioxide periods driven by natural climate variations, Krissek said, along with a better understanding of the processes that drive earthquakes, the causes of changes in global sea level, and the subseafloor biosphere. “Twenty-five years ago, the conventional wisdom said there were no microbes below a few tens of meters. That’s not true. Almost everywhere we’ve drilled, as deeply as we’ve drilled, there’s life. Who knows what these bugs will tell us about the origin of life?”

Krissek sailed on eight JR expeditions, including its fourth, after traveling on the ship’s predecessor, *Glomar Challenger.* “I’m a frequent floater,” he quipped. “I’m sure it demonstrates some deep personality flaw, but I love to do cores. When we get to the end of a shift, if I can say, ‘We described 150 meters of core today,’ I get a certain satisfaction from that. That’s what took me to sea repeatedly.”

Krissek said he’s seen a lot of changes since his first trips aboard JR. “One big improvement is the ability to contact home,” he said, with a progression from ham radio to limited email to satellite telephone calls at $10 per minute (“you didn’t talk very often”) to today’s almost constant contact.

Not every day at sea was a good one, though. In 1995, during Expedition 163, which studied the process of ocean formation off the coast of Greenland, the ship was caught in a severe storm. “We had 60-foot-plus waves and 100-mile-per-hour-plus winds,” Krissek said. “One of the waves broke out a window on the bridge, so a whole bunch of water flooded in. If not for some quick action by the crew and some of the technicians, we could have been in big trouble.” The expedition was abandoned as JR returned to port for repairs.

Losing Expertise

Today the big trouble for *JOIDES Resolution* is money. In the 6 July town hall, McManus reported that expenses have ballooned over the past decade, with costs for the most recent fiscal year totaling $72 million. NSF receives a line-item appropriation of $48 million per year to fund JR, which is operated by Texas A&M University. Some of the costs are borne by Europe and Japan, partners in the International Ocean Discovery Program (IODP). Partner contributions, however, have dropped from $16.5 million in 2015 to $12.5 million in 2023, with even smaller payments expected in the future.

“NSF is in an extremely tight spot,” said Keir Becker, an emeritus professor of marine geosciences at the University of Miami. “The decadal survey in 2015 said that ocean drilling and the JR were very important, but it flagged the fact that the cost per berth was much higher for U.S. researchers than for the international partners. But they have their own fiscal constraints, so they couldn’t increase their contributions.”

Becker has logged 22 ocean drilling cruises, including 17 on JR, and about 40 additional research cruises. “I’ve spent almost 7 years of my life at sea,” he said.

“The biggest challenge will be the loss of expertise. We’ve built up a lot of institutional knowledge over the past 50 years. A lot of small decisions go into how to approach ocean drilling. We’re losing the group that has made these decisions day in, day out.”

The Sun sets off the stern of the JOIDES Resolution *as the ship sails toward Costa Rica in 2021. Credit: Robert L. Burger, NSF*

Becker's work has included installing instrument packages in boreholes drilled by JR and other ships. They record temperature, pressure, and other environmental factors, and some packages in subduction zones include seismometers. Some are tied in to undersea cable observatories, allowing them to transmit their observations in near-real time. The rest must be retrieved from the ocean floor. Becker has been on many of those recovery missions aboard submersibles.

In addition to the limited partner contributions, the IODP agreement is scheduled to expire in 2024. And even with additional funding, it probably would be too expensive to renew JR's environmental impact statement when it expires in 2028, the NSF has said, requiring a new ship or other arrangements.

The combination of limited funding and expiring agreements left the agency with few options, according to McManus—extend JR operations until 2028 (contingent on finding more money) or demobilize the ship at the end of September 2024, the end of the fiscal year. It chose the shutdown, which will take a few years to implement, as scientific gear will be stripped from the ship in preparation for return to its owner, Overseas Drilling Ltd, and cores will be archived for later analysis.

Some scientists have said the loss of the ship is secondary to the loss of the team that operates the ocean drilling program—roughly 130 employees at Texas A&M who plan the missions, maintain the JR and its instruments, travel with the ship, process and distribute cores, and handle many other tasks.

"The biggest challenge will be the loss of expertise," said Lang. "We've built up a lot of institutional knowledge over the past 50 years. A lot of small decisions go into how to approach ocean drilling, and it's a lot more complex than I could ever get up to. We're losing the group that has made these decisions day in, day out."

"We have this incredible cohort of lab technicians, program managers, drilling engineers, some of whom have been working on the ship since we started," said Krissek. "I do not know of any way we will be able to keep most of those people."

Chikyu*, a Japanese scientific drilling ship, will continue to operate, although it's not certain whether American researchers will be able to sail aboard it. Credit: Gleam/Wikimedia Commons, CC BY-SA 3.0 (bit.ly/ccbysa3-0)*

Looking for a Plan

Scientists and NSF are trying to determine the path of U.S. scientific ocean drilling after JR completes its final mission, currently scheduled for June–August 2024. A plan may depend in part on the recommendations of the next decadal survey from the National Academies; its interim report is due in late 2023 or early 2024. The previous ocean sciences decadal survey, along with a 2017 survey of ocean drilling scientists, found that JR was a valuable (though increasingly expensive) asset, and many current researchers expect the new report to reach the same conclusion. Without a ship, they say, the field will languish.

"I'm concerned about the U.S. essentially ceding the leadership role in this field that we've had for 50-plus years," Krissek said. "The U.S.-supplied vessel has been the workhorse in this field. Losing that capability has a large impact both on the U.S. research community and on global drilling efforts."

Current international partners offer some oceangoing capabilities that with NSF funding, American researchers might be able to use.

The Japan Agency for Marine-Earth Science and Technology operates a large drilling ship, the *Chikyu,* which, using a different technique, can drill deeper than JR. That technique is more expensive, however, and the ship is limited to only one or two cruises per year. The European Consortium for Ocean Research Drilling hires commercial platforms for specific missions, but finding an available ship can be tricky. In addition, there's no agreement to extend the current alliance beyond 2024.

NSF has proposed "legacy research" involving existing cores. At the end of each mission, each core is split in two. Half is passed along to researchers, and half is archived for future use, when new equipment and techniques will allow scientists to address new questions. The current collection includes about 475 kilometers of cores, split among three major repositories in Texas, Germany, and Japan. Many scientists already poke through these archives to address their own research topics.

"The concept of a legacy expedition has been percolating a while," said Drury. Such expeditions could allow teams to address big-picture issues that are beyond the scope of a single research cruise, she said, while providing greater access for more researchers.

They also could ensure that "critical knowledge transfer and talent pipeline within the marine geoscience community is not lost, by facilitating the training of future researchers," Drury said.

Others, however, wondered whether graduate students and early-career researchers will stick with the field if there are no chances to collect new samples.

"I'm especially concerned for the younger generation," said Becker. "I made my first cruise as a graduate student in the 1970s. That made my career. And I made a lot of contacts. Spending 2 months at sea with esteemed scientists from around the world, you keep those contacts your entire professional life."

"The cruises are a very good launchpad for early-career folks," said Lang. "But people go where the opportunities are [and] I think there will be a bit of a missed opportunity" for ocean drilling.

Thirumalai, still an early-career researcher himself, is a little more optimistic. "It's not a fatal blow," he said. "It's a big blow because ocean drilling is such an amazing thing. We've lost access to past Earths as a laboratory until we have another ship.... But I don't necessarily think this is a death note for scientific ocean drilling. I think the community recognizes how valuable it is. If the U.S. doesn't pick it up, someone else will."

Author Information

Damond Benningfield, Science Writer

Read the article at Eos.org

Sikumiut–People of the Ice by Jamesie Itulu and the Arctic Eider Society depicts Inuit stories, ice knowledge, and satellite imagery over Sanikiluaq, Nunavut. The piece was commissioned by the Canadian Space Agency's Satellite Art Gallery. Credit: Jamesie Itulu from Mittimatalik and the Arctic Eider Society; photos by Johnny Kudluarok, Mick Appaqaq, Johnassie Ippak, and Joel Heath. RADARSAT Constellation Mission imagery © Government of Canada (2021)

WHY—AND HOW TO—

Engage Artists in Science

By Kimberly Blaeser, Dwight Owens, Sarah Zhou Rosengard, Kathryn Semmens, and Mika Tosca

Breaking down the artificial barriers between science and art can lead to collaborations, broaden understanding of problems facing communities, and grow engagement to explore solutions.

“Together art and science communicate in ways neither can achieve alone.”

Does it ever feel like there’s something missing from your work that you can’t quite put your finger on—something that would bring more meaning and accessibility to your science? That missing element may be art.

Art and science have enjoyed a symbiotic relationship throughout human history. Over the past 2 centuries, Western society began perceiving these disciplines as more exclusive than complementary. But recently, rejection of this artificial separation has spurred a movement to recognize and revive mutually beneficial art-science collaborations.

Dovetailing Through Time

The superficial notion that art engages in expression whereas science engages in reason fed the split between art and science. In reality, the pursuits of each are more complex, and the overlap between the two is more substantial. Both scientists and artists are engaged in deeply observing and interpreting the universe.

Sculptor Sara Black, a professor at the School of the Art Institute of Chicago, has described humans as more than *Homo sapiens*—as “this other being, *Homo aestheticus,* [aiming] to understand the world around us and one another through metaphor and analogy.” Her perspective echoes that of Albert Einstein, a violinist himself, who wrote in *Living Philosophies* that “the most beautiful thing we can experience is the mysterious. It is the source of all true art and science.”

This mystery, and the synergy of art and science, was evident in the first known drawing of an American mastodon skeleton, created by French naturalist Georges Cuvier and published in *Recherches sur les ossemens fossiles de quadrupèdes* in 1821 (38 years before the publication of Darwin’s *On the Origin of Species*). On the basis of fossil bones found in the Ohio River Valley, Cuvier imagined through his sketching a long-vanished species and introduced a new concept—extinction—that would change the field of biology forever. Cuvier was the first person to establish extinction as a fact that any future scientific theory of life would have to explain.

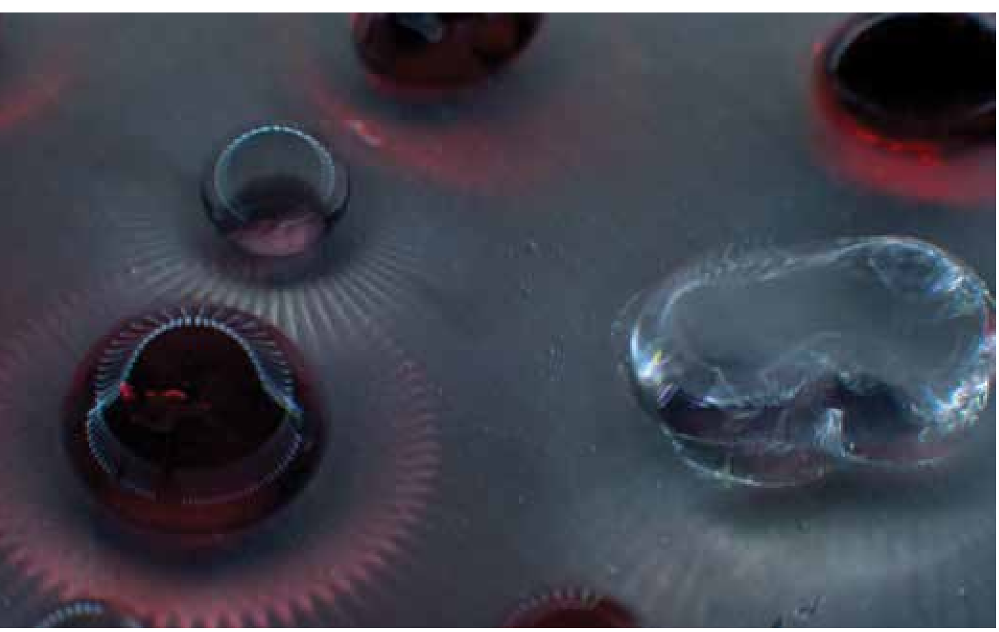
Cuvier’s drawings represent just one example of the myriad ways that art and science have dovetailed over centuries. Together art and science communicate in ways neither can achieve alone, and integrating art and science in research, engagement, and education efforts can expand the impact of any program or project.

Paul Slovic and Scott Slovic note in *Numbers and Nerves* that “anything that happens on a large scale seems to require that we use numbers to describe it, and yet numbers are precisely the mode of discourse that…leaves audiences numb and messages devoid of meaning.” And naturalist Aldo Leopold, in his 1949 book *A Sand County Almanac,* claimed, “We can only be ethical in relation to something we see, understand, feel, love, or otherwise have faith in.” For many, numbers are not enough to achieve this relationship. Enter: art.

Art can make scientific research and ideas accessible more broadly across society. It arouses emotions, illuminates connection to the world, and inspires action. Society ultimately benefits from art-science integrations as new ideas and approaches are increasingly seen as more engaging, hopeful, and relevant.

Finding Common Ground

In recent years, the arts have expanded into spaces where scientists network and exchange knowledge. Conferences have convened sessions exploring examples of synergies of art and music with science.



Still frame from the video work Water Organoids *(2022), which uses an “immersive microscope” to film and project an invisible reality of self-organizing water structures. The work, by Baudouin Saintyves and Kikù Hibino, was displayed at AGU’s Fall Meeting 2022. Credit: Baudouin Saintyves*

Scientific publishing platforms are embracing papers and commentaries on art in the lives of scientists. Science museums and research institutions are showcasing art galleries—such as the Canadian Space Agency's Satellite Art Gallery—to inspire scientific curiosity and advance scientific literacy. And that's just a sliver.

Globally, the idea of synthesizing art and science is attracting a larger audience as more scientists pursue interdisciplinary approaches to research and communication.

The depth of this growing interest was on display, for example, during AGU's Fall Meeting 2022, where interdisciplinary work was presented in on-site and virtual exhibits, a community poem elicited contributions from more than 100 conference participants from 13 countries (bit.ly/AGU22-poem), and an "Art and Science" plenary session attracted a large audience.

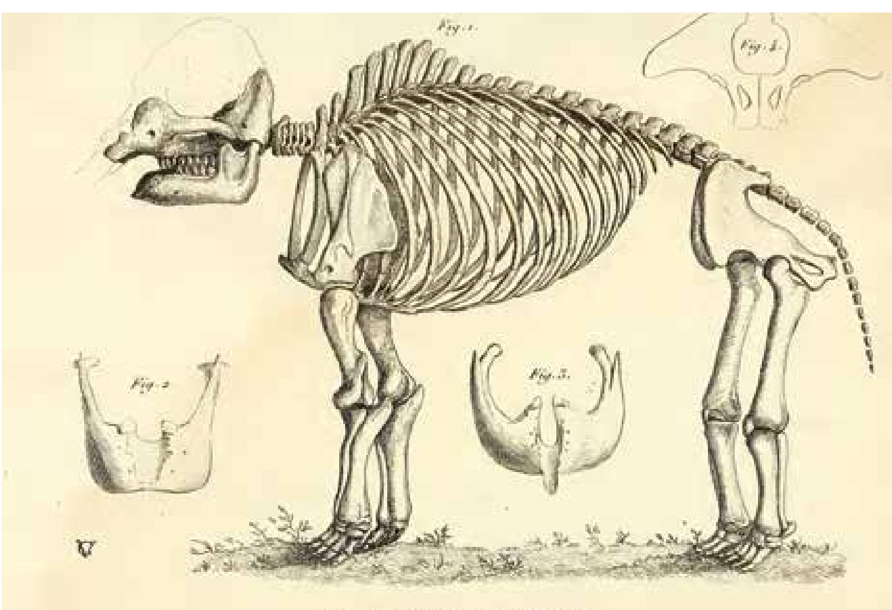
The plenary convened practicing artists and scientists, who shared views of and experiences with working across the art-science interface. Mika Tosca, a climate scientist at the School of the Art Institute of Chicago, described how art reaches us emotionally in ways that numbers cannot. She also highlighted how a solarpunk art ethos can help ground our response to climate change in joy and optimism instead of fear and despair. (Solarpunk is an art movement that broadly envisions how the future might look if we lived in harmony with nature in a sustainable and egalitarian world.)

Black noted the false narratives claiming "that scientists use one part of their brain and artists use another" and that "scientists need to do the serious work, get the information, then artists have to translate that to the public." She countered that "to become whole beings, we need both perspectives." She emphasized that artists and scientists have a responsibility to engage in "radical collaborations" that aren't just "a cool thing to do" but are essential in solving urgent challenges of our times, such as climate change.

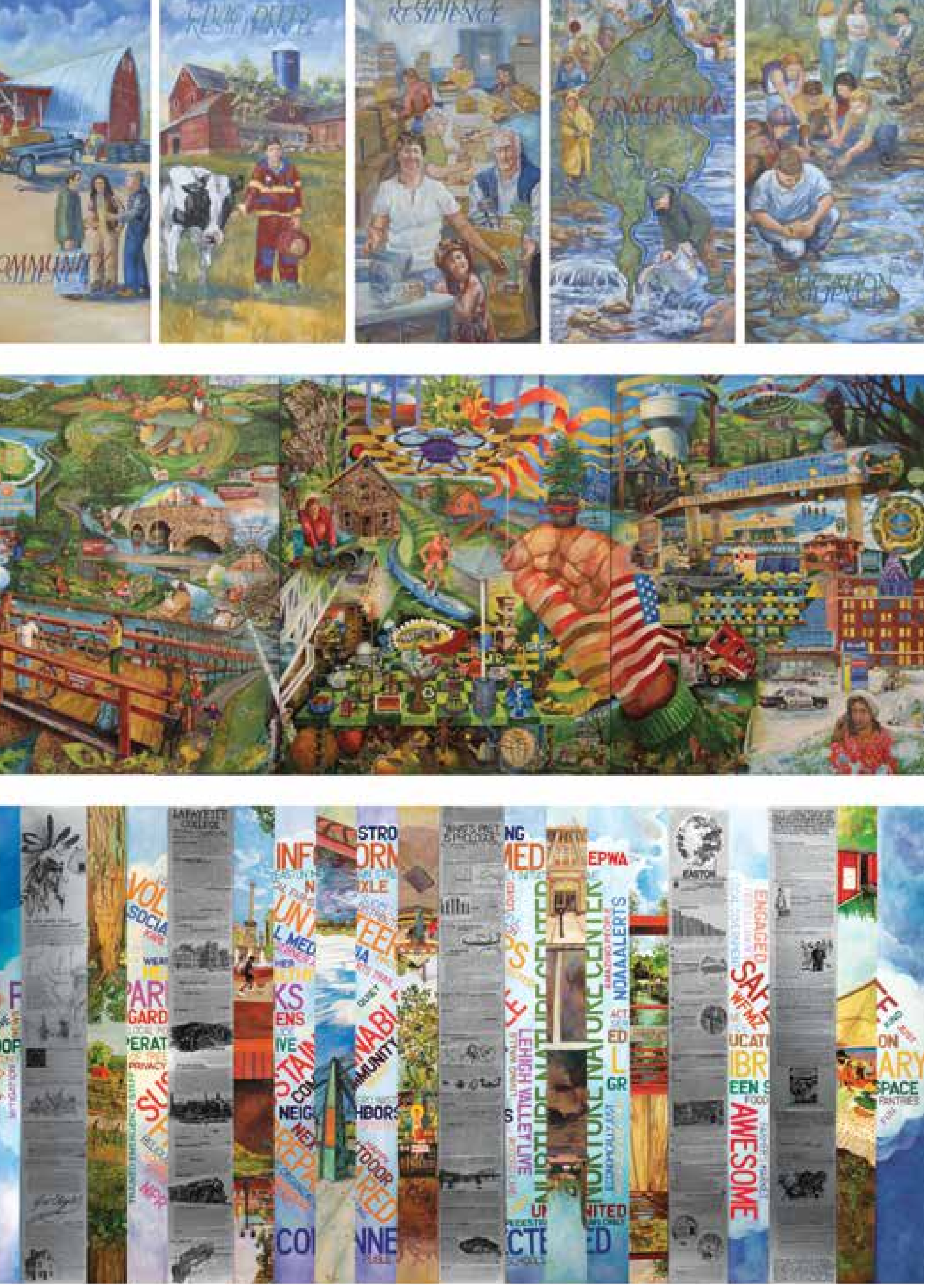
Baudouin Saintyves, a physicist, artist, and musician at the University of Chicago,

7000 Marks, *a sculpture by Sara Black and Amber Ginsburg, was installed during AGU's Fall Meeting 2022. The artists transformed a tanoak tree killed by sudden oak death disease into 7,000 pencils. This sculpture is used in community workshops that invite participants to address environmental anxieties through drawing and writing. Credit: Dwight Owens*

"The idea of synthesizing art and science is attracting a larger audience as more scientists pursue interdisciplinary approaches to research and communication."



Naturalist Georges Cuvier published this image of an American mastodon skeleton in 1821. Cuvier was the first scientist to articulate the concept of extinction, specifically by imagining how bones found in the swamps of the Ohio River Valley could constitute the skeleton of a nonextant species. Credit: Public Domain



Community visions of resilience appear in large murals for (top to bottom) Bangor, Wilson, and Easton, three communities in the Lehigh Valley in Pennsylvania. The murals were created by local artists as part of the CREATE Resilience project led by the Nurture Nature Center in Easton, Pa. Credit: Images courtesy of Nurture Nature Center. CREATE Resilience Murals by artists James A. Gloria (top), Don Wilson (middle), and Jackie Lima (bottom); CREATE Resilience is a project of the Nurture Nature Center, Easton, Pa. © 2022

described how he is "interested in questions first" and is "driven by aesthetics—something very common to both communities." He noted that artists and scientists both "love fancy tools" and "pushing their techniques." They often begin having fruitful conversations, he said, when they talk about these tools and methods.

Kimberly Blaeser, a poet, photographer, and professor emerita at the University of Wisconsin–Milwaukee, emphasized the similar "journey of inquiry" for both fields, "where you run into questions you had not expected, or contradictions."

Blaeser, who is Anishinaabe, is an enrolled member of the White Earth Nation of Minnesota, also described art and science in Indigenous cultures, noting how rituals pair ceremonial aspects like dance and song with environmental practices. The traditional harvest of wild rice, for example, includes reseeding, narrative teachings, and performative ceremonies that invite direct participation in both the art and science of sustainable natural food production.

"Beauty can also teach us things," she remarked, emphasizing the need for art to be both *affective* and *effective:* beautiful, but also "doing something in the world."

The final two panelists shared their individual experiences with art supporting direct action. Terry Evans, a photographer who resides in Chicago and Salina, Kan., related how her photos illustrate human predicaments in the face of industrialization and serve a pivotal role in inspiring community members to organize. Kikù Hibino, a Chicago-based sound artist, described efforts by courageous Japanese electronic musicians to oppose construction of a nuclear processing plant in their childhood community and recounted how that inspired him to become an artist.

How to Synergize Science and Art

There are several different modes of art-science collaboration. In science communication, or "SciComm," artists are recruited to help interpret and communicate scientific findings or conclusions for broader audiences. "SciArt" uses elements of science as inspirational seeds or media for artistic expression. Here artists may seek out scientists for access to tools and data to extend their artistic practice. A third mode, "ArtScience," involves artists and scientists working together in transdisciplinary ways to ask questions, design experiments, and formulate knowledge. This approach can expand perspectives and enable artists and scientists to step out of self-imposed disciplinary boundaries.

As Saintyves reflected during the Fall Meeting plenary, by "welcoming art in your process, you [the scientist] can make your questions evolve and also make your scientific work more connected to society."

In each of these modes, art can build bridges to bring community members into conversations involving science, helping to position them as knowledge holders and contributors. This process dissolves boundaries defining "who is the scientist" and enables equitable access and contributions to knowledge making.

There are many avenues for scientists and science organizations to collaborate actively with artists and integrate art and science deeper into scholarly work. Examples include artist residencies, community-building projects, joint publications, artivism (arts-driven activism), funding opportunities and grant programs, and different approaches to public engagement.

Artist residencies that invite artists to join scientific projects from their inception can be especially fruitful.

In one example, a chance encounter on the winter ice of Lake Baikal in 2017 led to an ongoing collaboration between Canadian sound artist Jol Thoms and the Neutrino and Dark Matter Group (also known as SFB1258) at the Technical University of Munich. Thoms serves as an artistic inspirer and adviser, supervising engagement between physics students and art students.

SFB1258, with Ocean Networks Canada, is also developing the Pacific Ocean Neutrino Experiment (P-ONE), which includes an ArtScience project that commissions compositions by musicians and sound artists. These compositions are transmitted in the deep ocean every full moon via a sound sculpture called Radio Amnion. Three other artists have also created and installed sculptures within some of the glass spheres that compose P-ONE test moorings.

Community and Collaboration

Community-building projects offer powerful opportunities for collaboration. The Nurture Nature Center in Easton, Pa., combines science, art, and community to engage local youths, artists, municipal leaders, and residents in the cocreation of a vision for community resilience while also enhancing knowledge of weather and climate science, hazard risks, and strategies for hazard mitigation.

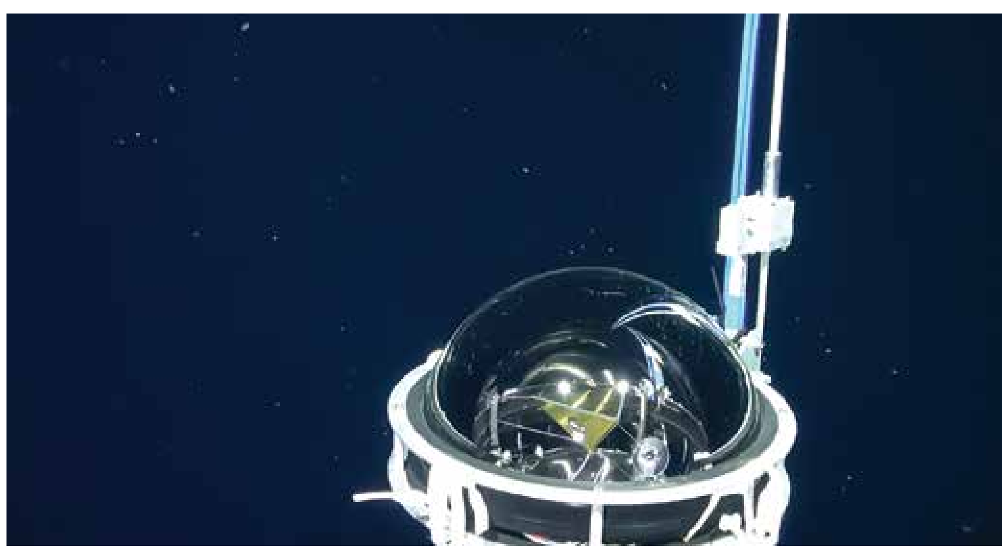
Through storytelling, forums, and other activities, participants collaborated with artists Jackie Lima, Don Wilson, and James Gloria to create large murals illustrating the community vision for three Pennsylvania communities. The murals highlight how art-science collaborations can help develop positive narratives about ideal futures and common goals to the benefit of public health and social cohesion.

Community-driven, science-informed art can also help communities heal after natural disasters by creating avenues for communication and connection and encouraging community members to gather and dialogue in public spaces.

Community building through art-science collaborations can leverage diverse knowledge sources, perspectives, and research priorities in the scientific process. For example, the Center for Limnology at the University of Wisconsin–Madison is creating space for youth artist mentees in its research projects via the Drawing Water program to "encourage the next generation to link art and science to generate a richer and wider value system." Their projects incorporate participants from the sovereign tribal nations of Wisconsin and the Tribal Natural Resources Department of Lac du Flambeau.

In addition to diversifying perspectives, art and science can pave the way for historically marginalized communities to drive research questions and design solutions. Recipients of the 2022 E(art)H Chicago grant, for example, showcased environmental challenges in Chicago by exploring intersections of art and environment. Projects ranged from the Filament Theatre bringing nature to youth in southeastern Chicago through a forest-themed

"In addition to diversifying perspectives, art and science can pave the way for historically marginalized communities to drive research questions and design solutions."



Every full moon, the Radio Amnion sound sculpture transmits new compositions by contemporary artists into the abyssal depths of the Cascadia Basin, 2,700 meters beneath the surface of the northeastern Pacific Ocean. The apparatus is housed within a glass sphere attached to the P-ONE neutrino telescope experiment's calibration system. Credit: Ocean Networks Canada, CC-BY 4.0 (bit.ly/ccby4-0)

A glint of water through the trees. Credit: Dwight Owens

performance to art-making workshops along the Rio de Bienvenida/River of Welcome (i.e., the South Branch of the Chicago River) with artists Cynthia Weiss and Delilah Salgado.

Support for community-driven work through art-science synergy is also illustrated by the SmartICE project, which extends across Indigenous communities of the Canadian Arctic and centers on ice knowledge. One dimension of SmartICE's work relies on Mittimatalik artist Jamesie Itulu's illustrations to share intergenerational knowledge of ice travel and safety more widely. The project highlights the important role of art in mobilizing Indigenous science and community knowledge of climate and ice.

Synergies to Solutions

The synergy of art and science provides opportunities to explore solutions to "wicked problems" such as climate change. In 2013, oceanographer Gregory Johnson presented key ideas from the Intergovernmental Panel on Climate Change's Fifth Assessment Report through 19 haiku and watercolors, making the dense report accessible to a much larger global audience.

ArtScience residencies can also serve as tools for exploring solutions through a combination of activism, futuring, and policy advising. An example is the *Tomorrow Is Already Here* exhibition held at the Headlands Center for the Arts in Sausalito, Calif., in 2020.

This exhibition summarized two thematic residencies that brought together artists, scientists, policymakers, and activists to consider solutions to climate change inequity via art making and imagination. Visual artist and Headlands Center program manager Aay Preston-Myint writes in the exhibition catalog, "The hope of this work is to produce a discourse which not only accepts climate change as truth (an unfortunately low bar)" but also fosters excitement, curiosity and determination in facing its challenges.

In *When Words Fail,* climate scientist Bill McKibben contends, "We haven't come up with words big enough to communicate the magnitude of what we're doing [to the climate]." Art can help bridge this gap.

Inspired yet? The above examples represent just the tip of the iceberg and will help keep us open to the possibilities and connections that art and science can bring as we study, imagine, and actualize a better world.

The urgent challenges of our time, like climate change, may seem insurmountable. However, Octavia Butler reminds us in her novel *Parable of the Sower,* "The world is full of painful stories. Sometimes it seems as though there aren't any other kind and yet I found myself thinking how beautiful that glint of water was through the trees."

Author Information

Kimberly Blaeser, University of Wisconsin–Milwaukee; **Dwight Owens,** Ocean Networks Canada, Victoria, B.C.; **Sarah Zhou Rosengard,** School of the Art Institute of Chicago, Ill.; **Kathryn Semmens** (ksemmens@nurturenature.org), Nurture Nature Center, Easton, Pa.; and **Mika Tosca,** School of the Art Institute of Chicago, Ill.

Read the article at Eos.org

iStock.com/John Law

THE ART OF Scientific Curation

BY KAYLIN BUGBEE, DEBORAH SMITH, STEPHANIE WINGO, AND EMILY FOSHEE

Scientific content curation provides users across diverse disciplines and levels of experience with a valuable means of accessing relevant and reliable information amid the growing data landscape.

At the end of *Raiders of the Lost Ark*, the mysterious Ark of the Covenant, recently recovered by Indiana Jones, is boxed up in a plain wooden crate and carted into a massive warehouse filled with countless stacks of similar crates. As the cart disappears around a corner in the warehouse, viewers are left to wonder what it would take to find the ark again.

The premise of this scene offers an apt analogy for what can happen to data—even valuable, hard-won data—stored in databases without adequate organization. For both experienced and novice scientists, navigating the information landscape to find such "hidden" data that are relevant to their research can require extraordinary efforts.

In today's open science environment, careful curation of data, software, documents, and other elements of the scientific knowledge ecosystem is essential for researchers to efficiently sift through the vast, ever increasing volume of information. Curation provides context and clarity around information, making it more findable and usable. Curated guidance also improves data and information accessibility. When done well, curation accelerates research progress and yields greater transparency in the scientific process and trust in scientific knowledge.

Here we explore the concept of scientific content curation and its value for enhancing the discovery and use of scientific data and information, focusing on two use cases within NASA.

What Is Scientific Content Curation?

In the art world, curation refers to the selection, organization, and presentation of works of art in a collection or exhibit. Curation can similarly refer to the organization of online content or information. In this context, content curation has been described as the act of discovering, gathering, and presenting digital content that surrounds specific subject matter. We build on this and other definitions to define scientific content curation as involving authoritative experts who identify, gather, validate, synthesize, organize, and present contextual details necessary to discover, understand, and use scientific data and knowledge effectively [e.g., *Rotman et al.*, 2012].

Essentially, scientific content curation is a value-adding effort. It includes any activity or process that accelerates progress toward actionable science or makes it easier for diverse audiences to digest scientific information. The scope of this curation is not limited to data and publications—it also includes detailed contextual information appearing in sources that often are not well preserved over time. Such sources can include literature that is made available outside traditional channels (e.g., scholarly journals) as well as tables, figures, diagrams of vital information, personnel lists, blogs from trusted sources, and other nonreviewed content.

Effective scientific content curation is guided by subject matter experts who validate and synthesize relevant and reliable information on given topics. These experts use a structured methodology to streamline research activities for data and information seekers. This process fosters confidence and trust among users of the curated content because they understand that trusted individuals or teams are responsible for it.

When done well, curation accelerates research progress and yields greater transparency in the scientific process and trust in scientific knowledge.

The Need for Curation

With the continuing expansion of scientific content, advances in technology, and policies that increasingly favor open science, more data and information are available to researchers than ever before. The sheer amount of information can confound and confuse anyone, especially those new to research or those delving into a new discipline.

Unfortunately, the proliferation of predatory publishers, sham societies, and bogus conferences complicates the information landscape by making it easier to disseminate authoritative-looking, but ultimately unreliable, material.

A lot of skill is required to search the mass of content to extract authoritative, authentic, and reliable data and information—a critical first step to addressing any science question. This effort can be lengthy and arduous. Researchers often repeat information collection efforts that others have done before them, diverting time and attention from other important research tasks. Through the process of identifying and providing relevant context about data and information, scientific content curation helps users navigate this vast landscape, facilitating more efficient scientific discovery by streamlining the initial research steps.

Models of successful scientific content curation are found across the sciences. The Smithsonian Astrophysical Observatory's Astrophysics Data System and the Smithsonian National Museum of Natural History's Encyclopedia of Life are good examples. Meanwhile, two ongoing NASA projects, the Catalog of Archived Suborbital Earth Science Investigations (CASEI) and the Science Discovery Engine (SDE), offer model use cases for scientific content curation in the Earth and space sciences. These efforts were each developed to meet the needs of particular communities, and in practice, they promote discovery of NASA data and information across a range of disciplines.

A Home for Suborbital Science

Since September 2018, NASA's Airborne Data Management Group (ADMG) has been building CASEI, a scientifically curated inventory containing more than a half century of NASA Earth science observations collected from airborne and field (i.e., suborbital) campaigns to improve on existing information search capabilities.

These observations have the potential to support new science investigations beyond the questions the data were originally collected to address. However, data users have reported that these observations are difficult to discover, access, and use because airborne and field investigation data are recorded in a wide variety of formats, coordinate systems, and spatiotemporal resolutions, using various data archival processes, metadata, and complex motivating and situational details [*Earth Science Data Systems*, 2018; *Smith et al.*, 2020]. Furthermore, airborne and field data are stored across a distributed network of data centers, each focused on different thematic topics of study and using different approaches to data stewardship.

These factors compound to create an inconsistent and cumbersome discovery process.

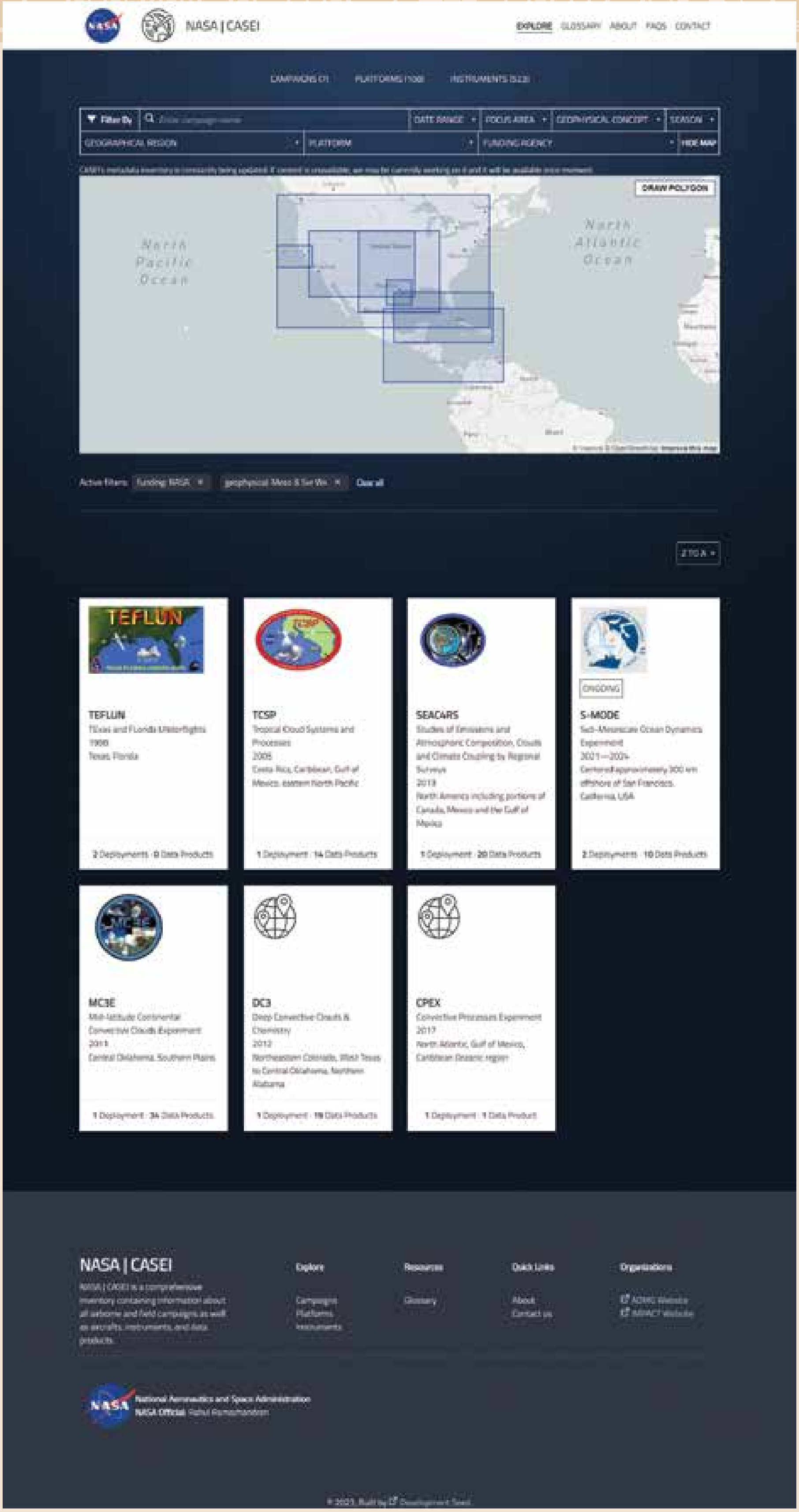
CASEI has a user-friendly application programming interface that enables users to browse, search, and filter database content easily, and it is based on a metadata model informed by user community needs. The CASEI model includes substantially more metadata than is typically gathered for data products added to the metadata registry behind NASA's Earthdata Search, the primary tool for searching NASA Earth science data. CASEI metadata include regions of study, significant event descriptions, vertical regions of observation, surface types, and other details that allow users to target subsets of the full data record quickly or to relate information and data across multiple campaigns.

For example, imagine researchers are interested in investigating effects of aerosol and chemical species on cloud development specifically in coastal regions. Metadata in CASEI make it easy to identify existing campaigns that collected aerosol, chemistry, and cloud-targeted observations over coastal geographies.

CASEI does not host or archive data products but, rather, serves as a curation service by pointing users directly to data stored at various NASA data centers (called Distributed Active Archive Centers, or DAACs). Curation for CASEI is performed by ADMG team members who are trained in the technical aspects of CASEI curation and understand the heterogeneity and complexity of airborne and field data.

The curation process begins with an examination of authoritative data and information sources such as peer-reviewed literature, field reports, campaign event summaries, and instrument operation tables. This review helps team members gather, validate, and synthesize critical contextual metadata associated with data sets that can extend observations' usefulness and support future science understanding via appropriate data use in new analyses.

Terms used in organizing and referring to airborne and field campaigns vary across disciplines and over time. To create the CASEI inventory, curators need to identify how to fit the existing campaign information into the catalog's metadata model. Curators use objective decision trees to ensure that they make consistent determi-



The Catalog of Archived Suborbital Earth Science Investigations (CASEI) improves access to and discovery of more than 50 years of NASA's Earth science airborne and field information and data. CASEI has a user-friendly application programming interface that enables users to browse, search, and filter database content easily.

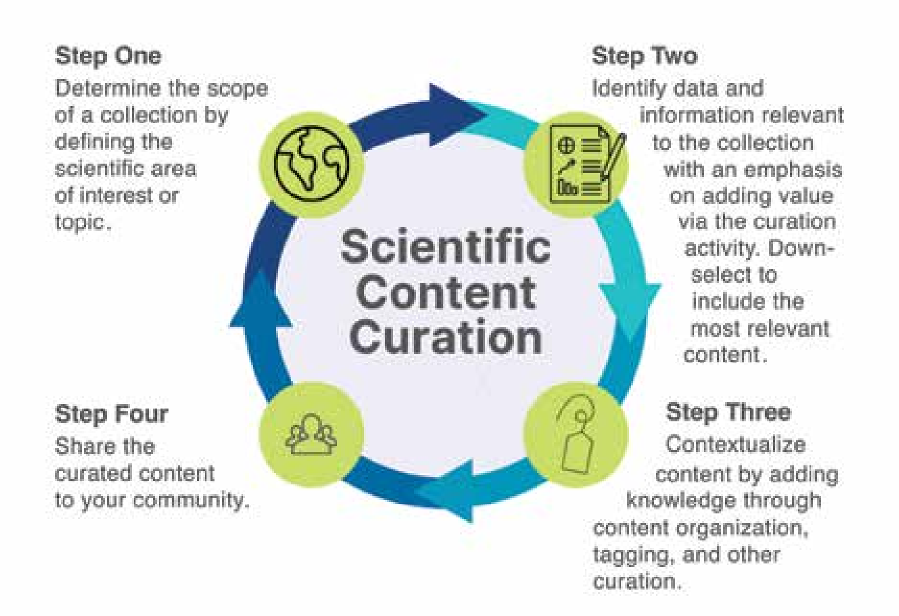


Fig. 1. Scientific content curation can be considered a cycle of several generalized steps. The scope of a curation effort is first determined on the basis of the needs of a community or use case. After relevant data and information are gathered, synthesized, and contextualized, a curated collection is shared with the user community. Feedback from that community restarts the cycle by helping to drive refinements and new content creation. Actual implementations of this cycle for specific projects are more detailed and nuanced.

nations in translating existing information in use to the CASEI definitions and metadata model [*Wingo and Smith*, 2023]. Three curators then fully review all metadata before content is published to the CASEI database.

To maintain content accuracy over time, curators complete quarterly database updates. These updates include maintaining compliance with standardized science keywords, adding new data products for active campaigns, and including URLs to new peer-reviewed publications. CASEI user interface updates and added features and capabilities are also developed, on the basis of user feedback. For example, developers are currently working on adding maps containing stationary platform locations and moving platform tracks.

The CASEI catalog was officially released in July 2023.

An Engine for Discovery

NASA's Science Mission Directorate (SMD) encompasses studies in five broad topical areas: astrophysics, biological and physical sciences, Earth science, heliophysics, and planetary science. A large variety of data, documents, images, models, tools, software, and code across these topics exists under the umbrella of SMD, but it is scattered across numerous archives, repositories, and websites, making data and information discovery a challenge.

Starting in early 2022, NASA's Open-Source Science Initiative developed SDE to support the agency's goals of increasing the availability, discoverability, and accessibility of open, interdisciplinary information. SDE provides a single access point for curated data and resources from across SMD's five subject areas.

Flexible filtering options—which currently include platforms, instruments, and missions and will be expanded to include other key concepts—provide a layer of organization and guide users to explore SDE content more effectively. With SDE, a user searching for information about galaxies could, for example, filter resources by specific platforms, such as the Hubble and James Webb space telescopes.

The curation process for SDE involves collaboration with subject matter experts to identify and add contextual knowledge to relevant tools, documents, data and image metadata archives, code repositories, and software available in existing but scattered locations. This task is challenging and time-consuming because of the sheer volume of information and because data and information are sometimes duplicated at multiple sites, websites go unmaintained, and hyperlinks are broken.

Content curation at SDE is ongoing as more data and resources are identified and incorporated. In addition, the SDE team curates the search term lists within each filtering option. Significant effort is required to create and maintain the term list for each filter, which synthesizes existing terms across SMD's scientific topic areas, but the context these filters provide is invaluable for new users.

The beta SDE, which is regularly growing as more content is added, was released at AGU's Fall Meeting 2022 in Chicago and currently holds more than 700,000 searchable documents, including 84,000 metadata records.

The Scientific Content Curation Cycle

Scientific content curation works best as a living activity that is repeated over time (Figure 1).

The cycle begins with the identification of a need or use case from the community. The use case highlights trends, topics of discussion, or gaps in knowledge and is essential for defining the scope of a curation effort. For example, creation of SDE was driven by an identified need to aid discovery of NASA's open science data and information and enable interdisciplinary science.

Once the use case is defined, human subject matter experts and/or artificial intelligence (AI) techniques are applied to identify related data and information and add value for users by selecting only the most relevant content. Further value and knowledge are added to this content through effective organization, annotation, visualization, and distillation of information into more understandable formats [*Dale*, 2014].

A curated collection is then shared with the user community—via integrated search platforms, web pages, online learning environments, or crowdsourced science portals—to enhance understanding of and access to the information. Community feedback drives additional content creation, beginning the curation cycle again.

Maintenance is essential to ensure that a collection remains up-to-date and continues to bring value to the community. There is a delicate balance, however, between the scientific value gained through maintaining curated content and the costs of doing so.

On the one hand, a curated collection represents a focused source of reliable knowledge and a significant investment of time and effort that should be recognized, valued, and incentivized. Ensuring the longevity of collections, along with the ability to cite them, aids in recognizing curator contributions, provides transparency, and fosters trust among users.

On the other hand, the costs associated with maintaining a curated collection indefinitely, which include those of the necessary infrastructure and the added effort to keep a collection fresh and relevant, can become unsustainable. For example, since 2016, administrators of the Climate Data Initiative (CDI) [*Ramachandran et al.,* 2016], a curated collection of federal government data relevant to climate change questions, have struggled to maintain the collection with the minimal support they receive. CDI originally curated more than 700 data sets but now maintains only 570.

Many questions must be considered to determine whether and how long to maintain curated resources. What commitments must be made to preserve them? Are decisions driven by metrics alone—and if so, what metrics—or are there other factors to weigh? And how can community needs for information be met most efficiently and with potentially limited support?

The scientific and data management communities must prioritize scientific content curation, which means recognizing and rewarding contributors' efforts, valuing the process, and preserving the outcomes

The Future of Curation

Scientific content curation takes many forms, including the following:

- aggregating existing information that's relevant to a use case (as in CASEI, CDI, and SDE)
- thoughtfully distilling aggregated content to guide users to enhanced understanding (as in Earthdata Pathfinders)
- bringing together new or previously unconnected content (e.g., curation around a topic like "landslides across the solar system") to create new perspectives
- developing new content to enhance existing curation efforts (e.g., adding campaign timelines to CASEI)
- applying AI and machine learning techniques to improve curation efficiency (as in ES2Vec [*Ramasubramanian et al.,* 2020], an Earth science–specific adaptation of Word2Vec, which transforms individual words into numerical representations for use in an AI algorithm)

Given the exponential growth of information availability, as well as growing pushes to improve transparency and equitable access to science outcomes, scientific content curation in all its forms is becoming increasingly vital. It is no longer feasible for a single human to effectively search through and assess the vast amounts of information available on a topic.

New curation approaches are being identified and leveraged as state-of-the-art technologies are developed and as more, sometimes underserved, communities join scientific efforts. These new approaches are helping scale up curation efforts to keep up with content growth and demands for rapid open access to data and information.

Recently, AI, machine learning, and natural language processing (NLP) have shown promise; examples include the use of NLP to improve gene annotations and text mining techniques to curate biomedical research [*Ohyanagi et al.,* 2015; *Alex et al.,* 2008]. However, for AI to be effective, it must be used in tandem with human expertise to train AI algorithms and validate their outputs.

Ensuring that this human expertise is available is a challenge. Scientists already face mounting demands on their time, including vying for increasingly competitive and constrained financial support and meeting expectations for faster, more open scientific outputs. Participating in curation as a subject matter expert only increases responsibilities. So how can we continue engaging scientists in this work?

As a start, the scientific and data management communities must prioritize scientific content curation, which means recognizing and rewarding contributors' efforts, valuing the process, and preserving the outcomes. To do this, the data management community must move beyond simply archiving data and instead focus on providing enhanced services to user communities. This involves fundamentally changing how we staff and operate repositories, with technologists and scientists working together. In addition, institutions should expect funding requests in scientific proposals to enable essential activities of scientific content curation. Finally, a method is needed to credit the work of scientific content curators—perhaps one similar to crediting work that goes into producing data sets.

Through such efforts, we can improve the long-term sustainability of well-organized, curated scientific repositories that help make sense of the vast information landscape, open more equitable access to information, and foster the interdisciplinary work needed to address many challenges facing the world today.

We can also ensure that valuable, hard-won data and information don't end up like the ark in *Raiders,* gathering dust in the dark and lost to time.

References

Alex, B., et al. (2008), Automating curation using a natural language processing pipeline, *Genome Biol., 9,* suppl. 2, S10, https://doi.org/10.1186/gb-2008-9-s2-s10.

Dale, S. (2014), Content curation: The future of relevance, *Bus. Inf. Rev., 31*(4), 199–205, https://doi.org/10.1177/0266382114564267.

Earth Science Data Systems (2018), Management of airborne data products: Challenges and recommendations, version: February 27, 2018, NASA, Washington, D.C.

Ohyanagi, H., et al. (2015), Plant Omics Data Center: An integrated web repository for interspecies gene expression networks with NLP-based curation, *Plant Cell Physiol., 56*(1), e9, https://doi.org/10.1093/pcp/pcu188.

Ramachandran, R., et al. (2016), Climate data initiative: A geocuration effort to support climate resilience, *Comput. Geosci., 88,* 22–29, https://doi.org/10.1016/j.cageo.2015.12.002.

Ramasubramanian, M., et al. (2020), ES2Vec: Earth science metadata keyword assignment using domain-specific word embeddings, in *2020 SoutheastCon,* pp. 1–6, Inst. of Electr. and Electron. Eng., Piscataway, N.J., https://doi.org/10.1109/SoutheastCon44009.2020.9249743.

Rotman, D., et al. (2012), Supporting content curation communities: The case of the Encyclopedia of Life, *J. Am. Soc. Inf. Sci. Technol., 63,* 1,092–1,107, https://doi.org/10.1002/asi.22633.

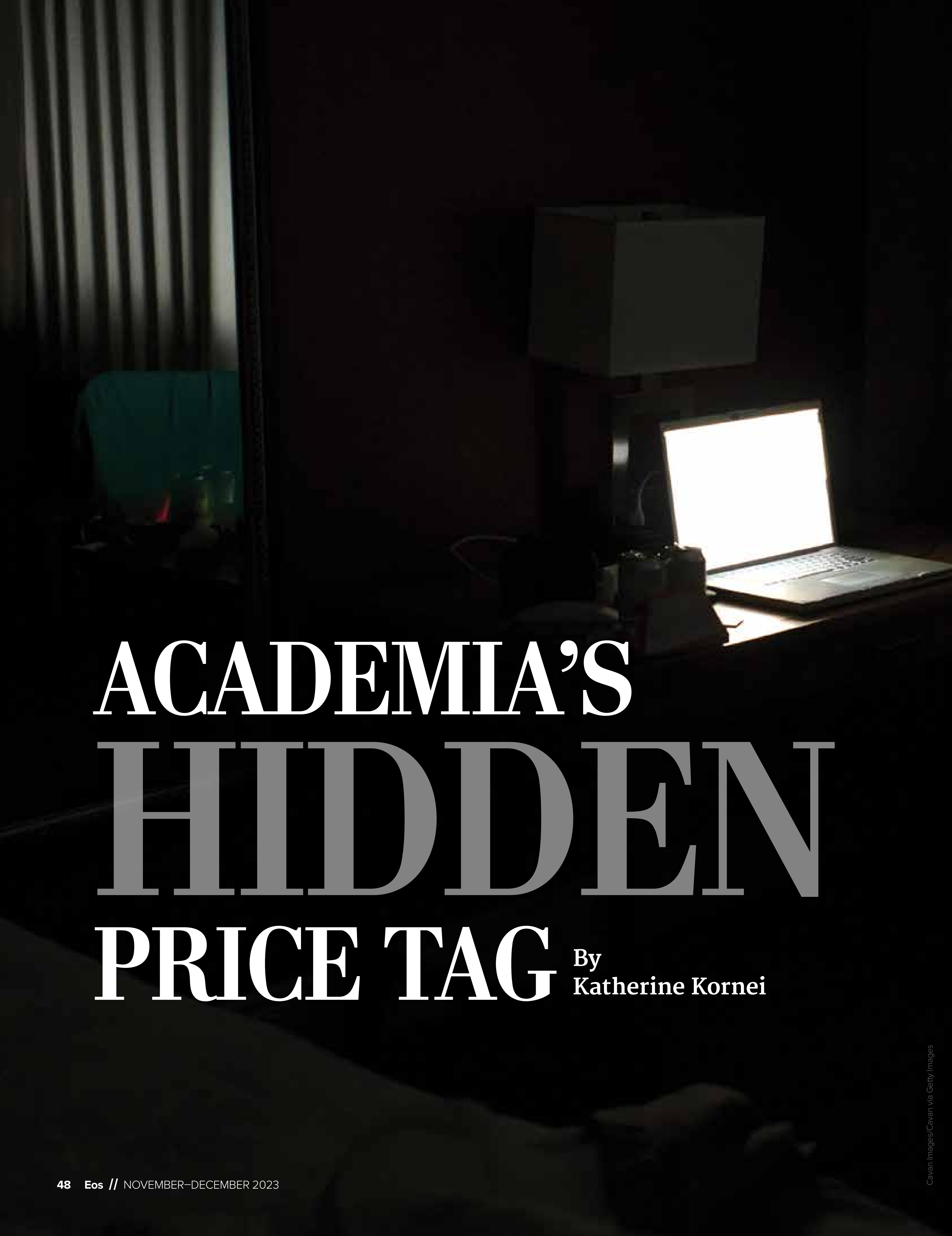
Smith, D. K., et al. (2020), Construction of an airborne data inventory for improved data discoverability and access, paper presented at AMS Annual Meeting 2020, virtual, Am. Meteorol. Soc., ntrs.nasa.gov/citations/20200000477.

Wingo, S. M., and D. Smith (2023), ADMG CASEI Inventory Terms Definitions, NASA Earth Sci. Data and Inf. Syst. Stand. Coord. Off., https://doi.org/10.5067/DOC/ESCO/ESDS-RFC-047v1.

Author Information

Kaylin Bugbee (kaylin.m.bugbee@nasa.gov), NASA Marshall Space Flight Center, Huntsville, Ala.; and **Deborah Smith, Stephanie Wingo,** and **Emily Foshee,** University of Alabama in Huntsville

Read the article at Eos.org



ACADEMIA'S HIDDEN PRICE TAG

By Katherine Kornei

Cavan Images/Cavan via Getty Images

Many academics feel burdened by overwork, but change is afoot as scientists strive to shift the culture of higher education.

For Nicole Gasparini, the constant pressure to keep working manifested early in graduate school. Long hours reading papers, analyzing data, and coding models felt like the norm in academia. There was simply the expectation that

Researchers working with theoretical astrophysicist Sera Markoff enjoy a group retreat at a farm outside Amsterdam in 2018. Credit: www.seramarkoff.com

everyone would overwork. "I was so stressed and nervous," she said. "Nearly every single day, I got sick in the bathroom."

Gasparini is a geomorphologist and professor at Tulane University in New Orleans, and even now, 2 decades after defending her doctoral thesis, it's still tough for her to shed the mindset of overworking. "I have tenure, and I still work myself way too hard," she said.

The flexibility and freedom that some say characterize academic pursuits often come with a hidden price tag: overwork. Many academics feel pressure to put in far more hours than are healthy or even necessary for success.

In light of data linking overwork with adverse mental and physical health effects, some scientists are beginning to acknowledge—and address—the far-reaching repercussions of potentially harmful work habits. And many try to encourage their students to internalize a safer and more balanced work life, even if doing so runs counter to a mindset that's deeply ingrained in the culture of higher education.

The Tolls of Overwork

Across a wide variety of careers, researchers have demonstrated again and again the detrimental effects of working substantially more than a standard 40-hour week.

For starters, overwork has been linked to diminished productivity: An oft-cited study of British munitions workers in the early 20th century showed that when employees logged more than 49 hours per week, their hourly output started to taper off.

Overwork takes a toll on mental health as well as on productivity: Longer working hours have been linked to increased rates of depression and anxiety. But academics often view personal suffering as a badge of honor, researchers found when they surveyed graduate students in the United Kingdom. One student reported, "There is a common belief…you have to suffer for the sake of your Ph.D.; if you aren't anxious or suffering from impostor syndrome, then you aren't doing it 'properly.'"

Working much more than 40 hours per week has also been linked to increased mortality. A recent study conducted by the World Health Organization and the International Labour Organization reported that a higher-than-average workload—more than roughly 55 hours per week—results in higher levels of stress hormones that in turn trigger behavioral responses such as increased tobacco and alcohol use, unhealthy dietary choices, decreased levels of physical activity, and impaired sleep. Corresponding upticks in the rate of heart disease and stroke linked to those behavioral responses claimed more than 740,000 lives in 2016, the researchers concluded.

Recent trials of shorter workdays—around 6 hours, rather than the typical 8—have reported increased job satisfaction, reduced usage of sick leave, and higher worker productivity.

Despite the sobering data—and mandates such as the European Union's Working Time Directive, which bans people from working more than 48 hours per week on average—overwork continues to proliferate. It's been documented in fields as disparate as health care, finance, and teaching, but it's not hard to see why it also readily crops up in academic settings.

A Culture of Overwork

Unlike many workers who have prescribed job schedules, researchers in academic settings generally aren't expected to report to their proverbial desk by a certain time and stay there for a set number of hours. There's accordingly no defined beginning and end to an academic's workday, which means that it's up to individuals to dictate their own schedule. That freedom could easily be viewed as a privilege—and it is, researchers such as Gasparini readily acknowledge—but it also comes with a catch: Academics are faced with a constant flood of work that's seemingly capable of inundating a researcher's time.

Academics typically take on a wide range of commitments related to research, teaching, and service. A researcher's week might include everything from collecting data to writing a paper to teaching to mentoring students to applying for grant funding to serving on committees.

A steady slew of responsibilities demand a scientist's time and attention, said Sera Markoff, a theoretical astrophysicist at the University of Amsterdam. "You're asked to do more tasks than you have hours for."

Markoff estimated that she devotes between 50 and 60 hours each week to her job. She isn't unique: A 2021 study conducted by the Organization for Economic Co-operation and Development found that nearly 80% of scientific researchers worked more than 40 hours per week.

The COVID-19 pandemic exacerbated the problem. A study of more than 150 academics found that people worked 3 more hours each week on average in 2020 compared with 2019. That bump in workload was mainly due to having to adapt to interacting with students remotely, the team concluded.

And though long work hours might seem par for the course for early-career scientists eager to prove themselves worthy of a permanent position, more senior academics aren't immune to the problem of overwork. If anything, career advancement means more demands on one's time, Gasparini said. There are suddenly committees to chair, new courses to develop and teach, and graduate students and postdoctoral scholars to mentor. And academics feel pressure to do everything, she said, because they often have a lurking sense that they could be replaced. (Far more Ph.D.s are minted each year than there are permanent academic positions.)

"Despite having to go to school until you're 30 years old and then having to do God knows how many postdocs, you're still disposable," she said. "That makes you nervous."

History offers some context for academics' work habits. Markoff said that during the 17th and 18th centuries, when the Enlightenment helped define the modern-

I was on campus not because my adviser told me to be there but, rather, because I had internalized that that's what I needed to do to be a successful academic.

day concept of academia in the West, the gentlemen of leisure who populated scholarly circles were expected to make sacrifices for their profession.

"This was a calling, a vocation," Markoff continued. Academics were expected to be devoted to their work because the pursuit of knowledge was seen as noble, she said, and relics of that sentiment no doubt persist today.

I can relate: When I was a graduate student in the mid-aughts, I spent more Saturdays at my desk than I care to admit. I was on campus not because my adviser told me to be there but, rather, because I had internalized that that's what I needed to do to be a successful academic. My tendency to overwork was self-imposed.

Overwork does not underwrite all academic work cultures, of course.

As a self-described "American workaholic," Markoff said she remembers being shocked when she first moved to Europe because her work schedule stood in stark contrast to that of her colleagues. "When I moved there from the United States, I was the only person working at night," Markoff recalled.

Other researchers regularly left the office at 4:00 p.m. and did not come in on weekends, said Markoff. One scientist whose work she particularly admired maintained an extremely regimented schedule and never worked more than 40 hours per week. "It really rocked my brain," she said.

Markoff's European colleagues weren't any less productive than their American counterparts, she soon realized—they just got their work done in a shorter span of time. Researchers focused on cognition have repeatedly shown that humans might be hardwired to work most productively for relatively short spurts of time—somewhere between 4 and 6 hours. (Anonymous surveys often reveal that workers log roughly 4 hours of productive work per day.)

Even after realizing the minimal productive payoff for overwork, however, Markoff admitted that she still works too much. "I can't say no, and I take too many things on," she said. However, she's adamant about not expecting the same from her graduate students and postdocs. "I definitely don't try to force that on my group," she said. "I try to be very aware."

Meanwhile, many early-career researchers carefully consider the negative repercussions of overwork as they navigate their career trajectories. "Early-career scientists are very concerned," said Gasparini. Survey data confirm that sentiment: A recent poll conducted by *Nature* of more than 3,000 graduate students revealed that a lack of work-life balance was one of the main reasons respondents were unlikely to pursue a career in academia (bit.ly/Nature-poll). One respondent put it plainly: "I don't think I want this kind of life." Fewer than half the students hoped ultimately to find full-time employment in academia, the poll revealed.

Luc Illien, a geophysicist at the GFZ German Research Centre for Geosciences in Potsdam, realized only over time that nonacademic pursuits actually advanced his enthusiasm and productivity at work. During his Ph.D. program, Illien would regularly work on weekends and bring research papers with him when he traveled. His academic life took precedence over everything else. "I was constantly thinking about it," he said.

The upheaval caused by COVID-19 helped Illien realize that he was exhausted from the go-go-go pace of his work. "The pandemic helped me change my perception," he said.

Illien began setting aside time to pursue interests that had nothing to do with his doctoral thesis, which focused on seismic observations of the critical zone. Devoting time to hobbies such as martial arts and filmmaking was a way for him to recharge and feel more prepared to do research. "I'm way happier, and I feel as productive," Illien said.

Illien is not an outlier: Numerous studies have demonstrated that engaging in leisure activities boosts well-being, and having meaningful nonwork outlets has also been linked to gains in productivity-related attributes such as increased creativity. Today Illien does a combination of research, project management, and outreach, and he credits his filmmaking experience with helping him land his current position.

Such conversations are particularly important for women to hear, Markoff said, because women scientists can face additional pressures. "On average, women often end up being asked to do a lot more things," she said. "When you're one of the few women at a certain level, you get asked too much to be on all these committees."

Women in the sciences also tend to encounter barriers to advancement. They are less likely than men to be credited with authorship on scientific papers. A 2023 report revealed that at Scripps Institute of Oceanography, women were systematically given less lab and office space than their male colleagues.

Some women choose to respond to inequity by working harder to compensate, Markoff said. "[Women] probably are harder on themselves because of the fear of being seen as lesser," she said.

Researchers of color also end up shouldering outsize burdens in academia, and those additional commitments can lead to overwork. Asian, Black, Hispanic, and Native American faculty all spent significantly more time per week advising students than white faculty members did, a 2009 survey of more than 25,000 faculty members revealed (bit.ly/invisible-job-labor). Such "invisible labor" is often just that when researchers are considered for tenure, academia's equivalent of a job promotion. "You don't have a metric for the type of service that I'm engaging in," a Black female faculty member at a predominantly white institution told researchers in a study on gender and race in academia (bit.ly-gender-and-race).

Change Is Afoot

Early-career researchers have begun speaking up about the culture of overwork in academia. Late in 2022, roughly 36,000 graduate students working across the 10 campuses of the University of California system went on strike.

"We are overworked and underpaid, and we are fed up," Jamie Mondello, a graduate student worker at the University of California, Los Angeles, told the *Los Angeles Times*. The strike, the largest in higher education in American history, lasted more than 5 weeks and netted graduate student researchers and teaching assistants child-care subsidies and roughly 50% increases in starting pay, among other benefits. (The issue of workload was addressed in the University of California negotiations, but it pertained specifically to teaching duties rather than the research-based positions held by many graduate students.)

> **"I'm trying to find different ways to do things that I think are more supportive."**

It's up to researchers to change the culture of overwork in academia, said Gasparini, because universities benefit from the extra labor. "There's no reason for a university to address this issue," she said.

More senior faculty—many of whom have the privilege of a permanent position—should set an example for their graduate students and postdocs when it comes to healthy work habits, Gasparini said. In recent years, she has made a conscious effort to rein in her service commitments such as committee work. "I say 'no' more often," she said. Saying no is not always possible, she admitted, and sometimes work that she's truly passionate about—such as mentoring more junior researchers—gets pushed to the wayside. But dialing back work is necessary for personal health, said Gasparini, who has suffered from work-related panic attacks in the past. "I don't want to have a heart attack at age 55," she confided.

Inspired by other researchers, Gasparini is taking steps to ensure that her graduate students and postdocs are aware of the issue of overwork and feel empowered—and comfortable—eschewing a debilitating work schedule. For starters, she is open with her group about her own struggles. "I talk with my students about how hard it was for me in grad school and how I got sick all the time," she said. "I don't think there's any reason to hide that stuff."

Gasparini maintains a "group agreement" that she shares with her graduate students and postdocs. The document outlines expectations about work, among other topics, and notes that researchers are expected to take time off.

This agreement is a living document, Gasparini explained, and the goal is to convey to junior researchers that they don't have to sacrifice their mental or physical health to be successful scientists. The agreement is also an implicit attempt to provide a better experience in academia, she said. "I'm trying to find different ways to do things that I think are more supportive."

Markoff is making similar efforts to normalize self-care. Prior to the pandemic, she took her graduate students and postdocs on group retreats, and she plans to resume the daylong outings. The meetups, which occurred off campus, often centered around discussions of personal development, career goals, time management, and mental health. "I started trying to be more open about the failures, the problems, the stress," Markoff said.

It's no secret that some researchers are choosing to leave academia. That attrition is occurring for a variety of reasons: high rates of exhaustion, low job satisfaction, and more lucrative opportunities in industry or the private sector, among others. But all too often, academics suffer in silence. "So many people are leaving academia," Markoff said. "There has to be a discussion of why."

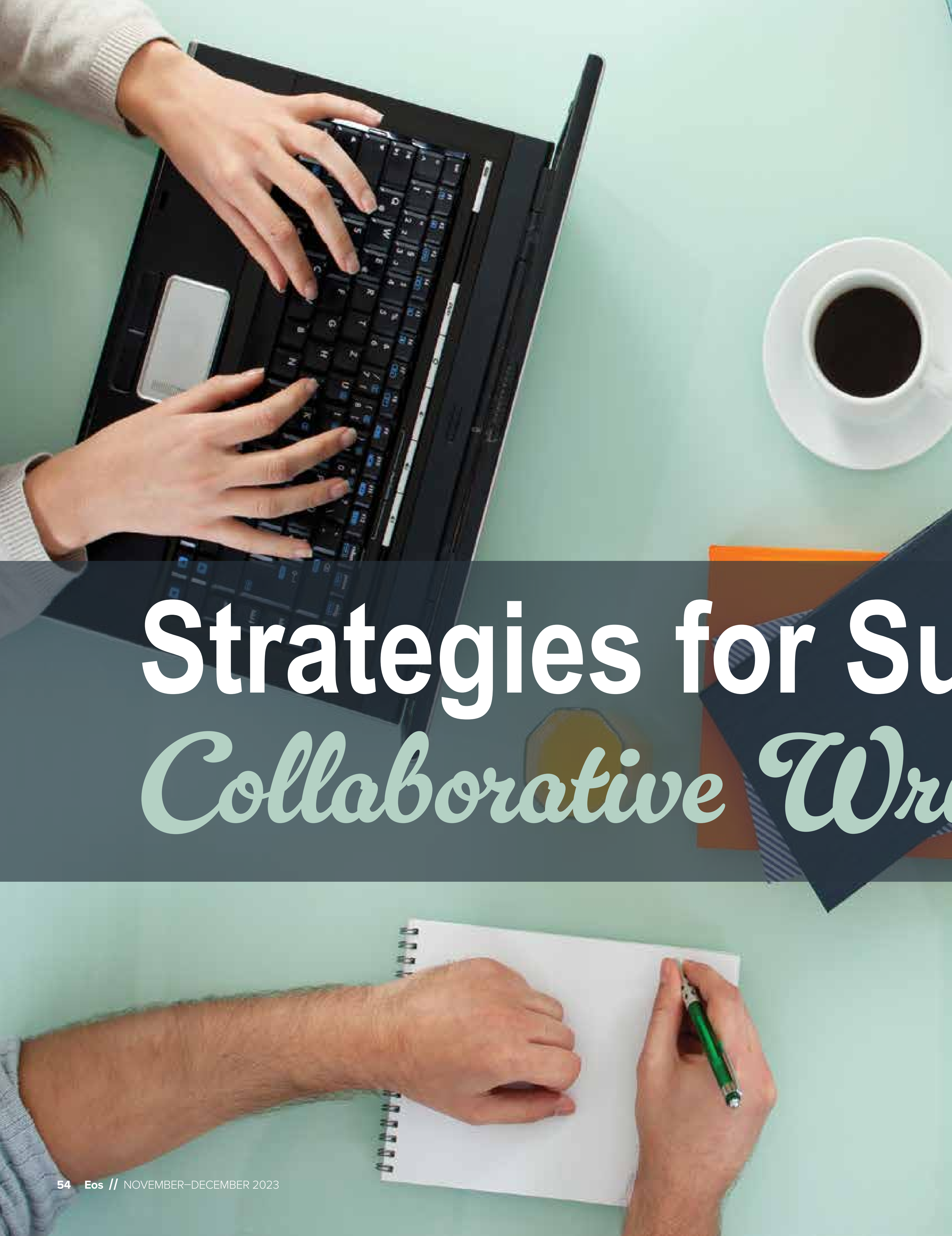
And though acknowledging the issue of overwork in academia is an important first step, action needs to follow as well. Markoff for one is hopeful that change is afoot in academia, and she believes that the younger generation will lead the way. Early-career researchers are seeing firsthand the toll of unsustainable work habits on both the physical and mental health of their supervisors, and that's not an existence they wish to emulate.

Many current graduate students count themselves among Generation Z, the cohort of people born between roughly the mid-1990s and 2010, and that group isn't shy about demanding change, Markoff said. "Gen Z doesn't put up with crap. They're really challenging these things."

Author Information

Katherine Kornei (@KatherineKornei), Contributing Writer

Read the article at Eos.org



Strategies for Su
Collaborative Wr

uccessful

iting

By Eric M. D. Baer, Karen M. Layou, R. Heather Macdonald, and Sharon L. Zuber

Lessons learned and applied during a recent workshop can help authors, from students to seasoned professionals, work together to produce more equitable and effective writing.

iStock.com/fotostorm

Nearly all writers know the sensation as the cursor blinks starkly on their screen and the pressure mounts. This uncomfortable feeling affects people of all ages, stages, and professions—including scientists—as they try to express their ideas in print. Ernest Hemingway is often credited with saying, “There is nothing to writing. All you do is sit down at a typewriter and bleed.”

If only it were that easy.

Scientific publications—whether traditional research articles or books, committee white papers, policy documents, or stakeholder reports—often involve multiple authors, a situation that introduces additional challenges to the writing process beyond the fundamental difficulty of putting words on a page. These challenges, which include accommodating different timetables, approaches, and opinions, as well as navigating interpersonal dynamics, can slow productivity and lead to unequal contributions and/or attributions in the end product.

To overcome barriers to writing, some people take advantage of writing retreats, boot camps, and accountability circles, which provide structured writing time and supportive communities providing tailored feedback. As researchers and educators familiar with the challenges of collaborative scientific writing, we incorporated and adapted approaches from these types of activities to design an innovative virtual workshop intended to make collaborative writing productive, equitable, and enjoyable.

The weeklong workshop involved more than 30 participants, including many new to scholarly publishing, grouped into 10 writing teams. Its success was demonstrated by positive participant feedback and the fact that all 10 teams completed full manuscript drafts in just 1 week! A year later, the resulting papers had all been published.

In addition to being effective in producing scholarly manuscripts, this workshop model could be adapted for other collaborative writing projects, scientific and otherwise. It could be used by researchers within lab groups, collaborating authors from different groups or institutions, and students in undergraduate and graduate courses.

Below, we describe the basic setup of the workshop and five key strategies we used to transform the task of collaborative writing and help writers overcome the blinking cursor.

Scientific publications often involve multiple authors, a situation that introduces additional challenges to the writing process beyond the fundamental difficulty of putting words on a page.

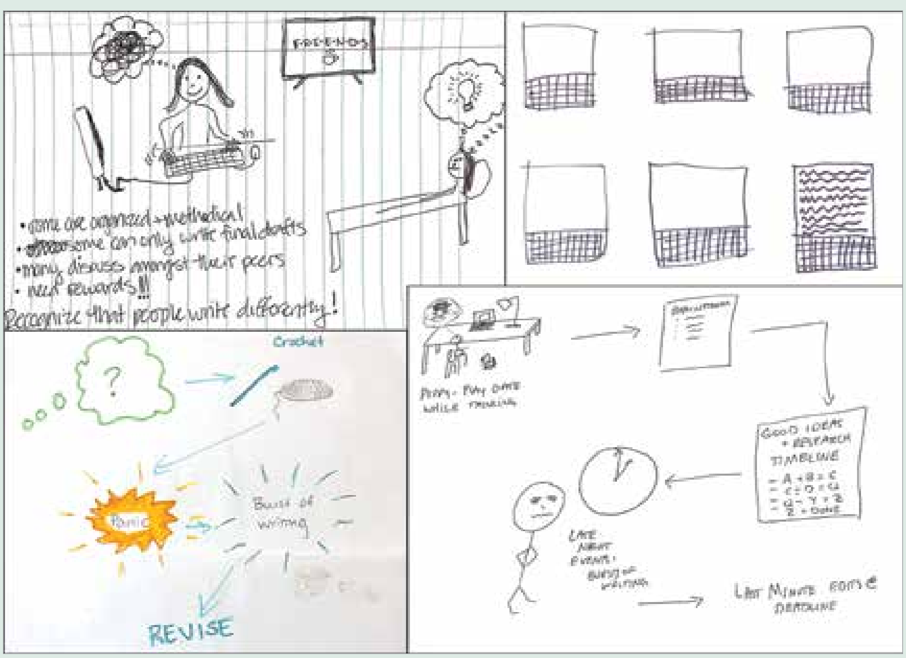


Fig. 1. Sketches by four authors illustrate their individual writing processes. Some writers need breaks and rewards to get ideas flowing; others stare at a blank screen thinking, thinking, until the words pour out. Good ideas may come anytime and anywhere and often begin with a question. The text is then shaped through multiple drafts and revisions. Credit: (clockwise from top left) Angela Daneshmand, Seth Miller, Christie Landry, Alyssa MacDonald

Order from Messiness

Our workshop was organized through the Supporting and Advancing Geoscience Education at Two-Year Colleges (SAGE 2YC) project and focused on facilitating small groups of community college faculty to develop manuscripts for an issue of the journal *New Directions for Community Colleges* titled “Catalyzing Change: STEM Faculty as Change Agents.” The author teams, typically three or four faculty from different institutions who had participated in SAGE 2YC, met for 4 hours per day in a 1-week virtual workshop that provided the necessary scaffolding to bring order out of the messiness of collaborative writing.

To form the author teams, participants first selected and prioritized subjects they were interested in covering in their manuscripts; the issue editors then arranged the teams based on participant responses.

Before the workshop, all authors completed a writing exercise describing their experiences with, for example, online instruction, inclusive teaching strategies, or undergraduate research with community college students. They shared their experiences, or “stories”—we deliberately used the word “story” to emphasize the narrative style we encouraged—with their coauthors to cross-pollinate and refine ideas.

The teams built on their shared stories to draft each section of their article, and full drafts emerged as they worked through a process of iterative revision.

Postworkshop support included a timeline with deadlines, individual consultations, online meetings to discuss progress, and low-stakes reviews of completed drafts before external review of each team's submitted manuscript.

1. Understand Writing as a Process

Writing is more than typing words; it is a process of creating meaning that evolves as authors compose and revise. The writing process is often divided conceptually into three stages: (1) prewriting, which includes research and brainstorming; (2) composing, during which the structure of authors' arguments emerges; and (3) revision, which includes re-visioning, or looking again to clarify the message among the writers and for their audience.

Feedback throughout the process helps writers refine ideas. The notion of writing as a process may seem intuitive, but it is easily forgotten. Keeping it in mind—and reinforcing it in workshop settings—can help writers remain patient and open to critical feedback.

It is also important to convey that despite the simplified outline above, everyone's writing process differs in the details. On the first day of the workshop, we prompted participants to think about and sketch their individual writing process. They then shared their process with the group, which illuminated the many different ways people approach writing (Figure 1). We learned, for example, that some people write best in the morning versus other times of day, and some begin with an outline, whereas others brainstorm through freewriting or concept maps.

Writers can be more effective if they understand their own process, and in collaborative writing settings, their expectations can be more realistic and flexible if they acknowledge and understand how the rest of their team approaches writing. They might even learn new strategies that work for them.

2. Brainstorm Through Freewriting

In freewriting, people write continuously for a specified amount of time, jotting down ideas as they come to mind without judging them or worrying about grammar and punctuation. Writing without self-censorship can get ideas flowing and can help people overcome writer's block. Freewriting is also a low-stakes way for writers to brainstorm and get feedback early in the writing process before they spend hours crafting individual sentences they may be reluctant to give up later.

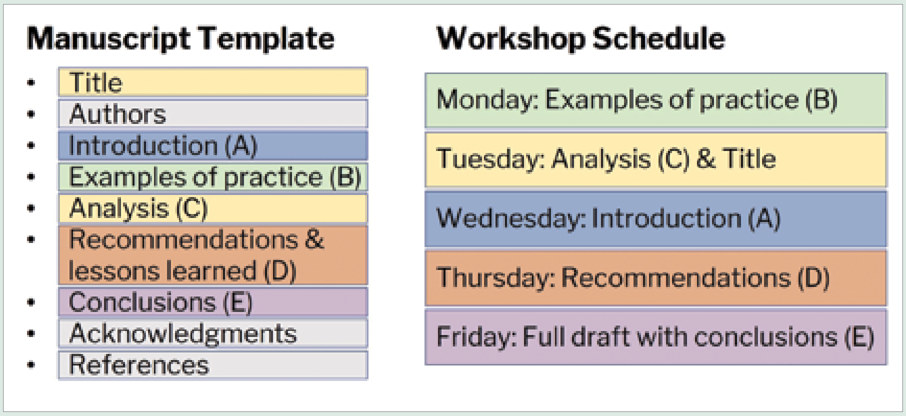


Fig. 2. The writing workshop schedule followed a nonsequential approach to manuscript development. The workshop website (bit.ly/SAGE-2YC-workshop) provides additional details of the program.

Throughout the workshop, we gave participants short periods of time to freewrite in response to such prompts as the following:

- What are common threads among your team's individual stories?
- Why is this work important? Why should the readers care?
- What are the biggest lessons learned from your topic?

After the time was up, the writers shared their ideas with their teammates, a process that was made easier because of the freewriting and that ensured that all voices were heard.

Many participants reported in daily checks-ins and postworkshop evaluations about the value of freewriting activities. For example, one person commented, "I sometimes think everything has to be perfect the first time. Freewriting allowed for writing without boundaries that I could go back and expound on later." Another noted that "the quick writes…gave each of us a chance to write our own thoughts first ('think, then share')."

The sequence of individual writing followed by round-the-team sharing and discussion led to productive collaborative writing, galvanizing consensus among team members and spurring new ideas. As another participant said, the "freewriting prompts aligned our internal compasses. Even when we had different ideas about how to get from point A to point B, we at least all had common terrain in mind."

3. Hold Off on the Introduction

An introduction is where writers articulate the purpose and vision of a manuscript for a specific audience, contextualize a hook to grab readers' attention, and, in a collaboratively written piece, help multiple authors set a consistent tone and voice. The introduction is a crucial part of any publication, often determining whether people continue reading into the core discussion.

A common tendency is to want to write sequentially, from beginning to end. In some cases, though, the exact message of a manuscript may emerge to authors only after they have written and clarified arguments, examples, and analysis in other sections of the document. Thus, the introduction may best be written out of sequence.

We reinforced this point by having teams begin drafting their introduction on the third day of the workshop, after they had spent time the first two days describing and sharing their stories and finding common themes and key points (Figure 2). In the opening session of day 3, the teams discussed the introduction's purpose and importance. As their main arguments became clearer, authors then considered how to hook readers, first individually following the freewriting prompt "How might you move the reader into the world of your chapter?" and then as teams.

We encouraged them to be creative and provided an example of a successful paper

Diversity by design: Broadening participation through inclusive teaching

Brainstormed titles:

- Make class meaningful: Inclusive teaching practices that engage all students
- Meeting the moment: The case for inclusive teaching practices
- Diversity by design: Examples of broadening participation through inclusive teaching from community college change agents

Hook:

"Diversity is having a seat at the table, inclusion is having a voice, and belonging is having that voice heard."
(L. Fosslien and M. W. Duffy (2019), *No Hard Feelings: The Secret Power of Embracing Emotions at Work*, Portfolio/Penguin, New York, p. 185.)

Successes with metacognition: Empowering faculty and transforming student learning

Brainstormed titles:

- Reaching out to the unprepared (underprepared?) student using metacognition
- A possible "silver bullet" for improving student success: Successes with intentionally infusing metacognition strategies into courses
- The value of metacognitive strategies to transform student learning and foster new habits of mind

Hook:

The following student quotations were in response to a class presentation about metacognition that followed their first exam in an introductory college geoscience course:

- "Thank you for showing me this! I always thought I just needed to study longer."
- "I was considering withdrawing from this class before this lecture and now I am motivated to do well."

Turning the page: The importance of faculty-led book clubs

Brainstormed titles:

- TooLS of the trade—Faculty book clubs to guide changes in STEM teaching
- Turn the page to faculty change in STEM—The importance of faculty-led book clubs
- Building community and improving student success through faculty book clubs

Hook:

Have you ever felt stuck in your pedagogical approaches? When important topics like racial justice or diversity become national discussion points, how do you start and support the conversation in your classroom? How do you find new strategies for student assessment? One easy-to-implement form of professional development that provides solutions to these questions is the faculty-led book club.

Fig. 3. Three examples of final titles (at the top of each box), revised from earlier brainstormed titles, and creative hooks used in manuscripts appearing in the New Directions for Community Colleges *issue titled "Catalyzing Change: STEM Faculty as Change Agents."*

Effective writing is conversational in some ways, anticipating and providing the context needed by a reader to understand the substance and significance of the authors' message.

that began with a quote and a hypothetical scenario to draw readers in. The authors generated many creative ideas for engaging audiences, including quotes, anecdotes, and scenarios (Figure 3).

Participants found that they liked writing their manuscripts out of order. One commented that it was "hugely beneficial," adding, "I'm a linear thinker, thus a linear writer, and can't often get beyond the introduction and examples. I was skeptical at first about the order but came to embrace it."

4. Write for Your Audience

Effective writing is conversational in some ways, anticipating and providing the context needed by a reader to understand the substance and significance of the authors' message. An important first step is to define the target audience (e.g., scientists, policymakers, the public) and intended outlet for publication, which will help authors tailor their arguments, style, and structure.

We stressed the idea of writing for one's audience through several workshop activities.

One focused on crafting successful titles, which give readers the first hint about the content and tone of a publication. In a fun exercise on the second day of the workshop, the teams generated a few possible titles for their manuscript based on emerging themes from the day's freewriting and discussions. Then other teams commented on the title options, indicating favorites and offering suggestions for improvement. By asking these external readers what they thought the article would be about, the participants discovered quickly whether their purpose was clear in the title.

Figure 3 shows several examples of final manuscript titles (in bold italic) that emerged after authors received feedback about possibilities brainstormed by their group. Some feedback, for instance, focused on keeping titles concise, more accurately reflecting the article's content, and being more engaging.

As in other exercises throughout the week, this one gave writers immediate feedback on and audience reaction to their in-progress ideas, encouraging teams to make early revisions.

> *Our focus on effective writing* **strategies and inclusive approaches to group work produced a community of writers working equitably and productively together.**

5. Honor All Voices

Viewing a topic from others' perspectives challenges writers to examine their own assumptions and explanations and potentially reveals their own implicit biases. This is especially important for successful collaborative writing, in which coauthors share a common goal but may have different opinions about how to achieve it.

In our workshop, each writer shared ideas for a particular section of the manuscript before the team drafted that section. After other brainstorming and freewriting sessions, team members similarly met to talk through their notes and agree on key points and promising ideas.

To support equitable and inclusive collaborative writing, we provided ground rules for these discussions, including listening actively and asking questions with the intention to learn, being respectful of others' ideas and perspectives, and including everyone in discussions (i.e., speak up, step back).

Beyond these ground rules, we also asked teams to discuss author order and set their own team norms, such as how they planned to handle differences of opinion about team decisions and deadlines. And we encouraged teams to share information—about time constraints and conflicting obligations, for example—that would help them establish realistic writing schedules. The authors also discussed what their writing process sketches revealed to help them understand one another and work successfully as a team.

Furthermore, in some teams, participants took turns serving as an equity monitor, who was responsible for ensuring that everyone had opportunities to participate. The structure of these discussions set the foundation for building a supportive writing community that honored all voices.

A Widely Applicable Model

Our focus on effective writing strategies and inclusive approaches to group work produced a community of writers working equitably and productively together. Participants' feedback made clear that the following workshop characteristics were important in helping them feel respected and valued:

- providing explicit structure to the group writing process through planned activities, including dedicated brainstorming and writing sessions
- building in inclusive, nonhierarchical practices that encourage cross-pollination of ideas from all authors, enable real-time feedback, and reduce feelings of isolation
- acknowledging that writing is hard work while providing positive encouragement within a supportive environment, where critiques are constructive and build confidence

> *This workshop model* **is ideal for collaborative writing among authors with a range of experience.**

This workshop model is ideal for collaborative writing among authors with a range of experience, including student writers. Novice writers reported feeling comfortable sharing unpolished drafts and found early recommendations for revisions easier to incorporate.

More inclusive and equitable approaches to collaborative writing are likely to open paths to more diverse representation among authors. By following the strategies and advice described here, authors also may find the writing process smoother and more enjoyable. In addition, the finished products may be clearer and more accessible, allowing findings and conclusions to be more easily applied in research, education, and policy.

Acknowledgments

We thank the workshop participants for their contributions to the workshop, supportive collegiality, and feedback. This work is supported in part by the National Science Foundation's Division of Undergraduate Education through grants 1525593, 1524605, 1524623, 1524800, and 1835935. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Author Information

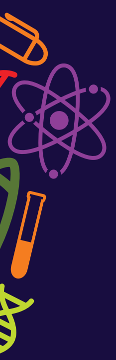
Eric M. D. Baer (ebaer@highline.edu), Highline College, Des Moines, Wash.; **Karen M. Layou,** Reynolds Community College, Richmond, Va.; and **R. Heather Macdonald** and **Sharon L. Zuber,** College of William and Mary, Williamsburg, Va.

Read the article at Eos.org

Latin American scientists and journals are strengthening research, evaluation, publication, and communication systems to help redefine ideas of professional success that have largely been determined by the Global North.

Raising the Visibility of Latin American Science

By Humberto Basilio



J. Henry Pereira/AGU

Graduating from a recognized university is a privilege in a world in which most don't have the financial means to achieve this. And building a "successful" scientific career is a challenge with added economic, structural, and language barriers.

Lina Pérez-Ángel knows the journey well. Her mother was the first woman in her family to migrate from Caparrapí, a small municipality in Colombia, to the capital city of Bogotá. And although Pérez-Ángel and her siblings were born and raised in the city, she remembers traveling to her mother's hometown—a place she identifies as her home, too—throughout her childhood. That rootedness in Caparrapí would lead to her interest in researching the paleoclimate of Colombia's Eastern Cordillera.

"I didn't grow up in that world of science and curiosity," said Pérez-Ángel, who originally wanted to become a chef but started her academic career studying engineering because her mother told her to. (She later found her real passion in the geosciences.)

As an undergraduate at Bogotá's Universidad de Los Andes, Pérez-Ángel noticed a pattern among the readings required for classes: No matter what subject she was studying, European and North American surnames dominated the literature. Much of the university's faculty also came from outside Colombia. Even among the Colombian professors, the most recognized had pursued their graduate degrees outside the country.

"You guys have to get out, get out of here to do science" was the most common advice Pérez-Ángel remembered getting from her professors.

That advice was informed by two trains of thought. The first was that countries in the Global North have more funding and better infrastructure to do science. The second was the widespread belief that learning about the world outside Colombia would give students new perspectives for their research.

Both ideas made sense to Pérez-Ángel at the time, but the constancy with which she heard them also made her feel pressured. "I came to have the idea that [staying in Colombia] was like a failure," Pérez-Ángel recalled. "Now I eat my words, but at that time it was something that remained in my subconscious…that if I wanted to become a [recognized] professor or researcher, I needed to leave."

Becoming more closely involved in the projects of her undergraduate professors allowed Pérez-Ángel to join the Smithsonian Tropical Research Institute in Panama. The connections she formed there opened the door to more opportunities. Eventually, she completed her Ph.D. in the geological sciences department at the University of Colorado Boulder and is now a postdoctoral research associate at Brown University.

Pérez-Ángel's career path isn't unusual among students at Latin American universities. Global visibility plays a significant role in establishing scientific careers, not only in terms of recognition but also in the effort to obtain funding, grants, and resources to continue doing science. The search for global visibility creates the pressure to study abroad.

"It was something that remained in my subconscious… that if I wanted to become a [recognized] professor or researcher, I needed to leave."

However, seeking recognition in so-called "global science" implies accommodating the norms, ideas, and people who lead research activity in the world's hegemonic scientific institutions—those of the Global North.

Internationalization: A One-Way Street

In 2019, Argentinean researcher Magdalena Martinez, a Ph.D. candidate in higher education at the University of Toronto, became interested in the ways that international engagement informs the research activity of highly cited Brazilian scientists. In other words, she analyzed the extent to which connections, academic exchanges, graduate studies, and international collaborations may have enhanced the researchers' careers.

To identify the most highly cited Brazilian scientists, Martinez and her team turned to the annual list of the entire world's most highly cited scientists, published by Clarivate every year since 2015. These lists derive from Web of Science–related databases and metrics, which serve to identify scientists who have "demonstrated significant and broad influence in their chosen field of research," according to Clarivate.

Among the 4,058 most cited researchers worldwide in 2018, 65% were from the United States, 13% were from the United Kingdom, and 13% were from China. "Unsurprisingly," authors pointed out, scientists affiliated with Brazilian universities occupied a more marginal position than their Western and Chinese peers—just nine of the 4,058, or less than one quarter of 1%.

Martinez and her team looked at more than 1,500 papers to analyze their date of publication, citations, and type of authorship and collaboration, as well as the countries where collaborating authors lived. Authors' curricula vitae were also analyzed.

The team found that of the nine highly cited Brazilian authors, almost all were involved in global research networks. Eight of the nine had 1- to 10-year international experiences, mainly in the United States and Europe. Those experiences and connections (mostly established early in the scientists' careers), Martinez said, were crucial to the researchers' success.

Other studies have analyzed the citation patterns of researchers from Latin America who don't copublish with peers from developed countries in recognized journals. Generally, when authors publish without global visibility, they are under-cited. One group of researchers readily acknowledged that scientific research visibility benefits from collaboration. However, they write, whether under-citation is due to a "psycho-social bias or real differences in scientific relevance of these articles" remains a concern.

Collaboration and Visibility

The degree of global visibility often depends on the study area in question, said atmospheric physicist Paulo Artaxo, one of the most cited Brazilian authors of 2018. For instance, he explained, environmental science combines different research areas and benefits from multiple partnerships. "Without collaboration," Artaxo said, "forget about it…you cannot do much."

Artaxo ventured into global science 40 years ago when he studied the effects of biomass burning in the Amazon with the Dutch atmospheric chemist Paul Jozef Crutzen, now deceased. Later, Crutzen invited him to the Max Planck Institute for Chemistry in Mainz, Germany, where Artaxo began networking with renowned scientists from around the world.

"I was lucky to be in the right area in the right moment," said Artaxo, now affiliated with the Universidade de São Paulo. "The number of citations of my papers reflects that."

While emphasizing that citation is by no means the determining factor of the quality of research, Artaxo noted that global visibility is the main reward of publishing in highly ranked journals. As of 2022, no journal published in Latin America appeared in lists of the world's publications with the highest impact factors; Latin American journals are more vulnerable to economic conditions and even closure. Spending years of work on research only to publish in a journal that will "die quickly" because it has no readership, Artaxo said, is a "waste of time, money, and everything."

> Signatories of the San Francisco Declaration on Research Assessment stressed the necessity to assess research on its own merits rather than on the basis of the journal in which the research was published.

Latin America's Struggle for Visibility

Western science has established itself as the world's epistemic authority. It determines which science is the "best" through its evaluation model, and it determines the right people to evaluate. Thus, "Global North journals are the gatekeepers of...research 'quality,'" said Hebe Vessuri, an Argentinean social anthropologist at the Environmental Geography Research Centre (CIGA) of the Universidad Nacional Autónoma de México.

Latin American institutions have largely adopted the same citation-based evaluation parameters as the Global North: If researchers want a high score, they need to publish in journals with a high impact factor—as determined by the traditional standards of the Global North. Publishing in these journals involves developing research within the limits of the Global North's interests. In most cases, local science is not part of that scope.

The prevailing citation-based evaluation model has been criticized for years. In 2012, during the annual meeting of the American Society for Cell Biology, editors of academic journals from around the world drafted a series of recommendations to improve evaluation practices at funding agencies, institutions, and other organizations.

The so-called San Francisco Declaration on Research Assessment pointed out the need to eliminate the use of journal impact factors as the basis for funding and consideration for professional advancement (sfdora.org). Signatories stressed the necessity to assess research on its own merits rather than on the basis of the journal in which the research was published.

Still, finding an effective way to solve the problem is much more complex than a thoughtful declaration.

Concentrating such power in publications in the Global North has caused scientists to lose interest in publishing in national or regional journals in Latin America. (Sometimes countries lose researchers themselves as the region grapples with brain drain to the Global North.)

The professional standing of these journals, where most regional scientific research is published, has also worsened due to economic and political crises. Latin America has one of the lowest investment rates in research and development, and that investment is not evenly distributed: Argentina, Brazil, and Mexico account for 85% of total scientific investment across Latin America.

For Vessuri, there is a delicate balance between the importance of international training for young scientists and retaining scientists for national research. Those who leave often do not return, and those who stay often prioritize producing research valuable to the Global North, Vessuri said. "It is an intellectual crisis of nation-states...they become mere appendages of the international system."

This problem has existed for decades and "continues practically unchanged," said Claudio Amescua, head of the editorial section of the Institute of Atmospheric Sciences and Climate Change of the Universidad Nacional Autónoma de México.

For Amescua, the issue originates not only with the dominance of the evaluation model of the Global North but also with the earliest stages of Latin American researchers' education. "It is the vision of how the scientist should be, the importance of prestige, the importance of where to publish," he said. This is the stage at which Pérez-Ángel felt the pressure to leave Colombia.

Following this vision, researchers can isolate themselves from Latin America because they are in "another world," Amescua said. Until the region's science policy encourages national research and publication, however, little or nothing will change, he admitted. "That's not to say that each world should function independently," he said, "but that they should function intertwined."

The Latin American Model

Unlike the private, high-impact journals of the Global North, most Latin American journals have historically been produced by public universities. Their financing depends not on authors or subscriptions but on the resources that federal governments provide to educational institutions. The "Latin American model," as Amescua described it, had an open access operation even before the concept was formalized 20 years ago.

In the beginning, Latin American journals functioned as a way to disseminate the research of scientists at individual schools. Adopting evaluation parameters led journals to formalize their structures and become internationally competitive.

Fed up with the fact that Latin American publications remained "gray literature" compared with journals from the Global North, physicist Ana María Cetto oversaw the entry of *Revista Mexicana de Física*, a physical science journal, into the Science Citation Index Expanded.

Even after taking this "big step," Cetto sought to strengthen the visibility and exchange of knowledge among the nations of Latin

America as well as with those outside it. Cetto started discussing the issue with people from the International Council for Science and UNESCO (United Nations Educational, Scientific and Cultural Organization), with whom she worked at the time. "Stop complaining and do something about it," Cetto remembered getting as a response. And so she did.

Cetto and a group of Latin American scientists and editors launched the Regional Online Information System for Scientific Journals of Latin America, the Caribbean, Spain, and Portugal (LATINDEX), a bibliographic information system that seeks to address Latin America's underrepresentation in indexes and databases produced in the Global North.

Today scientists in 23 Spanish- and Portuguese-speaking countries gather and disseminate information in LATINDEX, as well as in other regional databases for scientific publishing such as Redalyc and SciELO.

The creation of these initiatives is crucial to strengthening regional science and the progress of science education, Cetto said. "The [national] journals are a communication vehicle for a community of younger scientists. It's where they can have access to knowledge without having to pay or without having to belong to an institution. It's where they can learn to publish, train as referees, and establish contacts with other members of the community."

Although these projects have undoubtedly helped increase the visibility of regional journals, the relative lack of resources affects even already well-positioned publications. For instance, the Mexican journal *Revista Internacional de Contaminación Ambiental,* where Amescua has served as managing editor for 15 years, has had to negotiate collaboration agreements with other Mexican universities. "We work with teams of just a few people...the luckiest ones don't reach four people hired full-time," said Amescua.

In recent years, public universities throughout Latin America have invested in subscription packages so their scientists can access and publish in high-impact journals from the Global North.

Amescua believes financial resources should also be invested in regional journals.

> Latin American journals "are a communication vehicle for a community of younger scientists. It's where they can have access to knowledge without having to pay or without having to belong to an institution."

"We ran out of funding," said Karenia Córdova, who helped lead the *Terra* geography journal at the Universidad Central de Venezuela. *Terra* achieved important visibility among Venezuelan and foreign scientists, but in 2021 it published its final issue due to a lack of resources.

Córdova said the problems facing *Terra* were shared by other regional publications. They started with not being able to afford and maintain the DOI (digital object identifier) system necessary to remain in academic databases and included not having web editors or other necessary staff to publish the journal consistently. (When the publication folded, Córdova was *Terra*'s only full-time employee.) These infrastructure challenges result in a fall in a journal's impact rankings, Córdova said, which perpetuates the inequitable system by discouraging scientists' interest in publishing there.

Terra was part of a boom of Venezuelan journals in the late 1990s, a time when the nation experienced renewed investment in regional science and art. However, political and economic conflict compounded, and this effort gradually lost strength and funding. The crisis at *Terra* was part of larger budget cuts to universities in the country. Over the past 8 years, the number of registered journals in Venezuela decreased from 41 to 31 in the citation database Scopus.

The decline of investment in regional journals also meant a loss of national scientific production, said Córdova. Researchers in Venezuela have consistently published fewer articles every year since 2009, she said, and as of late 2022, the country had dropped from 50 to 70 among those ranked in Scopus.

For Córdova, internationalization is necessary to maintain the interest of researchers. But to make national and regional scientific production grow in parallel, it is essential to strengthen those journals' accreditation.

Low quartile (Q) indicators—which serve to evaluate the relative importance of a journal within the total number of journals in its field—also have repercussions for regional collaborations. (Q1 journals are considered most important.)

"Each article published in a Q4 journal plays against my certification of adviser of doctoral programs and grant competitions," said José Arumí, a researcher at the Center for Water Resources for Agriculture and Mining at the Universidad de Concepción, in Chile. "Therefore, I stop[ped] sending articles to *Tecnología y Ciencias del Agua*, which is a Mexican journal that publishes in Spanish, with which I have a long history and [for which I have] great affection," he said.

The Language of Science

Even before *Terra* ceased publication, the journal was forced to cut its Spanish-to-English translator. Córdova herself began to translate at least the titles and abstracts of the papers in *Terra* to expand its reach. "A title in Spanish has a third of the visibility that it has if you publish in English in any journal," she said.

English is the lingua franca of science. Of course, having a common language to share knowledge and create networks is an advantage in scientific progress and communication. However, the prevalence of English in a context already dominated by the Global North further perpetuates a cultural hegemony.

Latin American scientists have pointed out that this hegemony has manifested a dangerous idea among communities both within and outside the Global North: What is written in English is of higher quality than that which is written in Spanish or Portuguese. "Publishing in English is not the problem," however, explained Pedro Urquijo, a researcher in Latin American historical geography at CIGA. Instead, he said, belonging to a system that forces researchers to produce for English-speaking journals just to earn points and obtain high ratings no matter whether their community can read them: "That's the problem."

English is the native tongue of just slightly more than one third of the 1.5 billion people who speak it globally. In Latin America, it is no secret that learning English is a privilege, and many renowned public universities promote teaching English. The proficiency level obtained, however, could be not enough to face the English-speaking world, researchers said, especially in scientific careers.

"When I came to the U.S., I thought I knew English, but I didn't," said Pérez-Ángel. In fact, language was one of her biggest hurdles while completing her Ph.D. Living through that experience made Pérez-Ángel much more conscious of the limits brought about by placing a priority on English. At one point, she attended a conference in which the speakers discussed the lack of data on a Colombia-specific paleoclimate issue, and her patience reached its limit. "[The information] does exist, but it is written in Spanish and not published in a Northern journal," Pérez-Ángel said.

"It would be very unfair that a language that is spoken by almost 500 million people [such as Spanish] does not have its own spaces for publication."

The Science of the Future

Scientific knowledge is obviously not universally accessible, said Pérez-Ángel. According to the Organization of Ibero-American States for Education, Science and Culture, only 1% of all articles published in scientific journals in 2020 were written in Spanish or Portuguese, compared with 95% in English.

But Pérez-Ángel, along with other Colombian geoscientists, is trying to change that.

While chatting on the bus ride home from a field internship in 2014, Pérez-Ángel and Carolina Ortíz, a geologist at the University of Florida, decided to start a project to share what they were learning with their friends, colleagues, and family. What began as an Instagram account where they shared photos eventually transformed into a science communication initiative that aimed to spread geoscience research in Spanish to the public as well as their scientific peers.

After their experiences abroad, Pérez-Ángel, Ortíz, and Daniela Muñoz-Granados (now a geologist at the Servicio Geológico Colombiano) realized that the project could generate more outreach and be more useful if they took advantage of their bilingual capabilities. Thus, GeoLchat (a name chosen to be understood in both English and Spanish) was formalized across a website and social media platforms. GeoLchat allowed the scientists to create a community that could share and learn by breaking down the language barrier. "You have to create bridges where there are none," Pérez-Ángel said.

By creating and translating interactive content, as well as by fostering discussion spaces, GeoLchat has grown a diverse community interested in the Earth sciences. One of GeoLchat's most popular spaces, the YouTube series La Pola Geológica (The Geological Beer), has brought together researchers from Chile, Colombia, Cuba, Mexico, Puerto Rico, and Venezuela to share their research and generate discussions with Spanish- and English-speaking audiences. Such opportunities strengthen the Latin American community and provide peers from the Global North with an open platform to get to know the science that is being produced in Spanish.

"It's a way to show that many other things are going on that they [scientists and institutions of the Global North] do not realize because it isn't within their comfortable reach due to the language," Pérez-Ángel said. "Science is done with the same quality in many other places, but they don't see it because they are on the side of privilege, not on the side of those of us who have had to learn another language to be able to communicate."

GeoLchat is part of a much larger community supporting the idea that it's crucial to maintain Spanish-written research. LATINDEX, for instance, considers multilingualism a "matter of principle." Its databases accept journals from all over Latin America, but one of the quality criteria that gives the best scores is including abstracts of the articles in Spanish or Portuguese and another language.

"There are magazines in Latin America that have decided to no longer include even that [the abstract] in their mother tongues," said Cetto. "We want to induce them to adopt good practices that are favorable for the region.... It would be very unfair that a language that is spoken by almost 500 million people [such as Spanish] does not have its own spaces for publication."

Keeping Spanish and Portuguese as living scientific languages is also one of the goals sought by many academic journals throughout the region, said Amescua. However, the entire Latin American publishing and communication model must be strengthened, he contended, "making it grow based on its own characteristics, being congruent with its history, with its social development, and with its needs to remain as a valid peer of the North, and not as a favors requestor."

Global visibility ultimately manifests in different ways. Looking back on how she developed her career, for instance, Pérez-Ángel realized that being outside Colombia helped her to be more confident that she will use everything she has learned to continue studying the place where she grew up. Working on Colombia-focused research with her peers in Colorado, Pérez-Ángel said, has given her new insights, learning, and perspectives. But it also made her aware that the deep knowledge she has about Colombia's climate, geography, and people is irreplaceable.

For many Latin American scientists, there is only one way forward: to engage all parties in an equitable, inclusive, and diverse manner. "That is the real science of the future," said Pérez-Ángel.

Author Information

Humberto Basilio (@HumbertoBasilio), Science Writer

Read the article at Eos.org

When It's Too Hot for Fans

As temperatures rise, people look for relief from heat in various ways. Electric fans, which move air around a person's body and help evaporation cool their skin, are one of the most affordable cooling methods. However, fans' ability to fight the heat has limits.

According to the World Health Organization, when temperatures rise above 35°C, fans may no longer help prevent heat-related illnesses. And at higher temperatures, they can turn dangerous, moving too much hot air over a person's skin, potentially fostering adverse health effects.

Heat risks arise from a combination of temperature, one's health vulnerability and extent of exposure to high temperatures, and one's ability to adapt (such as by using cooling methods like air-conditioning or fans).

To better understand heat hazards and risks in the United States, *Parsons et al.* compared hourly temperature data based on historical weather observations over the continental United States from 1950 to 2021 with gridded population data to determine where people face the greatest heat hazards. They focused especially on the hazards when temperatures reached 37°C and 39°C, thresholds recently recommended by heat experts for safe electric fan use by older adults on certain medications and young, healthy adults, respectively.

The researchers found that in the past 2 decades, on average, U.S. residents have experienced roughly twice as many hours when fan use is unsafe compared with 50–70 years ago. And some very hot locations, such as hot spots across the West and South, now face at least 200 more hours—more than 8 more days—each year when conditions are unsafe compared with the mid-20th century.

In addition, the researchers compared the temperature and population data with the Centers for Disease Control and Prevention's Social Vulnerability Index (SVI), which includes factors such as socioeconomic status, ages and disabilities of household members, and housing type. The higher the SVI ranking is, the more at risk community members are to health hazards. The study revealed that high-SVI communities are exposed to higher temperatures than low-SVI communities, and high-SVI locations are facing faster increases in the number of hours when fan use is unsafe.

The researchers have said that they hope their work helps stakeholders decide how best to help vulnerable communities with sustainable, targeted heat management approaches. (*GeoHealth*, https://doi.org/10.1029/2023GH000809, 2023)
—Sarah Derouin, *Science Writer*

Visualizing the Deep Insides of Planets and Moons

Getting to know planets or moons inside out isn't easy. Like Earth and its Moon, many celestial bodies are multilayered and can contain anomalous internal features that reflect the complex history of their formation, collisions with other bodies, and ongoing planetary dynamics.

Within planets and moons, anomalous structures that have different densities compared with their surroundings can be detected using gravity data. Above such density anomalies, the force of gravity acting on spacecraft traveling nearby is higher or lower than at other locations.

Computational techniques known as gravity inversions relate differences in gravity acceleration to differences in internal density structure. Now, *Izquierdo et al.* present a novel technique that may help researchers infer the global structure of a planet or moon from the gravity acceleration data measured by orbiting spacecraft.

Compared with traditional methods, the new technique, dubbed THeBOOGIe (short for transdimensional hierarchical Bayesian object-oriented gravity inversion), allows more flexibility in inputting known geological and geographical data, and it does not require researchers to input a depth range of interest or information on a known internal density interface.

THeBOOGIe applies a Bayesian statistical approach that starts with a randomly generated model of a planet's or moon's interior. The model is then refined through hundreds of thousands of iterations until it best fits the input gravitational, geological, and geographical data.

The researchers tested the approach by applying it to determine the Moon's interior structure using synthetic input gravitational data that were representative of real lunar data. They found that the technique correctly identified the location and width of density anomalies in the lunar crust and mantle. However, it overestimated the vertical thickness of crustal anomalies.

Researchers are developing a new technique to help visualize the complex internal layering and anomalous structures inside planetary bodies, including the Moon. Credit: NGC 54/Wikimedia, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

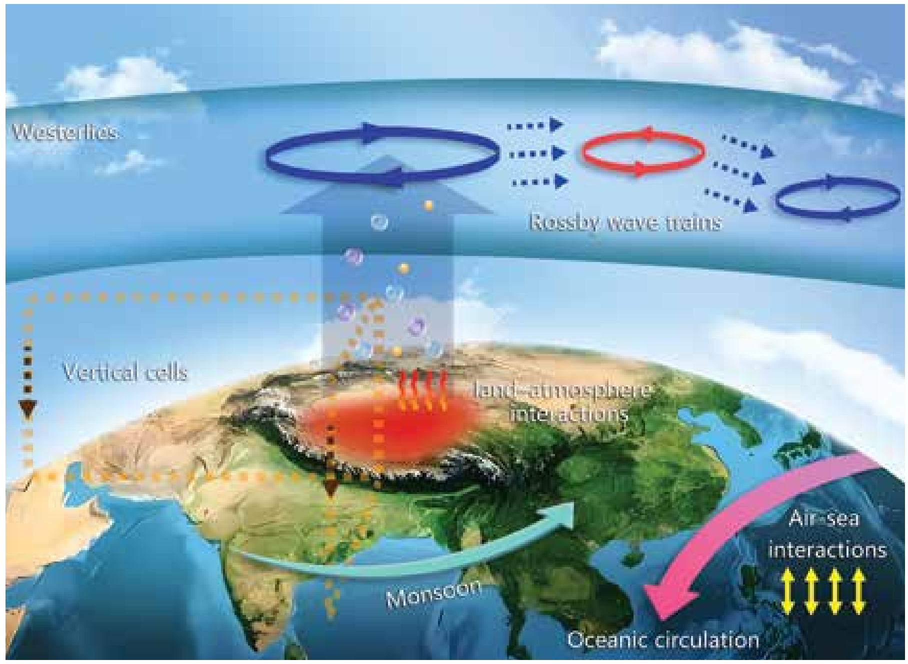
The researchers note that THeBOOGIe, which could be refined through additional work, is well suited for complementing models of planetary interiors based on seismic data and for determining the internal features of smaller bodies without a perfectly layered structure. They also point out that the flexibility and statistical strength of THeBOOGIe may help scientists visualize the interiors of planets and moons for which seismic and geophysical data are lacking. (*Earth and Space Science*, https://doi.org/10.1029/2023EA002853, 2023) **—Sarah Stanley,** *Science Writer*

Earth's "Third Pole" and Its Role in Global Climate

Located at the intersection of South, Central, and East Asia, the massive Tibetan Plateau is often considered to be Earth's "Third Pole." A land of large glaciers, permafrost, and heavy snow, the plateau feeds a vast network of rivers, including major waterways like the Ganges, Indus, Mekong, Yangtze, and Yellow. These rivers, which together make up Asia's "water tower," provide water to nearly 40% of the world's population.

The Tibetan Plateau also plays a substantial role in the global climate system by affecting atmospheric circulation and driving weather patterns, such as the Asian summer monsoon, around the planet. And, in turn, climate crucially influences the plateau. A projected warmer and wetter climate will affect the region's glaciers, snow cover, permafrost, runoff, and vegetation, affecting ecosystems locally and globally.

Huang et al. review the latest research investigating the Tibetan Plateau's role in and susceptibility to the changing climate. Although inquiry into the plateau's influence on climate dates to the 1880s, recent advances in observational data and numerical modeling offer new insights.



This schematic illustrates ways in which the Tibetan Plateau affects the global climate system. Credit: Jianping Huang

The researchers divide their review into six thematic sections, covering observations of land-atmosphere interactions, climate system changes over the Tibetan Plateau, the plateau's effects on atmospheric species transport, thermal and dynamical forcing of the plateau, its modulation of the global climate, and potential future changes in the plateau's climate and forcings. For example, they discuss research demonstrating how the plateau drives surface pollutants into the upper troposphere during the Asian summer monsoon. They also outline how the plateau couples with the monsoon to influence global climate patterns in the summer, whereas in the winter, it drives the climate through its effects on planetary Rossby waves.

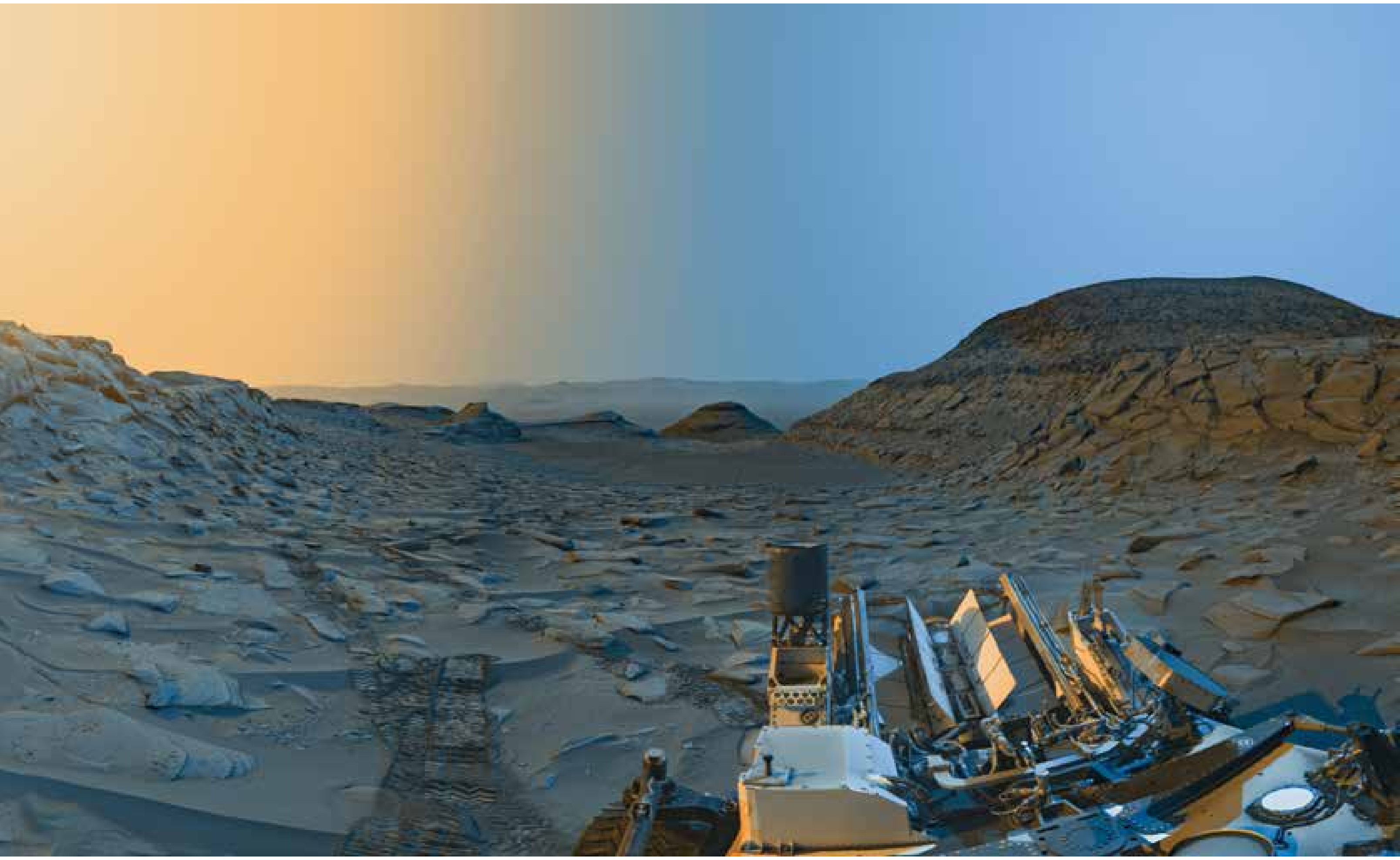
Ximencuo, a glacial moraine lake, sits among mountain peaks on the Tibetan Plateau in Dêqên Tibetan Autonomous Prefecture, China. Credit: Tenace10/Wikimedia Commons, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

In addition, the authors identify a suite of needs for future research, such as the following:

- improving data collection to quantitatively understand the role of climate in diabatic heating over the plateau
- improving the temporal resolution of observations (e.g., hourly to daily) to model atmospheric processes like clouds and precipitation more accurately
- improving regional and global climate model systems to reduce biases in their representation of the plateau
- crafting a complete physical image of the Tibetan Plateau's climate dynamics and thermal effects on the global climate

Focusing on these improvements will help scientists gain a more complete and systematic understanding of the plateau and its place in the current and future climate, the authors say. (*Reviews of Geophysics*, https://doi.org/10.1029/2022RG000771, 2022) **—Aaron Sidder,** *Science Writer*

Mars Has Far Fewer Minerals Than Earth Does



This panorama was merged from two colorized images of Marker Band Valley in Mars's Gale Crater taken by Curiosity on 8 April 2023, one in the morning (right) and one in the afternoon local time. Credit: NASA/JPL-Caltech

Whereas nearly 6,000 different minerals are known to exist on Earth, after more than 50 years of investigations, only 161 minerals have been recorded on Mars—a dramatically lower number for a planet that shares much in common with our own. According to a new study, the difference is because fewer pathways for minerals to form exist on Mars than on Earth, even though both planets began on very similar trajectories for mineral evolution.

Following on research to catalog mineral formation and evolution on Earth, *Hazen et al.* conducted a systematic study of all Martian minerals revealed through the past half century of Mars missions and analyses of Martian meteorites. Whereas earlier work identified 57 primary and secondary mineral-forming mechanisms on Earth, the new study identified just 20 modes of mineral formation on Mars.

Early in the planets' histories, minerals on Earth and Mars formed in similar ways. For instance, the first minerals on both planets likely crystallized directly from cooling magma. Hydrothermal activity likely also led to many new minerals on each planet. However, Earth's array of minerals went through extensive stages of diversification billions of years ago with the onset of plate tectonics and the proliferation of life—processes not known to have occurred on Mars.

Although there are undoubtedly many mineral phases on and below Mars's surface that have yet to be observed, the researchers note that the total count of Martian minerals is still likely an order of magnitude smaller than Earth's. (*Journal of Geophysical Research: Planets*, https://doi.org/10.1029/2023JE007865, 2023) **—Rachel Fritts**, *Science Writer*

Talc May Make Mexico's Subduction Zone More Slippery

The Mexican state of Guerrero, located on the country's Pacific coast, is known for its rich cultural history and iconic beach destinations like Acapulco. It is also home to a geologically curious subduction zone.

Below Guerrero, the Cocos plate slides beneath the North American plate in part via a fault-slip phenomenon known as episodic tremor and slow slip (ETS). In contrast to more common slip behaviors such as earthquakes, scientists understand relatively little about how ETS deforms tectonic plates.

Lindquist et al. developed petrologic models to study the variables that drive ETS, focusing on Guerrero as a natural laboratory for plate deformation research. Specifically, the authors investigate how the chemical alteration, or metasomatism, of serpentinized peridotite rock produces talc in the subduction zone. Talc is a weak, hydrous mineral that can preferentially host deformation in subduction zones and, the authors suggest, may facilitate ETS at subduction zone interfaces.

With their petrologic models, the researchers predicted mineral occurrences at the plate interface beneath Guerrero using realistic pressure, temperature, and composition conditions. They found that for talc to form where ETS occurs in the subduction zone, serpentinites must react with enough of the fluids to reach 43% silica by weight. However, even small silica additions beyond that amount result in significant volumes of talc at the plate interface that should then host deformation in the subduction zone. The team's models also predicted that talc grows in serpentinite mainly where subducting basalts undergo enough dehydration to produce sufficient volumes of silica-rich fluid.

Near Acapulco, Mexico, the Cocos plate slides under the North American plate at a rate of about 60 millimeters per year. Credit: Astrid Ameyalli Vázquez Salgado

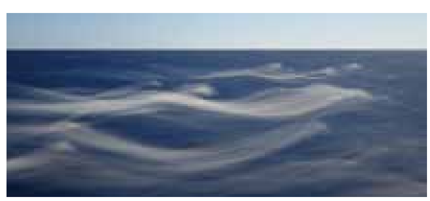
Although the models did not replicate the large, geophysically inferred talc volume in the subduction zone beneath Guerrero, they did predict the formation of thin zones of talc-rich rocks near where ETS occurs along the plate interface. The research, according to the authors, shows the importance of including metasomatism in fault slip models, and it provides direction for future research studying seismicity along Mexico's Pacific coast. (*Geochemistry, Geophysics, Geosystems,* https://doi.org/10.1029/2023GC010981, 2023) **—Aaron Sidder,** *Science Writer*

A Thin Skin Helps Regulate Ocean Carbon Uptake

At less than 1 millimeter thick, the ocean's skin—its uppermost layer—plays an outsize role in marine processes, orchestrating heat and chemical exchange between the sea and sky via diffusion. The water of the skin is about 0.2–0.3 K cooler and has higher salinity than the water at even just 2-millimeter depth.

Since it was first described in 1967, scientists have grappled with the skin's influence on carbon uptake and the global ocean carbon sink. Understanding its role is critical: Between 2011 and 2020, the ocean absorbed 26% of all human-generated carbon dioxide emissions, and variables that affect ocean carbon sequestration contribute to governing the carbon cycle and climate change.

Bellenger et al. toggled oceanic temperature and salinity gradients to represent the ocean skin over 15 years (2000–2014) in an



New research investigates how the carbon cycle functions in the uppermost layer of the ocean, seen here in a long-exposure photograph of the Caribbean Sea. Credit: Martin Falbisoner/Wikimedia Commons, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

Earth system model, assessing how the changes altered the amount of carbon absorbed by the ocean. The work represents the first model-based estimate of the ocean skin's influence on ocean-atmosphere carbon dioxide exchange.

Including the representation of the skin in the Earth system model led to a 15% increase in the simulated ocean carbon sink, the researchers found—a figure consistent with past estimates. However, when they allowed the ocean skin to respond to changing ocean carbon concentrations in the model, the effect on the sink was substantially reduced. With the dynamic skin, its contribution to the simulated ocean carbon sink was closer to 5%.

The research shows the importance of including the ocean skin in future climate and carbon modeling efforts, the authors say. And it demonstrates that an interactive parameterization of the ocean skin yields a more accurate model that reduces regional errors in carbon dioxide flux. (*Journal of Geophysical Research: Oceans*, https://doi.org/10.1029/2022JC019479, 2023) **—Aaron Sidder,** *Science Writer*

Beavers Remake Microbial Ecosystems in the Arctic

As the Arctic has warmed and beaver populations have rebounded, the animal architects known for greatly modifying their natural environments have expanded their habitats. Now, *Shannon et al.* show that beaver-instigated alterations translate all the way to the microscopic level, reshaping microbial communities in Arctic waterways.

In northern Alaska, the researchers waded into the water and sampled sediment from seven ponds formed by beavers and from seven beaver-free lakes and streams. Back in the lab, they analyzed the populations of bacteria, archaea, and fungi present in the samples.

The overall prevalence of microbes in the sediments from beaver habitats and in those from beaver-free streams was similar, whereas microbial communities from lakes lacking dams differed from those in beaver ponds. The diversity of bacteria and archaea was particularly variable, whereas abundant fungal communities were less influenced by the presence of beavers.

The team's analysis turned up some surprises. For example, the researchers found that the beaver ponds contained low levels of archaea that produce methane, a potent greenhouse gas. In contrast, previous research suggested that beaver activity can increase microbial methane production, leading the team to hypothesize that the sampled beaver ponds may be young and may become more methanogenic as they age.

Beaver-induced changes at the microbial level may result in ecosystem-scale shifts, the researchers note, although it's too early to tell exactly how the animals will affect northern Alaska as the climate changes. Beaver dams favor microbes that promote plant growth, and as vegetation moves farther north into the Arctic, beavers will surely follow. The increasingly plant rich environments will likely capture more carbon, helping to mitigate emissions from the environment, but in the long run, those gains may be offset by carbon released as microbes break down the vegetation. Also, the standing water that forms when beavers make dams may hasten permafrost thaw, potentially stimulating microbial growth.

In any event, it's likely the influence of beavers will run deep. (*Journal of Geophysical Research: Biogeosciences,* https://doi.org/10.1029/2023JG007408, 2023) **—Saima May Sidik,** *Science Writer*

Current Agriculture Adds More Phosphorus to Streams Than to Lakes

Phosphorus is an important nutrient, but too much of it in lakes and streams can diminish water quality and lead to eutrophication, resulting in harmful algal blooms and dead zones. To restore waterways degraded by excess phosphorus, decisionmakers must understand which sources of the nutrient could be reduced to make the biggest impact on water quality.

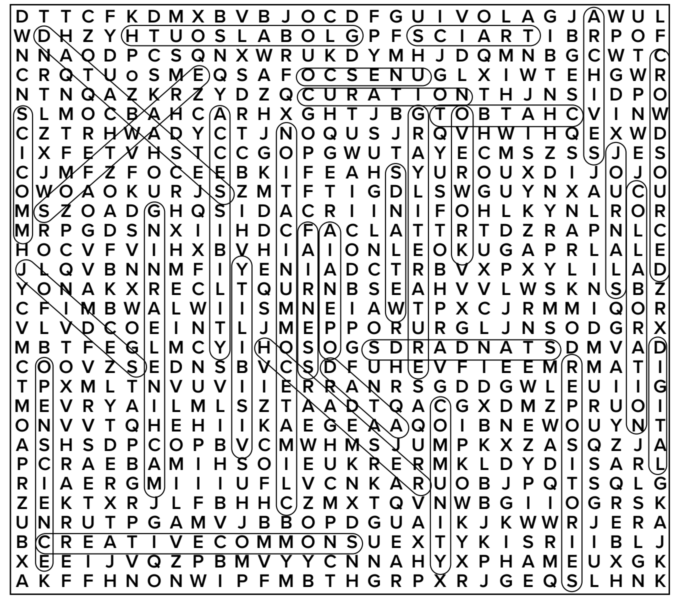
Agricultural runoff from fertilizers and manure is a common source of phosphorus, but the impact of agriculture is not uniform across different bodies of water. *Sabo et al.* applied several statistical approaches to analyze data from the U.S. EPA's National Lakes Assessment and the National Rivers and Streams Assessment to determine the most influential drivers of phosphorus levels in the country's lakes and streams and better understand how these systems differ in their responses to changing inputs from various phosphorus sources.

The researchers found that phosphorus levels in streams were most strongly influenced by the amounts of fertilizer and manure introduced to nearby farmland, as well as by legacy sources of agricultural phosphorus released by erosion. Lake phosphorus levels, meanwhile, were determined by a more complex mix of variables: Agricultural runoff played a role, as did historic inputs from erosion, internal recycling, and other factors.

Quantifying the biggest sources of phosphorus in U.S. waterways, such as Hazel Creek in North Carolina (pictured), is important for informing effective policy aimed at restoring these waters. Credit: Jerry Ackerman, U.S. EPA

The study indicates that in the short term, efforts to mitigate agricultural runoff would have the greatest impact on reducing phosphorus surpluses in U.S. streams. However, higher temperatures and more precipitation also correlated with increased phosphorus levels in the data set, and the authors note that these factors could contribute to greater phosphorus loading in surface waters in the future due to climate change. (*Journal of Geophysical Research: Biogeosciences,* https://doi.org/10.1029/2022JG007227, 2023) **—Rachel Fritts,** *Science Writer*

The research reported here supports **Sustainable Development Goal 6.** AGU is committed to supporting the United Nations 2030 Agenda for Sustainable Development, which provides a shared blueprint for peace and prosperity for people and the planet, now and into the future.



TEXAS
The University of Texas at Austin

ASSOCIATE/FULL PROFESSOR IN CRITICAL MATERIAL AND MINERAL RESOURCES

DESCRIPTION
The Jackson School of Geosciences at The University of Texas at Austin seeks to hire an outstanding scholar in the general field of **Critical Material and Mineral Resources**. We are looking for scholars whose research addresses the properties, distribution, mobilities, exploration, extraction and geological occurrences or potential recycling of elements and materials that are critical for energy transition, information and infrastructure technologies using laboratory, field and/or computational approaches. The search is for a tenured **Associate or Full Professor** who will hold a joint appointment between the Department of Earth and Planetary Sciences and the Bureau of Economic Geology

The Department of Earth and Planetary Sciences (EPS) and the Bureau of Economic Geology (BEG) are both parts of the Jackson School of Geosciences (JSG), a large community of faculty and research scientists with a broad range of specialties and access to outstanding research facilities and support. The mission of BEG is to serve society by conducting objective, impactful, and integrated geoscience research on relevant energy, environmental, and economic issues. BEG is the State Geological Survey of Texas and has been an integral part of the development of the state's economic success through the years. The mission of EPS is to advance our understanding of the Earth and educate the next generation of geoscientists. EPS is one of the leading Geoscience programs in the world with a vibrant blend of basic and applied research organized into three programs: Surface, Subsurface and Life; Lithosphere and Deep Earth; and Water, Climate and the Environment. In addition to programs in Geosciences, JSG hosts a multidisciplinary graduate program in Energy and Earth Resources.

QUALIFICATIONS
We seek an individual with an established research and mentorship record who will develop new and expand existing collaborations among faculty, researchers, and students within the JSG, across campus, and around the globe. The successful candidate will have a reduced teaching load relative to full-time faculty and is expected to develop funding at BEG for multidisciplinary team research in the area of Critical Earth and Mineral Resources.

Candidates are encouraged to describe how their work will address topics of acute scientific interest and critical societal importance related to the dual challenge of supplying the world with affordable, reliable energy while also reducing the environmental impacts of all forms of energy. We are especially interested in candidates who demonstrate an ability to think across traditional disciplinary boundaries and forge collaborative research endeavors within and beyond the JSG. Candidates should describe how their research can be developed into a multidisciplinary research program in critical minerals and energy transition at the BEG.

The Jackson School of Geosciences embraces its place within Texas' academic flagship, The University of Texas at Austin, a large, bold, and ambitious top-ten public research university. UT Austin's cutting-edge research and top-quality, diverse student body contribute to the state's vibrant growth and diverse economic base, which powers the ninth-largest economy in the world and creates a myriad of opportunity for impactful and entrepreneurial research. The university sits at the heart of Austin, the "live music capital of the world," with a vibrant mix of culture, sports, entrepreneurship, higher education, and politics which make it one of the fastest growing cities in the country. Austin lies within the beautiful Hill Country of Texas, which provides extensive opportunities for outdoor recreation, with extensive parks, trails, and waterways.

APPLICATION INSTRUCTIONS
Review of applications is planned to begin **September 10, 2023** and will continue until the position is filled. Interested applicants should submit a cover letter; CV; a research statement that articulates scientific questions and a plan for addressing them, including a collaborative research vision; a teaching and mentoring statement that describes a philosophy and a plan for enacting it. Contact information for at least three individuals who would be able to provide letters of reference should be supplied on a separate document. Submit copies of these materials through Interfolio's 'Apply Now' option. Questions concerning the application process should be sent to Charlie Kerans at **ckerans@jsg.utexas.edu**.

UNC CHARLOTTE
Department of Geography & Earth Sciences

POSITION NUMBER 006922
ASSISTANT PROFESSOR IN EARTH MATERIALS
DEPARTMENT OF GEOGRAPHY AND EARTH SCIENCES
UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE

The Department of Geography and Earth Sciences in the College of Humanities & Earth and Social Sciences at the University of North Carolina at Charlotte invites applications for a tenure- track appointment at the rank of **Assistant Professor in Earth Materials**. We are seeking a dynamic and broadly trained Earth scientist who employs field, laboratory and/or modeling techniques for the study of Earth materials (e.g., minerals, sediments, and/or resources). This position will begin on **August 15, 2024**.

QUALIFICATIONS: Candidates are required to have earned a PhD in Geology, Geosciences, Earth Sciences, Environmental Sciences, Physical Geography, or a related field at the time of appointment. Candidates will be expected to demonstrate evidence of scholarly productivity, their ability to secure appropriate external funding, and the potential for engaging students in a diverse academic environment. Finalists will be asked to discuss how their teaching practices engage students of different ages, races, ethnicities, backgrounds, identities, and abilities, helping to remove barriers in order to ensure the success of all students regardless of their entry pathway into the university.

Candidates should demonstrate the ability to contribute to the department's undergraduate curricula in Geology, Geography, and/or Earth and Environmental Sciences programs, and graduate curricula in Earth Sciences, Geography and/or the interdisciplinary Infrastructure and Environmental Systems (INES) degrees. Applicants should explain how they will build a sustainable, cutting-edge, externally funded research program, and develop coursework in their area of expertise.

Desired qualifications include the ability to articulate their potential for interdisciplinary collaboration in their research and teaching as it relates to Earth surface geosciences, especially in the "Critical Zone," defined as the region where Earth's atmosphere, biosphere, lithosphere and hydrosphere interact. We seek a geoscientist who can relate their research to broader questions addressing, for example, critical zone evolution, climate change, human- environment interaction, health and hazards, energy transitions, and/or sustainability.

THE DEPARTMENT: The Department of Geography and Earth Sciences (**https://geoearth.charlotte.edu/**) is a diverse community of physical, geospatial, and social scientists composed of over 35 faculty members, 400 undergraduate majors, and 60 graduate students. Our mission is to inspire discovery of the Earth and its inhabitants with a vision for an informed and diverse community that strives for a sustainable Earth and an equitable world. We create and disseminate knowledge of the Earth's human and natural systems to adapt to an ever-changing environment in which we live, work, and interact. The Department offers undergraduate degrees in Meteorology (BS), Earth and Environmental Sciences (BS), Geology (BS), Geography (BA/BS), and Environmental Studies (BA). At the graduate level, we offer an MS in Earth Sciences, an MA and PhD in Geography, and participate in the interdisciplinary Infrastructure and Environmental Systems (INES) and Public Policy (PPOL) PhD programs. The Department is also home to the Center for Applied Geographic Information Science (**CAGIS, https://gis.charlotte.edu/**) and the Charlotte Action Research Project (**CHARP, https://charp.charlotte.edu/**). We are committed to excellence in disciplinary and interdisciplinary research and teaching.

THE COLLEGE: The Department of Geography and Earth Sciences is housed within the newly established College of Humanities & Earth and Social Sciences (CHESS), which includes 15 departments, 18 interdisciplinary programs, and 6 applied centers. The College plays a pivotal role in delivering on the University's goals in the areas of research excellence, student success and experience, and community engagement. Through scholarship and teaching, the College's 350+ faculty members seek to deepen our understanding of complex problems related to the intersection of human and natural systems.

THE UNIVERSITY: UNC Charlotte is the second largest institution within the University of North Carolina system. This fall, UNC Charlotte enrolled 30,298 students and experienced record growth in its incoming first year class and graduate programs. UNC Charlotte is also the fastest growing institution in the UNC System, comprising 10 academic colleges offering 171 undergraduate majors in 77 programs leading to Bachelor's degrees, 65 Master's degrees, and 24 Doctoral degrees. UNC Charlotte is proud to have 3,545 passionate and committed faculty and staff members and more than 120,000 living alumni.

APPLICATION: Candidates should submit the following to **https://jobs.charlotte.edu [Position Number 006922]**: (1) a cover letter; (2) a research statement; (3) a teaching statement; (4) a curriculum vitae; and (5) contact information (including email addresses) for at least three professional references.

Review of applications will begin on December 15, 2023 and will continue until the position is filled. For more information, contact search committee co-chairs Dr. Patricia Fall (**pfall@charlotte.edu**) and Dr. Martha Cary (Missy) Eppes (**meppes@charlotte.edu**)

As an EOE/AA employer and an ADVANCE Institution that strives to create an academic climate in which the dignity of all individuals is respected and maintained, the University of North Carolina at Charlotte encourages applications from all underrepresented groups. The candidate chosen for this position will be required to provide an official transcript of their highest earned degree and submit to a criminal background check.

Assistant Professor of Earth Sciences, Geochemistry - Dartmouth College

The Department of Earth Sciences at Dartmouth College invites applications for a full-time tenure track position at the rank of Assistant Professor in the general area of geochemistry. We are particularly interested in low temperature geochemists and biogeochemists with research in the broad area of modern surface processes and/or land-water interactions. We will prioritize applicants who focus on understanding fundamental processes with a state-of-the-art laboratory, modeling, and/or field research program, provide synergy with existing research activities at Dartmouth, and actively support the Department's commitment to promoting diversity.

As the person in this position will continue Dartmouth's strong traditions in graduate and undergraduate research and teaching, effective classroom teaching is essential for this position. Teaching responsibilities consist of three courses spread over four ten-week terms. The teaching assignment for this position includes a course on low temperature aqueous geochemistry. To create an atmosphere supportive of research, Dartmouth offers faculty members grants for research-related expenses, a quarter of sabbatical leave for each three academic years in residence, and flexible scheduling of teaching responsibilities. The Department of Earth Sciences is home to 13 faculty members in the Faculty of Arts and Sciences and enjoys excellent graduate (Ph.D. and M.S.) and undergraduate programs. We are especially interested in applicants who have a demonstrated ability to contribute to Dartmouth's diversity initiatives in STEM research, such as the Women in Science Program, E.E. Just STEM Scholars Program, and the Academic Summer Undergraduate Research Experience (ASURE). Beyond our department, our graduate students and postdoctoral scholars are supported by the Guarini School for Graduate and Advanced Studies, including their diversity and inclusion initiatives

The Department of Earth Sciences and Dartmouth are committed to fostering a diverse, equitable, and inclusive population of students, faculty, and staff. Dartmouth recently launched a new initiative, Toward Equity, that embraces shared definitions of diversity, equity, inclusion, and belonging as a foundation for our success in institutional transformation. The specific efforts of the Earth Sciences department are highlighted on our website. We are especially interested in applicants who are able to work effectively with students, faculty, and staff from all backgrounds and with different identities and attributes. Applicants should provide a statement addressing how their teaching, research, service, and/or life experiences prepare them to advance Dartmouth's commitment to diversity, equity, and inclusion. This statement will be evaluated as part of the selection process.

Qualifications: Applicants should have a PhD in Earth Sciences, Geology, or a closely related field, or be ABD with degree received before the start of the appointment. Effective classroom teaching is essential for this position.

Application Instructions: Please submit all materials electronically via Interfolio: http://apply.interfolio.com/130093

1. Cover letter
2. Curriculum vitae, including contact information for three references
3. Statement of teaching experience and interests
4. Statement of research interests and objectives
5. Statement addressing how the applicant's teaching, research, service, and/or life experiences prepare them to advance Dartmouth's commitment to diversity, equity, and inclusion
6. Writing samples: reprints or preprints of up to three (3) of your most significant publications

Review of applications will begin on October 1, 2023 and continue until the position is filled.

Equal Employment Opportunity Statement: Dartmouth College is an equal opportunity/affirmative action employer with a strong commitment to diversity and inclusion. We prohibit discrimination on the basis of sex, race, color, religion, age, disability, status as a veteran, national or ethnic origin, sexual orientation, gender identity, gender expression, or any other category protected by applicable law, in the administration of its educational policies, admission policies, scholarship and loan programs, employment, or other school administered programs. Applications by members of all underrepresented groups are encouraged.

If you are an applicant with a disability and need accommodations to assist in the job application or interview process, please email ADA.Institutional.Diversity.and.Equity@Dartmouth.edu. In the subject line, please state "Application Accommodations" and include the job number r title. Someone from the ADA Compliance Office will be in touch within 2 business days.

For additional employment opportunities at Dartmouth College, please visit the Dartmouth Interfolio Job Board, the Office of the Provost, and the Office of Human Resources.

Offers of employment are contingent upon consent to a pre-employment background check with results acceptable under Dartmouth policy. Please visit the Office of Human Resources for details.

All Dartmouth College employees, whether working on-site or remotely, must be fully vaccinated against COVID-19 or receive an approved medical or religious exemption from vaccination through Dartmouth's Division of Institutional Diversity and Equity (IDE). Compliance with the Dartmouth COVID-19 Employee and Appointee Vaccination Policy is a condition of employment, and every offer of employment is contingent upon submission of appropriate documentation evidencing either vaccination against COVID-19, or the receipt of an approved exemption. Failure to meet this condition of employment may result in Dartmouth, in its sole discretion, delaying employment or rescinding its offer of employment.
Visit https://dartgo.org/vaxpolicyto review the Policy and for details and information on requesting an exemption and/or reasonable accommodation.

U.S. NAVAL RESEARCH LABORATORY

POSTDOCTORAL AND PERMANENT RESEARCH POSITIONS – OCEAN DYNAMICS AND PREDICTION BRANCH

- **Naval Research Laboratory**, Stennis Space Center, MS
- Postdoc annual 2023 salary is **$79,363 + benefits**, renewable up to 3 years
- Permanent position **$80,000 to $150,000 + benefits**, commensurate with experience

We are researchers seeking to understand and numerically represent ocean, ice, and wave dynamics for prediction systems with the long-term goal to transition for operational use. We collaborate with researchers across the globe from government agencies to academia. Research results are published in peer reviewed journal articles. The research and development at NRL require close collaborations between interdisciplinary scientists.

Information on projects, publications, and opportunities is at: **www7320.nrlssc.navy.mil**

Send your resume or any questions to: **7320jobs@nrlssc.navy.mil**

Because the work is multi-disciplinary, we seek people with knowledge and expertise in any of the following: oceanography, geophysical fluid dynamics, computer science, mathematics, data assimilation or related fields. Applicants should have skills in ocean modeling, data analysis, computer programming, or high-performance computing. With all people in our group, career advancement is a central concern. Therefore, we work with applicants to determine exciting projects with engaging mentors that will enable their growth in the field. We expect research results to be published in leading journals and to be presented at conferences. Research projects span global to nearshore scales. The physics include the ocean, surface waves, and sea ice.

With access to major high-performance computing resources, we utilized over 300 million CPU hours in the last year. Co-located with the Naval Oceanographic Office and Fleet Numerical Meteorology and Oceanography Center, we work closely with these operational groups to bring new research systems to application. Our systems are used in a broad range of daily decision applications around the globe. This is an opportunity to work with the nation's largest group of dedicated ocean prediction researchers. The work involves building numerical systems that forecast ocean dynamics, developing techniques to process satellite and in situ information, and assimilating observations into numerical models.

- **Postdoctoral Fellowships** – Annual 2023 salary is $79,363. Renewable up to 3 years. Benefits: Medical, Dental, Vision, Life.
- **Permanent Researchers** – Annual salary for full time federal civilian positions ranges from $80,000 to $150,000, commensurate with experience. Benefits: Medical, Dental, Vision, Life, Pension, Retirement.
- Variable work schedules with partial telework options. (No remote work.)

Be part of the future of ocean prediction!

Email us at **7320jobs@nrlssc.navy.mil**

Our research areas include:

- Thermohaline circulation
- Ocean dynamics
- Surface wave prediction
- Air-sea interactions
- Nearshore hydrodynamics
- Marginal sea upwelling
- High latitude ocean dynamics
- Arctic sea ice modeling
- Turbulence modeling
- High performance computing
- MPI computational coding
- Mesoscale dynamics
- Submesoscale structures
- Submesoscale eddy dynamics
- High resolution coastal modeling
- Frontal processes
- Predicting small scale features
- Probabilistic prediction
- Ocean internal wave modeling
- Coupled ocean/acoustics
- Nearshore hydrodynamics
- Cryosphere forecasting
- Optimal UUV sampling plans
- Automated unmanned control systems
- Autonomous controlled systems
- Satellite observations
- In situ observations
- Data assimilation
- Covariance modeling in assimilation
- Variational assimilation

PRINCETON UNIVERSITY

VISITING RESEARCH SCIENTISTS

In collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), the Atmospheric and Oceanic Sciences Program at Princeton University solicits applications to its **Visiting Research Scientist Program** funded by the Cooperative Institute for Modeling the Earth System (CIMES).

The AOS Program and GFDL offer a stimulating and supportive environment with significant computational and intellectual resources in which to conduct collaborative or independent research. Independent researchers and more senior scientists who wish to visit GFDL for the purpose of collaboration, for sabbatical or short visits, will be considered for partial support. We seek applications in all areas of Earth System Science comprising the atmosphere, oceans, biosphere, cryosphere, ecosystems. The three research themes of CIMES are: **1)** Earth System Modeling; **2)** Seamless prediction across time and space scales; **3)** Earth System Science: Analysis and Applications.

Further information about the Program may be obtained from: **http://aos.princeton.edu/**, and about GFDL from **http://www.gfdl.noaa.gov**. Applicants are strongly encouraged to contact potential hosts at GFDL and Princeton University prior to application to discuss areas of possible research.

Complete applications, including a CV, copies of recent publications, three letters of recommendation, and a research proposal of approximately 5 pages including the project title, should be submitted by **December 8th, 2023, 11:59pm EST**, for full consideration. A goal of our department is providing equal opportunity, diversifying the community of scientists and making the Program more equitable and inclusive. With this in mind, candidates are welcome to describe how their experiences and approaches on diversity-related issues inform their professional work, such as in scholarship, teaching and advising as part of their research proposal. Applicants must apply online at **https://www.princeton.edu/acad-positions/position/32324**. Advanced degree is required. We would like to broaden participation in earth system scientific research and therefore encourage applications from groups historically under-represented in science.

This position is subject to the University's background check policy. Princeton University is an equal opportunity/affirmative action employer and all qualified applicants will receive consideration for employment without regard to age, race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability status, protected veteran status, or any other characteristic protected by law.

FACULTY POSITIONS – DEPARTMENT OF ATMOSPHERIC SCIENCES, NATIONAL TAIWAN UNIVERSITY

The Department of Atmospheric Sciences (DAS) at National Taiwan University (NTU) seeks one to two faculty members at the **Assistant, Associate, or Full Professor levels**, beginning in **August 2024**, with expertise in the fields of severe weather (typhoon and mesoscale convection), east-Asia monsoon, extreme weather and climate, atmospheric physics and chemistry, observation/instrument/remote sensings, or emerging critical topics in atmospheric sciences.

NTU is a world-renowned university that attracts most competitive students and faculty from Taiwan and abroad. DAS is one of the core institutions of the Earth System Science in College of Science of NTU. DAS offers complete educational programs of atmospheric sciences from Bachelor to Ph. D. level and has various laboratories with excellent facilities for teaching and research in three major directions: **(1)** Dynamics and forecasting of severe weather; **(2)** Global change, climate dynamics, and air-sea/air-land interaction; **(3)** Physical/chemical processes of atmospheric phenomena and related environmental issues. Faculty and students of DAS are dynamic and forward-looking in pursuing academic excellence. The recruit of new faculty is expected to further strengthen research and teaching activities of DAS and to develop unique and creative study programs.

The basic salary will be 13.5 monthly salaries (up to 51K USD annual). Additional other benefits include the reputable national health service in Taiwan and other possible benefits. Outstanding candidates may also apply for various sources of additional stipends on competitive basis (Please check **https://reurl.cc/XEvvma** for more detail).

Applicants must hold a Ph.D. degree in atmospheric sciences or closely related fields, preferably with postdoctoral experience, capability of developing distinctive and innovative research projects and teaching experience. Application documents should be submitted online through the Academic Jobs Online by including **(1)** curriculum vitae with a complete publication list, **(2)** statement of research interests, **(3)** statement of teaching experience and interests, and **(4)** contact information of at least three references (indicate in the cover letter including name, title, affiliation, official email and phone). The application deadline is **30 November, 2023**.

Further information and inquiries can be addressed to:
Faculty Search Committee
Department of Atmospheric Sciences,
National Taiwan University,
E-mail: yuku@ntu.edu.tw

Website for application: **https://academicjobsonline.org/ajo/jobs/25510**

Word Search: Wide. Open. Science.

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

Search up, down, forward, backward, and on the diagonal in the grid above to locate the words listed below.

accessibility
archives
chatbot
climate communication
collaboration
community
creative commons
crowd sourced
curation
data
databases
digital
fairness
Global South
gray literature
JOIDES
journals
machine learning
open AI
open science
overwork
repositories
research
sci art
sci comm
software
standards
UNESCO
visibility
wetlands

See p. 71 for the answer key.

NASA, ESA, CSA, and STScI

Greetings from 4.6 billion years ago!

This is the first deep field image from the James Webb Space Telescope, centered on the galaxy cluster SMACS 0723. Beyond the stars of the Milky Way (which have 8 points) are thousands of galaxies, trillions of stars, and a vast, untold number of planets. This image would fit within a grain of sand held at arm's length against the night sky—truly, science is wide open.

—**Kimberly Cartier,** Senior Science Reporter