Eos

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SCIENCE NEWS BY AGU

What's next for science?

you!

AGU
ADVANCING EARTH AND SPACE SCIENCES

What's Next for Science? Look in the Mirror

AGU24 gives us an opportunity to reflect on how science can grow in breadth and depth and how scientific communities can help define the future.

This year, AGU's Annual Meeting is taking place in Washington, D.C., on the cusp of a new presidential administration in the United States, an administration whose policies will have far-reaching implications for Earth and space scientists around the world.

So "What's next for science?" we ask.

The complex, transdisciplinary techniques of modeling and mapping can help scientists answer that question from pole to pole. In "The Arctic's Uncertain Future" (p. 32) Grace van Deelen unspools why climate models become less and less sure as longer and longer time periods are forecast. On the other end of the world, we learn how scientists have mapped the growing extent of vegetation in Antarctica (p. 4).

Communities, too, are determining what's next for science. Deaf scientists are literally "Crafting Signs for Geoscience's Future" (p. 26) with innovative new language to encourage and empower their fellow researchers, Kimberly M. S. Cartier reports. In "Empowering Genderqueer Geoscientists: Being and Building the Change," (p. 13) leaders of AGQ share how the group has grown from an "informal gathering of friends and colleagues" to a powerful chorus of voices in the science community.

Of course, no one community or discipline will determine where science is headed. In "Can the Belt and Road Go Green?" (p. 18) author Mark Betancourt explores how the sustainable development potential of China's Belt and Road Initiative offers a real-world (and realpolitik) glimpse into the opportunities and challenges of a globe-spanning project.

So what's next for science? You, of course! Whether you're an author or reader, a scientist modeling the future, or a member of a contemporary affinity group, your character and contributions define AGU today and will continue to define it in the future.

Caryl-Sue Micalizio, Editor in Chief

Eos

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Janice Lachance, Interim Executive Director/CEO

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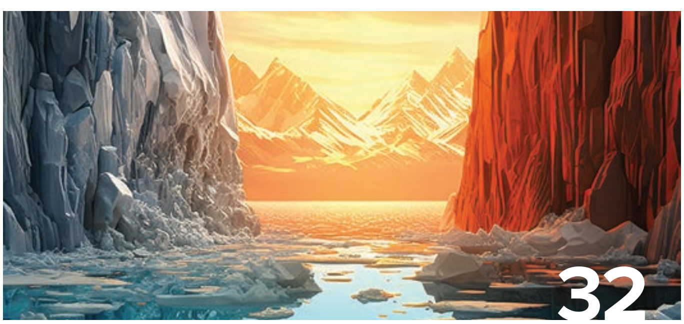

Columns

On the Cover

Design by Beth Bagley; illustrations by Mary Heinrichs

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Prince Sultan Bin Abdulaziz International Prize for Water

Recognizing Innovation

Winners for the 11th Award (2024)

Creativity Prize

Creativity Prize

[1] The team of Maria Cristina Rulli (Polytechnic of Milan, Italy) and Paolo D'Odorico (University of California, Berkeley, USA)

for spearheading novel analyses of the water-energy-food nexus that describe how numerous complex factors interact, providing for better freshwater stewardship in a changing, globalised world.

Maria Cristina Rulli

Paolo D'Odorico

[2] The team of Zhiguo He (Zhejiang University, China)

for developing working, versatile soft robots with unprecedented manoeuvrability that have the capacity for numerous underwater research and monitoring applications. Team members include: Pengcheng Jiao and Yang Yang.

Zhiguo He

Surface Water Prize

Surface Water Prize

Qiuhua Liang (Loughborough University, UK) and his team

for developing innovative, open-source, multi-GPU hydrodynamic models to support real-time flood forecasting at fine temporal resolutions. Team members include: Huili Chen, Xiaodong Ming, Xilin Xia, Yan Xiong and Jiaheng Zhao.

Qiuhua Liang

Groundwater Prize

Groundwater Prize

Chunmiao Zheng (EIT, Ningbo, China) and his team

for powerful management tools to understand groundwater processes in ecohydrologic systems under diverse hydrological and climatic conditions, considering environmental and socioeconomic factors at local and national scales.

Chunmiao Zheng

Alternative Water Resources Prize

Alternative Water Resources Prize

Virender K. Sharma (Texas A&M University, USA) and his team

for the effective removal of antibiotics and pharmaceuticals from wastewater through advanced oxidative processes by activated ferrate, which work at high, even enhanced, efficiency in water containing commonly occurring natural organic matter. Team members include: Ching-Hua Huang, Chetan Jinadatha and Radek Zbořil.

Virender K. Sharma

Water Management & Protection Prize

Water Management & Protection Prize

Joseph Hun-wei Lee (Macau University of Science & Technology, China)

for developing unique and highly effective hydro-environmental modelling systems for the sustainable water management of smart cities.

Joseph Hun-wei Lee

Invitation for Nominations

12th Award (2026)

Nominations open online until 31 December 2025

www.psipw.org e-mail: info@psipw.org

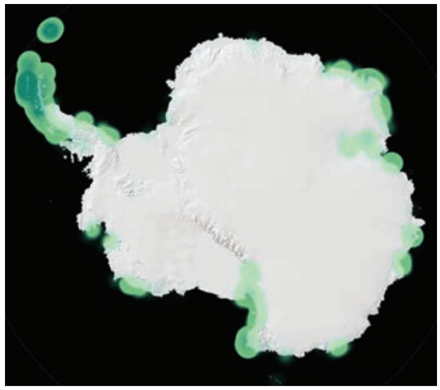
New Map Reveals the Extent of Vegetation in Antarctica

Antarctica's icy white interior gives the continent the appearance of a still and barren landscape. A recent study, however, has documented that the mostly monochrome backdrop hosts a vibrant community of hardy and colorful vegetation.

Scientists have now mapped out vegetation across the whole of coastal Antarctica. Patches of vascular plants, bryophytes, lichens, and algae dot ice-free areas, and green snow algae cover sections of coastal snowpack.

The vegetation spans an area of just 44 square kilometers (17 square miles)—a small fraction of Antarctica's 14.2 million square kilometers (5.5 million square miles). "It is about the size of Manhattan Island on a continent larger than Australia," said Claudia Colesie, a polar ecologist at the University of Edinburgh and a member of the research team.

The group created the map using data from the European Space Agency's Sentinel-2 mission. Instruments aboard the mission's pair of satellites detect light reflected from Earth's surface. The color of the light helped the scientists distinguish vegetation from rock and snow. Field observations helped to ground truth the imagery.



This map shows the distribution of plant life in Antarctica (green circles) detected in Sentinel-2 images. Credit: Charlotte Walshaw; background image from Landsat data`

Other satellites with coarser imaging capabilities have not been able to detect Antarctica's patchy, sparse vegetation accurately. Previous research was limited to small-scale maps for monitoring, making it difficult to tell whether vegetation changes at a particular site were significant or minor.

Sentinel-2 images have a resolution of 10 meters (33 feet), allowing the satellites to detect these smaller-scale features throughout the continent. The new map, which uses data from 2017–2023, provides a broader perspective that will allow scientists to compare future observations with the complete picture of vegetation distribution and more accurately assess changes.

The study and map were published in *Nature Geoscience* (bit.ly/Antarctic-map).

Vegetation in Antarctica is dominated by lichen and mosses. Credit: Felix Grewe

A Base Map

"This project made me realize how important this map is going to be for conservation and in identifying vegetation in key areas, which might not be currently protected," said Charlotte Walshaw, the study's first author, who is pursuing a Ph.D. in remote sensing at the University of Edinburgh.

As a result of climate change, the ice covering much of Antarctica is melting, exposing more land. "There is clear evidence from local-scale studies that populations of Antarctica's two flowering plants and some mosses have expanded rapidly in recent decades," said Peter Convey, a polar ecologist and biogeographer at the British Antarctic Survey and a study coauthor.

The new map could be used to monitor vegetation and document changes throughout the Antarctic.

"Given the lack of large-scale mapping and data on plant distribution and status in Antarctica, there are significant controversies and knowledge gaps regarding the response trends of Antarctic ecosystems to global change," wrote Wenjin Wu in an email. Wu is a remote sensing scientist at the Chinese Academy of Sciences who was not involved in the study. "The mapping presented in this paper is very helpful for understanding the impact of global change on Antarctic plants and will aid our efforts to protect them," Wu continued.

By merging the new map with data from prior studies and using more satellite imagery, researchers may be able to construct forecasts for biodiversity changes in Antarctica, according to Colesie and Walshaw.

By **Larissa G. Capella** (@CapellaLarissa), Science Writer

Some Urban Trees Suffer Under Climate Stress

Van Cortlandt Park, in northwestern Bronx, N.Y., is one site where researchers studied how climate change affects the growth of urban trees. Credit: Steven Pisano/Flickr, CC BY 2.0 (bit.ly/ccby2-0)

Trees in northern U.S. cities are feeling the impacts of climate change. Heat and water stress might be hindering tree growth more severely in the urban forests of Boston and New York City than in surrounding rural areas—although experts say more work is needed to know for sure. That's according to a new study published in *Ecological Applications* (bit.ly/urban-tree-stress).

If trees struggle to grow in a warmer future, they may not offer cities the same benefits that trees today provide, said environmental ecologist Andrew Reinmann of the City University of New York, who supervised the work.

"There is a lot of research in natural or near-natural environments that are dwindling on our planet, and there is not enough research in managed and urban areas," said forest ecologist Flurin Babst of the University of Arizona, who was not involved with the research.

The new study begins to fill that gap.

A Tale of Three Cities

Urban trees bring a plethora of benefits, from providing shade to removing pollutants from the air to improving mental health.

But urban trees also experience unique stresses. Cities tend to be hotter than surrounding areas, their soil tends to be more compacted, and city air tends to be drier and contain more particulate matter.

These stresses are compounded by heat waves and droughts brought on by climate change, according to the new study. In his previous research as a postdoc at Boston University, Reinmann and his colleagues found that unusually hot weather affected the growth of trees in Boston's urban forests more strongly than that of trees in nearby rural forests (bit.ly/urban-forests). He wondered whether the same was true in other cities.

> **"There is a lot of research in natural or near-natural environments that are dwindling on our planet, and there is not enough research in managed and urban areas."**

In 2020, Barnard College undergraduate student Kayla Warner used her time during COVID lockdown to dig into the question of how urban forests respond to climate change by analyzing tree cores that had been collected for other research prior to the pandemic. The cores came from several dozen trees in each of three cities—Baltimore, Boston, and New York—as well as from nearby rural forests. The researchers selected these locales because they have similarly humid, temperate climates.

Warner correlated the growth rings of three species that are common in these cities—red oak, white oak, and red maple—with climate data going back to the 1990s.

Distinct Behavior

During much of the year, the growth rates of oak trees in Boston and New York suffered more from hot, dry weather than the growth rates of trees in surrounding areas, the researchers found. For all trees in Massachusetts and New York, the distance between rings grown during hot, dry years was smaller than between those grown during wetter, cooler years. But that distance was reduced more significantly in city trees than in their rural counterparts.

Baltimore's urban forests also suffered from water stress, but unlike in the other two cities, they were not strongly affected by heat stress.

"I don't have a clear answer for why Maryland behaves a little bit differently than New York and Boston," Reinmann said.

"It reminds me of some research on people's experiences of heat stress," said quantitative ecologist Ailene Ettinger of The Nature Conservancy. "People in northern latitude cities also tend to be much more sensitive to high heat events because we're not as well acclimated."

"It reminds me of some research on people's experiences of heat stress."

It's possible that each city contains genetically distinct subspecies of maples and oaks that have adapted to different weather patterns, Reinmann said. Given that hypothesis, Babst said it could make sense to compare the growth of trees derived from all three cities side by side under a range of climate conditions—a "common garden experiment," as it's called in the field. "That would be a really, really cool project," he added.

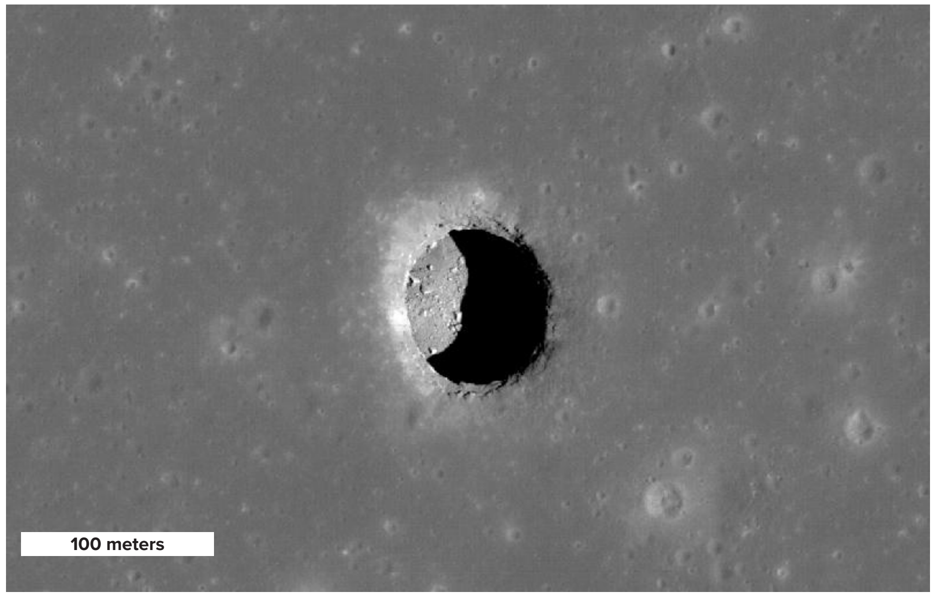
The study is a nice start, but scientists have a way to go before they fully understand how urban trees are responding to climate. "Sample size in this research is relatively small," said forest ecologist and postdoc Jiejie Wang of Université Laval. Analyzing more trees will help researchers draw robust conclusions. Babst suggested analyzing longer time series.

Measuring water stress also can be tricky because it can be difficult to say how much of the water in the environment is actually available to trees. Wang said she thinks analyzing soil moisture would be the most appropriate way to determine this. Instead, the researchers used a combined measure of heat and water. "I would have liked to see a water-only metric, like simply precipitation, for example," Babst said.

The sooner follow-up work can happen, the better, Ettinger said. "Urban trees are critical for bolstering our climate change resilience."

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

Lunar Lava Tube Revealed Beneath Collapsed Pit



The Lunar Reconnaissance Orbiter took this high-Sun image of the Mare Tranquillitatis pit in 2010. Credit: NASA/GSFC/Arizona State University

The Moon's surface is pockmarked with more than 200 known pits where rocks and regolith collapsed into depths unknown. New research has found that one of those pits, in Mare Tranquillitatis, leads into a lava tube, making an underground cave conduit accessible from the lunar surface.

"We found a sort of front door to enter the subsurface," said Leonardo Carrer, a planetary scientist at the Università di Trento in Italy and first author of the research. Its access to the otherwise shielded lunar subsurface makes this pit a tantalizing site for future human and robotic exploration and could provide new insight into lunar volcanism.

Reflections from Below

The Moon was once covered in seas of magma that eventually cooled into the dark basaltic maria visible today. Lunar scientists have long thought that like Earth, the Moon could host other volcanic features such as lava tubes.

Lava tubes form when a lava stream cools and forms a hardened exterior shell. Hot lava continues to flow through it like sludge through a pipe. Eventually, lava flows out of the tube and leaves a hollow conduit that could connect to emptied magma chambers or caves.

"We had a lot of evidence on the surface of the Moon suggesting that lunar lava tubes could have existed," Carrer said. Lunar pits, elliptical craters that formed not from an impact but from the surface collapsing into an underground void, have been some of the most compelling evidence for these tubes. More than 200 of these pits have been imaged on the Moon's surface, and scientists have speculated that they may be skylights into cave conduits, which happen on Earth when the top of a cave collapses and exposes it to the surface.

"It was quite easy to understand the signals seen on the Moon, thanks to the Earth validation."

Carrer and his colleagues, including fellow Università di Trento planetary scientist

Lorenzo Bruzzone, wanted to know whether it was possible to map a hidden cave using orbital synthetic aperture radar (SAR) instruments. They first tested this method at a terrestrial cave system in Lanzarote, Spain, and another at the Well of Barhout in Yemen. Both are planetary analogues. They used the SAR data to create 3D reconstructions of the two terrestrial cave systems near their entrances.

"We verified that the cave characteristics we were measuring from space matched what the speleologists measured on the ground," Carrer said. That gave them the confidence to try out the technique on the Moon.

The researchers focused their attention on the Mare Tranquillitatis pit, a nearly circular sinkhole about 100 meters across and 105 meters deep. The radar data were taken in 2010 by the Lunar Reconnaissance Orbiter, which sent a signal into the pit at an angle and received a radar reflection from the bottom.

"We could detect from this pit…a reflection that clearly proved an opening on the bottom and the entrance of a cave, which probably is a part of a lava tube," Bruzzone said. "It was quite easy to understand the signals seen on the Moon, thanks to the Earth validation."

They fed those radar measurements into their computer model to create a 3D visualization of the lava tube with estimates of its dimensions. The model suggested that the entrance is at least 45 meters (148 feet) wide. Depending on how sharply the conduit slopes downward, it extends 30–80 meters (100–260 feet) from the entrance and reaches 135–175 meters (443–574 feet) below the lunar surface. This research was published in *Nature Astronomy* (bit.ly/lunar-conduits).

"Studying the rocks there, since they are pristine rocks not altered by the harsh surface, could give a lot of insight about lunar volcanism and the history of volcanism on the Moon."

Pristine, Unweathered Lunar History

"[This] analysis certainly indicates that there's a passage that goes deeper than we've been able to see with visible-wavelength images," said Robert Wagner, a planetary scientist at Arizona State University in Tempe who was not involved with this research. The passage might not connect with a larger cave, he cautioned, "but this new study is consistent with present-day access to a lava tube. The next step is really to send a mission to this pit to go in and directly investigate what's down there."

With international focus on lunar exploration and even permanent habitation, lunar caves are of interest for their potential to shield astronauts from radiation. But Bruzzone and Carrer are more excited by the geologic history that may be preserved inside this lava tube within rocks shielded from weathering and alteration by the solar wind and cosmic rays.

"Studying the rocks there, since they are pristine rocks not altered by the harsh surface, could give a lot of insight about lunar volcanism and the history of volcanism on the Moon," Carrer said.

What's more, if there is one intact lunar lava tube, there may be many, Wagner added. The prevalence of subsurface lava tubes could shed light on how lunar magma moved, cooled, and settled.

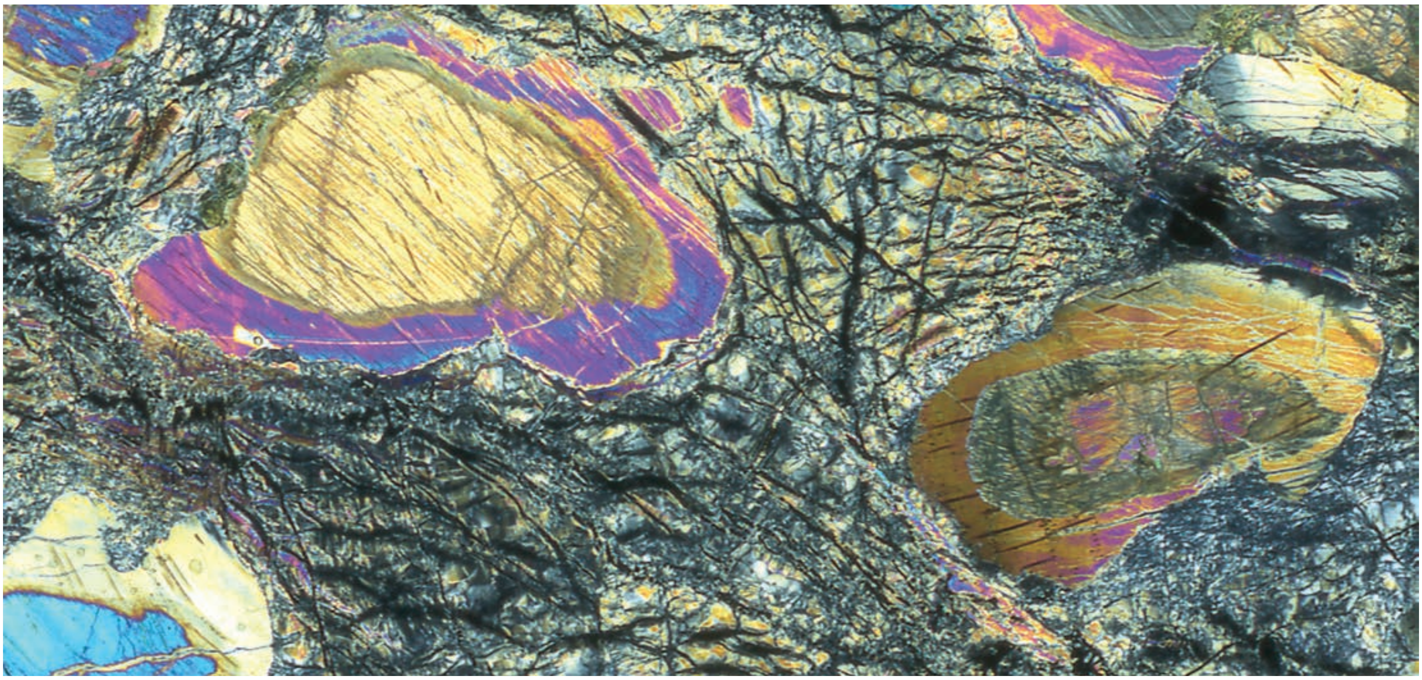
"Finding one that is completely intact, apart from one comparatively tiny hole in the roof, indicates that there may be quite a lot of deeply buried conduits waiting for us to get down on the surface with seismometers, gravimeters, or radar in order to find them," Wagner said.

However, exploring whether other pits connect with lava tubes will have to wait for better radar coverage of the Moon. "This cannot be seen with an optical camera," Bruzzone said, and currently available lunar radar data either are not of high enough resolution to study smaller pits or do not cover the maria regions where pits have been found.

"With the data that we have," he added, "it is not possible to clearly identify reflections that prove the accessibility from a pit and then into a cave."

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

Lost City's Plumbing Exposed by the Longest Mantle Core Ever Drilled



A cross section of the core extracted by International Ocean Discovery Program Expedition 399, seen here under a microscope in cross-polarized light, reveals the mantle's history, including interactions with seawater. Credit: Johan Lissenberg

In 2023, researchers with the International Ocean Discovery Program (IODP) returned from a drilling expedition in the Atlantic Ocean with a notable prize: a cylinder of rock more than three quarters of a mile (1.2 kilometers) long containing material from Earth's mantle.

Described in a new paper in *Science,* the cylinder, a core drilled from the ocean floor, is a long cross section of mantle rock that reveals the chemical and physical processes happening deep beneath an active hydrothermal field, which scientists have little ability to visit or study (bit.ly/mantle-core). Researchers expect the core to fuel years of research into how mantle rocks rise and change, as well as how their interactions with the environment feed processes that may have kick-started life itself.

Though other holes drilled through the crust have gone deeper, none has retrieved as much rock from the mantle.

"This recent core is really exciting," said Matthew Schrenk, a geomicrobiologist at Michigan State University who wasn't involved with the research. "I was really impressed with how deep they got, how much recovery they were able to yield."

The core owes its existence, in part, to sheer luck. The research team was aboard R/V *JOIDES Resolution*, the IODP's venerable ocean drilling ship, as part of a mission to deepen an existing borehole.

"I was really impressed with how deep they got, how much recovery they were able to yield."

"We didn't actually plan to drill this deep" into mantle rocks, said Andrew McCaig, a geologist at the University of Leeds and a study coauthor. In fact, the researchers almost didn't drill at all. Their first drill bit got stuck in a shallow pilot hole, forcing them to sever the line connecting it to the surface. Another effort, this time to place a reinforced concrete casing in another hole, broke a different drilling system.

"We basically used what I call the dartboard method in the end," McCaig said, dropping the casing down the drill string to land smack-dab in the hole, half a mile (800 meters) beneath the ocean's surface. From there, the drilling proceeded surprisingly smoothly, reaching 4,160 feet (1.3 kilometers) beneath the seafloor and allowing the scientists to retrieve long sections of rock.

They ended up preserving 71% of the core, significantly more than other cores drilled from the region.

"We stopped when we had to go back to the Azores," McCaig said. "If we'd had another week, we would have carried on drilling."

A Rocky History

Drilling into Earth's mantle is not usually possible. Overwhelming pressure and heat at those depths make it difficult for a bit to reach beneath the crust.

Most physical evidence from this region comes from ophiolites—bits of the mantle thrust to the surface along the edges of tectonic plates—and pieces of mantle dredged from the ocean floor.

"It's like a grab bag of rocks that come up, and you don't know what their context was," said Jessica Warren, a geologist at the University of Delaware who wasn't involved with the research. "Drilling is one of our main ways that you can go in. And with that drill core, you can see how one piece of rock relates to the other."

The IODP expedition was drilling atop the Mid-Atlantic Ridge, a section of ocean floor where two tectonic plates are pulling apart at about an inch (2.5 centimeters) per year. That spreading allows rock from deeper in the mantle to rise: It's one of few places where mantle material is close to Earth's surface, albeit under 2,790 feet (850 meters) of water.

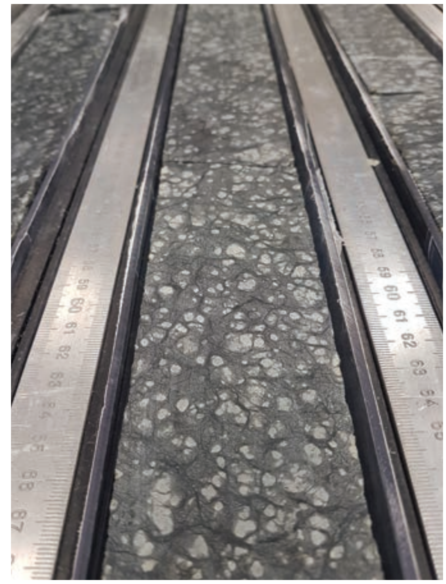
The core tells a story of millions of years of geologic activity, beginning when melted rock from deep within Earth began rising. As it did, it became depleted in certain elements such as calcium and potassium, whereas other elements such as magnesium and silica remained. The rising rock, which is largely peridotite, a dense and coarse-grained rock that makes up much of the solid part of Earth's mantle, eventually cooled.

The core sheds new light on exactly how the process of melting and cooling occurs. The researchers saw, for example, how different minerals were removed from the mantle materials as they rose, creating different types of rock at various depths.

The JOIDES Resolution *crew used rotary drill bits to extract the core from the seafloor. Credit: Sarah Treadwell, Communications Officer, IODP Expedition 399*

Other once-theoretical processes can be seen clearly in the core as well, including one known as focused melt transport. Horizontal veins of dunite and a densely interwoven mesh of gabbro are visible. Some are fractions of an inch wide; others, dozens of feet. They reveal how later surges of melted rock moved through porous areas of the peridotite that function as channels, allowing material from below to reach the surface and form basalt outcrops.

"Being able to see that deeper part of that system is really unique."



The core is composed mostly of serpentinized depleted mantle peridotite. Credit: Johan Lissenberg

"We've got a brilliant section through a net vein complex here within peridotite," McCaig said. "We can look at the scale of these things, we can look at the compositional variations in the gabbro."

Later, as the cooled peridotite was exposed to seawater percolating from above, it underwent a chemical reaction known as serpentinization, creating serpentine and magnetite, along with heat, hydrogen, and methane. Though the existence of this reaction was already known, the core is giving researchers the chance to dig deeper into the serpentinization process and how it contributes to other processes on the ocean floor.

For example, in the area the core came from, serpentinization reactions help circulate warm, hydrogen-rich water back to the seafloor, where it powers the Lost City hydrothermal vent system, an eerie collection of spindly carbonate towers hosting a rich ecosystem of microbes and other sea creatures, all fed by the reactions happening below.

Digging Into the Plumbing

The core's proximity to Lost City—the drill site was half a mile (800 meters) away—makes it exciting for not just geologists but also microbiologists and others interested in the origins of life.

"What we've basically sampled is the best thing we'll ever get for the substrate of Lost City," McCaig said.

By drilling through the "plumbing" of the hydrothermal vent system, the expedition has given researchers a glimpse into the processes that created and sustain Lost City.

The core reveals, for the first time, information about how deep below the ocean floor serpentinization occurs and, from the kinds and amounts of different minerals found, exactly what other kinds of chemical reactions are happening. That information will allow researchers to shape theories about how organisms have adapted to these and other similar vents, which some scientists suggest may have been where life first emerged on Earth.

"Being able to see that deeper part of that system is really unique," Warren said.

The new drill core will likely deliver surprises for years to come on everything from the chemical reactions happening deep underground to the movement of melt from the mantle to the life cycles of microbes.

And the drill core may be one of the last of its kind for some time. The *JOIDES Resolution* made its final journey as the United States' dedicated scientific drilling vessel earlier this year. The ship is no longer funded by the National Science Foundation, restricting scientists' access to new materials from deep below the seabed. For now, researchers have plenty of new rock to study.

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

Fiber-Optic Cables Used to Measure Changing Soil Moisture

The vadose zone—the underground region between Earth's surface and the water table—plays an important role in the water cycle. But so far, monitoring the vadose zone's moisture content has been challenging. Now, seismologists have managed to trace moisture fluctuations in this zone using fiber-optic cables.

The study, published in *Nature Communications,* focused on the city of Ridgecrest, Calif., which lies in a drought-prone region southwest of Death Valley and northwest of the Mojave Desert (bit.ly/soil-DAS). The results suggested that soil moisture in the vadose zone is strongly affected by drought and may vary significantly over several kilometers.

"This study showcases a novel application of using telecommunication fiber-optic cables to monitor soil moisture with remarkable spatiotemporal resolution," said Shujuan Mao, an assistant professor of seismology at the University of Texas at Austin who was not part of the research. "[It] improves our ability to observe and understand water dynamics in the vadose zone and opens the possibility for broader applications."

Studying the Shallow Subsurface, in Depth

Although the vadose zone contains only a fraction of Earth's fresh water, it has a large impact on the hydrologic cycle: It supplies water to plants and crops, transports nutrients and pollutants, and controls the rate at which aquifers refill after droughts.

But determining how much water is in the vadose zone and how quickly it is lost or replenished isn't easy. "Current [tools] for soil moisture monitoring, such as remote sensing satellites and physics-based land surface models, often suffer from low spatial resolution and struggle to measure below 200 centimeters [80 inches]," Mao said. These difficulties impede detailed studies of the vadose zone, which can extend more than 100 meters (330 feet) into the ground.

Instead of satellite data, the new study's authors used distributed acoustic sensing (DAS) to monitor moisture. In DAS, a laser pulse is sent into an underground fiber-optic cable, such as those that supply Internet and telephone connections. Small defects in the cable scatter the light. When the cable bends or vibrates, the scattered light changes, too.

By analyzing wiggles and blips in the light, scientists can monitor vibrations along the entire length of the cable, producing data with meter-scale spatial resolution.

> **"Current techniques for soil moisture monitoring… often suffer from low spatial resolution and struggle to measure below 200 centimeters [80 inches]."**

The 8-kilometer-long (5-mile-long) Ridgecrest DAS array was originally installed to record aftershocks of the magnitude 7.1 earthquake that rocked the city in 2019. But the researchers quickly realized that ambient vibrations—mainly from vehicular traffic—recorded in the DAS data could be used to monitor groundwater, said Zhichao Shen, a seismologist at Woods Hole Oceanographic Institution (WHOI) and the first author of the study.

To determine the soil's water content from their data, the scientists looked to seismic wave speeds, which depend on the material through which the waves travel. If the ground is dry, seismic waves move through it quickly. If the soil is wet and soft, seismic waves travel more slowly.

By observing how seismic wave velocities beneath Ridgecrest changed across space and time, the researchers traced fluctuations in the vadose zone's water content.

A Reservoir's Worth of Water Lost from the Mojave

"The level of detail resolved by our fiber-optic seismic sensing principle is quite exciting and surprising," Shen said. The results illustrate that water saturation in the vadose zone increases rapidly after rainfall, then decreases over timescales of days to months as the moisture is lost to evaporation or plant transpiration.

In times of drought, the loss of moisture can be drastic. Shen and his coauthors calcu-

The city of Ridgecrest, Calif., is located in the northern Mojave Desert. Credit: GeorgeCoffey/Pixabay lated that the vadose zone below Ridgecrest lost the equivalent of a 25-centimeter-deep (10-inch) layer of water each year from 2019 to 2022.

Ridgecrest receives only about 5 centimeters (2 inches) of rainfall every year. "[This result] implies that during drought years, groundwater is only minimally recharged by precipitation or surface water," Shen said.

"In water-stressed urban areas, this information is useful for supporting more effective drought mitigation strategies and water resource planning."

Extrapolating the water loss in Ridgecrest to the area of the Mojave Desert, the researchers estimated an annual loss of 30 cubic kilometers (7 cubic miles) of water. For comparison, Lake Mead, the reservoir created by the Hoover Dam, currently contains about 10.7 cubic kilometers (2.6 cubic miles) of water.

A Cost-Effective Water Monitoring Method

The high spatial resolution of DAS data could make this new tool useful for water monitoring, Mao said. The eastern end of the Ridgecrest cable recorded a higher moisture loss than the western end, suggesting that water dynamics in the vadose zone can vary considerably across several miles. Such information could help to identify areas that are especially sensitive to drought.

It's a cost-effective way to complement current water monitoring methods, Shen said. Because it uses telecommunication cables that are already in place, it can be implemented quickly and cheaply.

"In water-stressed urban areas, this information is useful for supporting more effective drought mitigation strategies and water resource planning," Mao concluded. "In agricultural regions, detailed soil moisture data can optimize practices such as irrigation scheduling and crop health monitoring."

By **Caroline Hasler** (@carbonbasedcary), Science Writer

Clays May Have Slowed Earth's Recovery After the Great Dying

The loss of small organisms that build their skeletons and shells out of silica may have played a role in Earth's slow recovery from the Great Dying. Such silicifying organisms, shown here in a scanning electron microscope image, include radiolarians and diatoms. Credit: Sofia Rauzi

At the end of the Permian, around 252 million years ago, volcanoes in the Siberian Traps spewed lava over an area almost the size of Australia, igniting massive wildfires, burning vast oil and coal deposits, and pouring greenhouse gases into the atmosphere.

Global temperatures spiked by around 10°C, with the sea surface in the tropics approaching 40°C. The oceans acidified and lost oxygen, and 80%–95% of marine species were extinguished in the Permian-Triassic extinction event. This "Great Dying" was Earth's worst mass extinction but not the only one our planet has endured.

After such apocalypses, Earth's climate typically reverts more or less to normal within 80,000–200,000 years, largely thanks to the interaction of the global carbon and silica cycles via a process called silicate weathering.

But as the Late Permian gave way to the Triassic, Earth stayed warm for an unusually long time—around 5 million years—according to oxygen isotopes preserved in prehistoric fish teeth and other fossils. A new study published in the *Proceedings of the National Academy of Sciences of the United States of America* suggests that the reason lies in the Early Triassic's near-lifeless oceans and a process called reverse weathering, or the formation of marine clay (bit.ly/reverse-weathering).

Not Business As Usual

Atmospheric carbon dioxide dissolves in rainwater and forms a weak acid that reacts with, or weathers, rocks on land, dissolving silica and producing ions of magnesium, calcium, and bicarbonate that then wash into the sea. There, marine creatures use the silica and bicarbonate to make their shells and exoskeletons.

The warmer atmospheres that accompanied many mass extinctions resulted in increased rainfall, leading to more weathering and thus converting atmospheric carbon dioxide (CO_2) into dissolved carbon at higher rates. This process usually stabilizes the climate within several hundred thousand years.

Why the Early Triassic was an outlier—remaining so warm for so long—has been a mystery until now.

Researchers collected colorful cherts from exposures on Waiheke Island in New Zealand. Credit: Sofia Rauzi

In search of an answer, doctoral student Sofia Rauzi and her supervisor, biogeochemist Terry Isson, both from the University of Waikato, chipped colorful chert samples from rocks on New Zealand's Waiheke Island. They then traveled to Norway's icebound Svalbard archipelago to collect similar-aged cherts and marine shales. A colleague sent some more from Japan.

"You can't just find 250-million-year-old rocks anywhere, so you have to go to the places where they are," Rauzi said. The cherts they collected came from before, during, and after the Early Triassic.

Back at the lab, Rauzi, Isson, and their colleagues analyzed the relative proportions of lithium isotopes trapped inside clay minerals within the samples. "When clay forms, it takes up the lighter lithium isotope and enriches the surrounding water with the heavier lithium isotope," Rauzi said. "So you can track clay-forming processes by measuring the lithium isotopic composition of these rocks."

The signatures from the 250-million-year-old rocks were "dramatic," Isson said, showing limited clay formation before the mass extinction, a significant increase in clay formation afterward, and then a return to baseline after about 5 million years.

These findings lend support to a theory Isson and a colleague first proposed in 2018. Along with alkaline metals, dissolved silica is an essential ingredient for marine clay formation, he explained. As it does today, the ocean during the Permian teemed with tiny organisms such as diatoms and radiolarians, which used silica to build their exoskeletons—so there was little left to precipitate into clay.

This precipitation is called reverse weathering because the chemical reaction that occurs emits the CO_2 captured by weathering, Isson said. "It's undoing what the weathering has done."

So when the vast majority of those animals were wiped out in the Great Dying, the ocean's dissolved silica became available for clay formation. The lithium ratios the group measured suggest that reverse weathering did accelerate immediately following the extinction, releasing extra CO_2 into the atmosphere, countering the carbon-trapping effect of weathering, and keeping Earth warmer for longer.

Tuning Earth's Thermostat

"This study provides some of the first geochemical evidence that demonstrates that how much and where clays are forming is intimately connected with...the ecological success of marine ecosystems and the Earth's climate system," Isson said. "It gives us an insight into how the Earth's thermostat really operates."

Other researchers have used carbonates to infer the lithium isotope ratios of seawater and thus how widely clay formation varied over time, Rauzi said—a less direct method. The lithium signatures she and her coauthors measured, however, contradict those studies, with implications for our understanding of the way the ocean's lithium isotope composition has changed over time.

"It's provocative," Isson said. "This is really the first time anyone's pointed out that the siliceous archives tell you a drastically different story from the carbonates." This suggests that researchers should use carbonate archives with caution, Rauzi added. "Maybe they were not such a good recorder of seawater during this time," she said.

"This is really the first time anyone's pointed out that the siliceous archives tell you a drastically different story from the carbonates."

Using clay was an innovative approach, said Hana Jurikova, a biogeochemist at the University of St Andrews in the United Kingdom who was not involved in the study.

The study highlights the importance of accounting for reverse weathering in climate models, she said. "It's a process that we don't know enough about." More research is needed to firmly establish whether the Early Triassic was the only time in the past 500 million years when the process played a significant role in Earth's climate system and to fine-tune our understanding of how rocks get their lithium signatures, she said.

The work also is a reminder of the complex interconnections between life on this planet and the grand global systems that sustain it. "Sometimes we are surprised that we are able to affect the climate, but, actually, many organisms have figured that out," Jurikova said. "Everything is intertwined."

By **Kate Evans,** Science Writer

Empowering Genderqueer Geoscientists: Being and Building the Change

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Over the past decade, members of AGU and AGQ—the LGBTQIA2S+ affinity community of AGU—have witnessed the emotional and inspiring transformation of our communal space. What began as gAyGU, an informal gathering of friends and colleagues that was largely invisible to official AGU channels and organized solely by word of mouth, has evolved into the current organization of AGQ, a recognized community that has sponsored panel discussions, networking pods, and reception events at AGU annual meetings.

Interest in and support for AGQ (bit.ly/AGU-AGQ) continue to flourish and expand: At AGU's Annual Meeting 2023 in San Francisco, the AGQ reception hosted more than 300 community members and allies.

Though progress has been made within AGU to support its own scientific communities, we still live in a world in which groups with marginalized sexual orientations and gender identities consistently face violence, discrimination, and legislation that attempts to infringe on their rights. There is no shortage of examples of exclusionary behaviors and systemic biases in academia [*Gibney*, 2016; *Marin-Spiotta et al.*, 2023] that raise a barrier to participation and reduce the retention rate of historically excluded groups in the Earth and space sciences [*Olcott and Downen*, 2020].

Despite various calls to improve equity and inclusion through the actions of individuals, institutions, funding agencies, and scientific societies, the transgender, gender nonconforming, and nonbinary (hereinafter referred to as genderqueer) communities have not traditionally been the center of diversity, equity, and inclusion (DEI) initiatives in the Earth and space sciences [*Kanungo and Barrow*, 2021; *Ulrich*, 2021]. Data on the needs of these individuals and the impact of DEI programs on their well-being and career development are sparse [*Clancy et al.*, 2014; *Coffield et al.*, 2023]; thus, more support is needed to empower these scientists and researchers.

Recent social and political attacks on genderqueer individuals in the United States (as broad as "anti-DEI legislation" in some states and as specific as "bathroom bills" in others) have exposed the need to be intentional in supporting genderqueer communities in the Earth and space sciences.

To that end, members of AGQ and Coriolis, the LGBTQIA2S+ affinity group of the American Meteorological Society (AMS), collaborated to host a virtual panel during Pride Month in June 2023 to center the voices of genderqueer scientists. The event, "Uplifting Transgender & Gender Non-conforming Geoscientists Through Allyship & Empowerment," was moderated by the presidents of AGU and AMS, Lisa Graumlich (she/they) and Brad Colman (he/him), respectively. Several panelists, including coauthor Akilah Alwan (she/they), shared their personal experiences as genderqueer individuals working in various fields of the Earth and space sciences.

We still live in a world in which groups with marginalized sexual orientations and gender identities consistently face violence, discrimination, and legislation that attempts to infringe on their rights.

The panelists discussed their backgrounds, how their identities intersect with their careers, and what support they have received from their colleagues and professional societies. The event also gave panelists an opportunity to share directly with leadership at AGU and AMS what the organizations can do to meaningfully support the genderqueer community.

Call to Action

The panel stressed that it is beyond time to create and nurture a culture of inclusion for genderqueer Earth and space scientists. The onus of fostering such an environment, they emphasized, should be not on the individuals who have been systemically targeted and excluded but, rather, on those who benefit from various forms of privilege, those who can listen to the needs of their marginalized colleagues and leverage their privilege to create lasting change.

Progress on this front is multidirectional. As individuals, we can build a personal ethic of inclusion with impacts that scale up to our professional circles, places of work, and disciplines as a whole. Academic institutions and professional associations can complement this personal ethic to advance our culture in ways that incentivize and model change systemically.

Individuals

To support the genderqueer community in the Earth and space sciences, we, the authors, recommend that individuals listen, learn, and speak out.

Listen. In forums like AGQ, genderqueer scientists are empowered to share accounts of their lived experiences. It is crucial for cisgender scientists to listen to these accounts because by doing so, they are better able to empathize with the consistent challenges faced by genderqueer people.

For example, a cisgender person might not consider the fear and anxiety a genderqueer scientist might experience while traveling for a conference to a place that does not have firm protections for genderqueer individuals. Unease or apprehension from prospective conference-goers reduces opportunities for an individual, engagement for a society, and progress for science itself. And the apprehension is well founded: In 2023 alone, 49 U.S. states introduced measures to erode safety and belonging for the genderqueer community, and reports have shown that the risk that a genderqueer person will be harassed or assaulted is much higher in states where anti-trans legislation is actively being drafted or passed.

Consistently listening to such concerns is especially relevant for those in decision-making positions (e.g., department or society leadership). Their words, behavior, and choices about policies and practices can help or harm genderqueer individuals.

Learn. Cisgender people can be nervous about interacting with genderqueer colleagues for fear of making a mistake—using the wrong pronoun, for example. To combat this fear, we encourage our colleagues to draw on their scientific background and be open to constructive feedback, as well as to the opportunity to learn more about evolving concepts and language surrounding identity.

> **Cisgender people in the Earth and space sciences must be vocal about injustices to the genderqueer community, whether or not members of that community are "in the room."**

Individuals who are unfamiliar with the discourse around pronouns or what it means to be genderqueer, can educate themselves by seeking out academic resources on gender inclusivity. We encourage our colleagues to be proactive learners to ensure that mistakes are minimized: It is not solely the duty of the person harmed by the mistake to teach the person causing the harm why they were wrong, regardless of whether the harm was intentional or unintentional.

Speak out. Individuals with privilege conferred by their race, gender, education, class, or other identities have a responsibility to leverage their privilege to advocate for those without. This includes speaking up and speaking out against verbal and structural gender discrimination; actively engaging genderqueer colleagues in decisionmaking processes; being intentional in structuring activities where equity is present for genderqueer individuals, specifically regarding travel and lodging arrangements and the availability of restrooms that align with gender identity; and choosing to collaborate with individuals and institutions that are welcoming and supportive of genderqueer identities.

Most critical, cisgender people in the Earth and space sciences must be vocal about injustices to the genderqueer community, whether or not members of that community are "in the room." Many times, those who hold privilege do not speak out when they witness an incident of discrimination because it does not affect them directly. However, as panelist Alwan said at the AGQ-Coriolis event, "complacency is a form of violence."

Academic Institutions

Institutions serving Earth and space scientists need to increase diversity of representation among their faculty and staff, which remain overwhelmingly heterosexual and white [*Dzombak*, 2020; *Kanungo and Barrow*, 2021; *Ulrich*, 2021; *Marin-Spiotta et al.*, 2023]. The change in faculty and staff composition might require institutions to reexamine criteria used for hiring and promotion, as these criteria may inadvertently (or even intentionally) dismiss qualified candidates on the basis of, for example, pedigree bias.

Increasing the representation and visibility of genderqueer faculty and staff can have spillover effects that increase the diversity of the institution as a whole. Students, research assistants, and lab technicians with marginalized identities, for example, may feel a stronger sense of belonging if they have mentors with whom they share an identity. Institutions should adopt human resources and communications systems that allow individuals to be acknowledged by their preferred name and pronouns while also striving to protect individuals from exclusionary behaviors.

Geoscience departments, schools, and institutions must foster a sense of inclusion for genderqueer individuals by affirming that they are heard, believed, and supported.

When exclusionary behaviors do occur, institutions need swiftly and transparently to pursue action that is not solely punitive and that uses the exclusionary behavior as a learning tool.

For example, defaulting to assumptions about cisnormativity and heteronormativity for relationships can lead to discomfort and harm by denying victims of the exclusionary behavior recognition of their lived experience. However, this exclusionary behavior can create opportunities to expand perceptions of gender identity.

In this case, institutions can be proactive by incorporating cultural competency training into onboarding activities. Furthermore, individuals in positions of power (supervisors, professors, department chairs, deans) should encourage members to ask for and use pronouns and create a safe environment for others to share.

Using the exclusionary behavior to effect change could also take the form of sponsoring bystander training to raise awareness of sexuality and gender and equip learners with

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the skills needed to respond to bias, discrimination, and harassment.

To help foster inclusive learning and ensure that their environment is inclusive and welcoming, institutions can allocate funding to allow their members to attend DEI workshops.

Professional Societies

Recognizing that one of the strengths of a scientific community lies in the diversity of its scientists, association leadership must take a firm stand to support genderqueer members in the face of discrimination and bigotry. Societal research, initiatives, and programming should focus on learning more about and prioritizing the needs of genderqueer members, as limited scholarship on this demographic group exists. This programming may include constructing strategic DEI plans, hiring staff with genderqueer cognizance in DEI issues, and inviting experts to provide training to members of the professional society.

Although the immediate reaction to the recent flood of anti-trans legislation may be to want to boycott certain cities or states for sanctioned meetings, the issue is far more complex.

Society statements are starting points to affirm support for genderqueer members and promote a culture of equity and justice. Such support should also include elevating the voices of genderqueer members on panels and in societal awards. A deeper commitment may include enforcing a zero-tolerance code of conduct toward hatred. By unequivocally condemning and penalizing speech that promotes or incites hatred, discrimination, or violence against genderqueer scientists, societies would set an example of protecting every single one of their members' welfare and upholding their commitment to building a safe and inclusive environment for everyone.

Professional associations have unique duties to prioritize the safety and inclusion of their members in planning annual and special meetings [*Johnson and Chin*, 2020; *Nicolson*, 2018].

Of 23 annual meetings planned for AGU, AMS, the Geological Society of America, and the American Astronomical Society at the time of this writing, 20 of them—87%—will be held in states with low equality or negative policy tallies, according to the Movement Advancement Project.

Although the immediate reaction to the recent flood of anti-trans legislation may be to want to boycott cities or states for sanctioned meetings, the issue is far more complex.

In 2020, one third of all LGBTQ+ Americans and two fifths of transgender Americans lived in the South, home to some of the nation's most reactionary anti-trans legislation. Metropolitan areas in the South, such as Atlanta, Houston, New Orleans, and Tampa, have reputations as LGBTQ+ havens, especially for queer people of color. (In fact, Houston is the birthplace of the National Association of Black Geologists and Geophysicists.) Although genderqueer individuals still face violence in these places, it is oversimplistic to apply a blanket ban on these cities under the premise of their being anti-LGBTQ+.

There are many factors relevant to the lived experiences of genderqueer scientists to be mindful of when choosing conference sites, including a city's or venue's affordability, accessibility, immigration policy, and access to reproductive rights [*Woolston*, 2022]. Genderqueer individuals possess vast multiplicity within the layers of their identity [*Burnes and Chen*, 2012], and dismissing the importance of their experience with disability, ethnicity, race, sexuality, or socioeconomic class within the context of belonging and safety would be a loss to the Earth and space science community.

A Holistic Approach for AGU Meetings

In short, when evaluating sites for meetings, AGU must engage members whose identities intersect at multiple margins of oppression in the decisionmaking process, ensuring that those who make up the diverse range of identities within its genderqueer membership have adequate representation to advocate for and have agency over their needs. Finding a balance between safety, affordability, and accessibility in future meeting sites will require a holistic approach that relies on understanding the intersectional identities of AGU's LGBTQIA2S+ membership.

Initiatives such as SocialOffset offer societies a partial solution to finding this balance by providing donations to vetted charities located in travel destinations with legislation that does not align with the values of attendees. We acknowledge that though this and similar initiatives might be well intentioned, they still are unlikely to make travelers with marginalized or minoritized identities feel safe on the ground or to create lasting change.

At large scientific conferences, actions that are relatively easy to achieve—such as including pronouns on badges and making all-gender restrooms accessible—speak volumes and encourage greater engagement from all attendees.

Finally, to better track progress related to the genderqueer community, societies should measure gender identity (along with other marginalized identities) and query members belonging to these groups on their well-being through voluntary data collection efforts, such as surveys and polls.

Finding a balance between safety, affordability, and accessibility in future meeting sites will require a holistic approach that relies on understanding the intersectional identities of AGU's LGBTQIA2S+ membership.

We, as AGU members, have reached a watershed moment when we can leverage unprecedented momentum toward making lasting change. The list of actions presented here is not comprehensive but, rather, intended to be a starting point for individuals, institutions, and associations engaging more intentionally with the genderqueer community to expand DEI efforts and create a more inclusive and thriving scientific community.

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A FIRST LOOK
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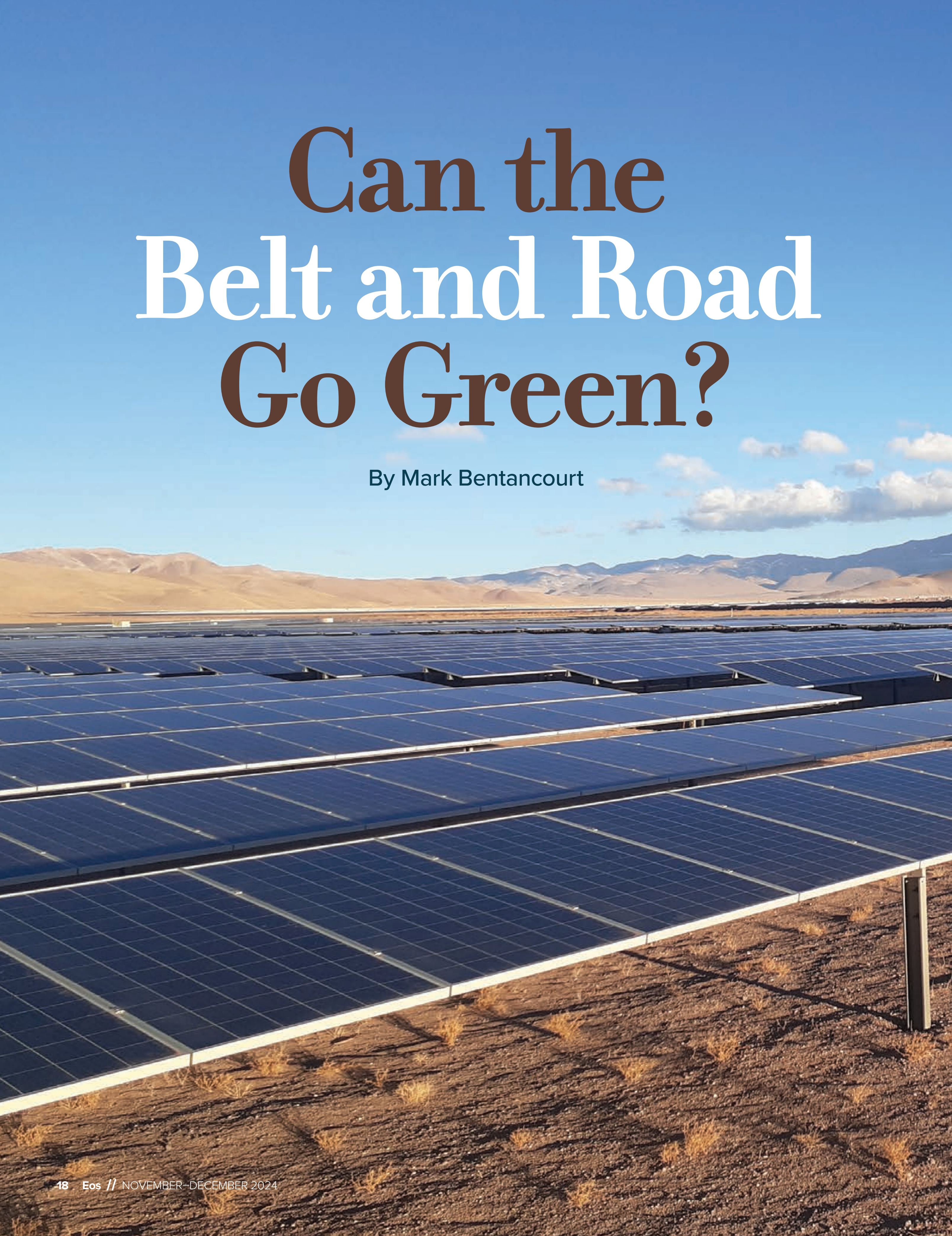
Can the Belt and Road Go Green?

By Mark Bentancourt



China's global infrastructure investments could tip the scales on climate change, but its relationship with partner countries is complicated.

The solar panels of the Cauchari solar power complex in Jujuy, Argentina, were supplied by a Chinese firm as part of the country's Belt and Road Initiative (BRI). Credit: Manuel arequipa/Wikimedia, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

In the high desert of northwestern Argentina sits a vast array of solar panels, surrounded by barren hills of gray-brown sand. Thanks to clear skies, clean, cool air, and a 4,000-meter altitude, the spot is among the best on Earth for harnessing solar power—it boasts about 15% more generating potential than North America's Death Valley or the scorched Arabian Desert.

The Cauchari Solar Plant, which came online in 2019, can generate up to 300 megawatts of power at a time, making it the largest solar park in South America. The government of Jujuy, the Argentinian province that owns and operates Cauchari, wants to expand the park to add enough panels to generate an additional 200 megawatts, plus make enhancements to aging transmission lines. But the expansion has stalled because a government nearly 19,000 kilometers away has yet to commit the funding.

> BRI projects could, in theory, provide a green path for developing countries to climb out of their economic craters and do it with clean energy.

Most of the cost to build the initial stage of Cauchari came as a loan from the state-owned Export-Import Bank of China, with the rest covered by a bond issued by Jujuy. China's two main power companies, PowerChina and Shanghai Electric, built the park. Chinese manufacturer Talesun Solar provided the panels.

China has emerged as a dominant force behind Argentina's engineering infrastructure, partly because Western banks have been hesitant to support the country, whose ongoing macroeconomic crises have made it an unreliable debtor for decades. China, on the other hand, has poured more than $26 billion into Argentina's infrastructure since 2005.

It's not just Argentina. China has backed or plans to back ambitious infrastructure projects in more than 150 countries, from ports to highways to power plants, as part of a foreign policy strategy designed, in part, to strengthen its global trade networks. In 2013, President Xi Jinping named this policy the Silk Road Economic Belt and 21st-Century Maritime Silk Road development strategy, nicknamed One Belt One Road in China and the Belt and Road Initiative (BRI) elsewhere. Eight years later, Xi announced that China would no longer build new coal power plants abroad, signaling a major shift to green infrastructure that could bend billions of dollars toward slowing climate change.

Argentina is a case study in the challenges both China and its partner countries face in pursuing sustainable development on the BRI. As a signatory to the Paris Agreement, Argentina has vowed to reduce its carbon emissions by 19%, relative to its 2007 maximum, by 2030. But it has a long way to go; about 60% of the energy it generates still comes from fossil fuels. With runaway inflation and unemployment, poverty at 40%, and crushing debt, Argentina is also urgently in need of economic recovery.

BRI projects could, in theory, provide a green path for Argentina and other developing countries to climb out of their economic craters and—unlike China or any developed nation—to do it with clean energy.

But after a rightward swing in Argentina's last election and a slowdown in Chinese lending to foreign governments, the fate of green infrastructure in the country and elsewhere in the Global South hangs in the balance.

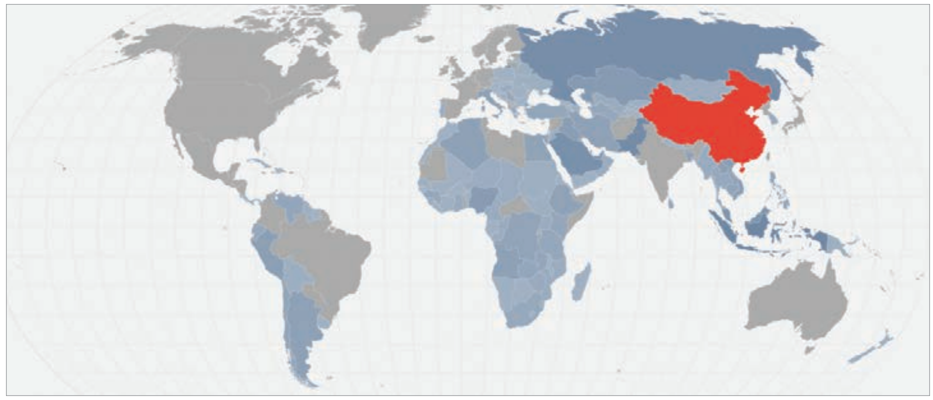
Chinese engineers begin work on the BRI-funded Santa Cruz hydroelectric project in Argentina, in 2015. Credit: Xinhua/Alamy Stock Photo

Rise of the World's Builder

China's own growth from an unstable dynastic empire at the turn of the 20th century to an economic powerhouse at the turn of the 21st was meteoric. According to the World Bank, more than 800 million of its people have climbed out of poverty since 1978, with China's gross domestic product growing an average of 9% every year.

Chinese leaders understood that booming industry required reliable sources of electricity; the country generated 5 times more power in 2020 than it did in 2000. That growth has been fueled mostly by coal, making China by far the largest emitter of greenhouse gases in the world.

As China's domestic economy cooled in the mid-2010s, its government needed to drum up demand for products and services overseas. At the same time, the country enjoyed a strong trade surplus and needed an efficient way to spend foreign currency. The developing countries that were hungriest for such investment, however, didn't have the infrastructure to support it. The Belt and Road Initiative was developed to serve all three needs, with more than



More than 140 countries have signed memoranda of understanding with China to develop their infrastructure under the Belt and Road Initiative. To date, China has invested more than $1 trillion in the effort. Credit: American Enterprise Institute

$1 trillion invested in foreign infrastructure since the initiative began in 2013.

For the first few years of the initiative, BRI projects were proposed and driven by partner countries; China's approach was simply to provide financial and industrial muscle. If a country had lots of coal, China helped it build a coal-fired power plant. (Many of these plants were constructed in coal-rich India, Indonesia, and Russia.) If there was a large river, they built a hydroelectric one. (Two power stations on the Nile in Uganda are examples of this strategy.) Chinese construction companies offered lightning-fast completion timelines, making them the go-to building partners for many developing countries.

And unlike loans from Western multilateral banks, Chinese loans, while high interest, rarely came with stringent requirements on how money was used or how projects were monitored.

"Conditionality is out of the question," according to Yixian Sun, a political scientist at the University of Bath who specializes in sustainability governance of the BRI. That's not just because China wants to provide an alternative to the Western lending model but also because of its relatively recent time spent as a poor country. "China doesn't want to draw an image of itself as a kind of new colonizer," Sun said.

That somewhat hands-off approach came with geopolitical benefits as well as economic ones, Sun explained. "The idea is to rebuild the global governance system to be less Western-centric and, to some extent, more [of a] China-centric network."

Adapting the BRI to Global Market Trends

The BRI's innovative approach has come with some setbacks.

It has complicated China's role in the climate crisis, for instance: The country has been criticized for supporting carbon-intensive projects. In 2015, 45% of China's investment in foreign energy projects was in coal-fired power plants, with another 27% going to oil and gas. (China has been investing in oil and gas projects in Argentina since 2010.) In recent years, however, China's massive investment in renewables has led energy watchdogs to estimate that the country's greenhouse gas emissions will peak years earlier than previously anticipated.

China's buckshot approach to foreign investment also had mixed results in terms of the infrastructure itself. The Chinese-built Coca Codo Sinclair hydroelectric dam in Ecuador, for example, is only 7 years old but is visibly cracked, and rapid erosion threatens the facility.

Some underdeveloped countries (Sri Lanka and Zambia, notably) have defaulted on China's BRI loans. Such defaults have led Chinese banks to shift their lending strategies and rethink their approach of saying yes to so many projects. "Now [the BRI's] previous model is in trouble because many governments in the Global South are already [in] or on the verge of bankruptcy," said political economist Wei Shen of the Institute of Development Studies at the University of Sussex.

"[China] assumed these countries would grow rapidly, just like China did," he said. "In most countries, it did not happen."

These problematic developments have China concerned with protecting its reputation, both as an infrastructure builder and as an international climate leader, Shen added. "China always wants to position itself as a more kind of responsible player [on the] global stage, in particular in the climate governance area."

China has largely been able to adapt to the shifting fortunes of the coal industry to pursue the goals of the BRI, however. Thanks to regulatory pressure in many countries and the decreasing cost of wind and solar power, coal's profitability plummeted in the 2010s and 2020s. According to Carbon Tracker, by 2026 nearly all of the world's coal power plants will be more expensive to run than building and operating renewable plants.

In 2021, President Xi announced that China would no longer finance the building of new coal-fired power plants abroad. It was a seismic, if vague, proclamation—it's unclear whether China will fulfill agreements it's already signed, convert some projects to renewables, or help partner countries to retire existing coal plants.

> "China doesn't want to draw an image of itself as a kind of new colonizer."

How aggressively China will pursue renewable power remains to be seen, but more than 40% of the country's investment in BRI energy projects was in wind and solar during the first half of 2023, up from only 20% in 2021. In November 2023, Xi and U.S. President Joe Biden agreed to triple global renewable energy capacity by 2030. "It's a quite exciting time to see how China is going to fulfill these commitments," Sun said. "To turn the word into practice—I think that's the challenge."

A Complicated Ground Game

As developing economies grow, so do their potential greenhouse gas emissions. In 2021, lower-income non-OECD (Organisation for Economic Co-operation and Development) nations, including China, were projected to increase energy-related carbon dioxide emissions 30% faster than OECD nations over the next 3 decades. In a recent report, the International Renewable Energy Agency recommended that renewable power capacity be increased faster in developing countries to meet their growing needs without pushing global climate targets out of reach.

But economic growth isn't a given. In the near term, China's promise to stop building coal-fired plants abroad may hurt the poorest BRI partner countries. Shen pointed out that the current potential for economic growth in such countries as Zimbabwe depends largely on using conventional energy resources to build an electrical grid capable of supporting new industry. Without new industries and the opportunities they provide, they will have trouble improving economic conditions. “They will be just stuck there,” he said.

Argentina has a more developed economy than many BRI partner nations and a load of untapped renewable resources. (In addition to its solar gold mine, it also has some of the world’s best wind fields, totaling as much as 3 terawatts of potential wind power both onshore and offshore.) But even with those advantages, Argentina’s path forward is fraught.

The country’s largest alternative energy project built with Chinese help to date is a $4.7 billion hydroelectric dam complex on the Santa Cruz River in Patagonia. For years, China has found that hydroelectric dams are the easiest alternative energy projects to invest in because the required technology and project management practices to bring them to fruition have existed for a century. But dams don’t always provide truly clean energy, as decomposing biomass in their reservoirs can create an often-overlooked source of greenhouse gas emissions.

The Santa Cruz project is a joint venture between the Gezhouba Group, a Chinese builder that owns the majority of shares in the complex, and two Argentinian companies. It is financed with a loan from three state-owned Chinese banks.

The complex—comprising the Néstor Kirchner and Jorge Cepernic dams, just 65 kilometers apart—was a political football in Argentina from the jump. Construction on the project began in 2015 under then president Cristina Fernández de Kirchner.

“The environmental impact assessment was a joke,” said Juan Uriburu Quintana, an Argentinian lawyer who has facilitated relations with China on several joint infrastructure projects. The report, he explained, addressed impacts in disjointed segments and failed to notify the public. In addition, environmental advocates have said the dams’ potential damage to glaciers at Los Glaciares National Park, a UNESCO World Heritage Site, as well as to a population of endangered hooded grebes in the Santa Cruz estuary, was not sufficiently studied.

Fernández de Kirchner was succeeded in 2015 by center-right reformist Mauricio Macri, who supported investment in renewables but was critical of Argentina’s dependence on China. With backing from the World Bank, Macri created Argentina’s first renewable energy auction to attract a range of new foreign investment in green power projects. The program, RenovAr, awarded more than 2,400 megawatts’ worth of renewable energy contracts through an internationally competitive bidding process.

Once Macri took office, he put the Santa Cruz hydro project on hold. Even after his administration finally approved the project, environmentalists sued. The Supreme Court of Argentina ruled that before dam construction could move forward, the environmental impact assessment had to be done again and the government had to hold public hearings.

Chinese investors and builders, who ultimately answer to China’s centralized government, found themselves on unfamiliar ground.

> “China always wants to position itself as a more kind of responsible player [on the] global stage, in particular in the climate governance area.”

Argentina’s different administrations and different branches of government working independently, effectively stymieing a project that had already been green-lighted, was, Uriburu said, “unthinkable in the Chinese mindset.”

Ultimately, the Santa Cruz project was downscaled to use fewer turbines to meet environmental standards and now is projected to generate 25% less electricity than originally planned.

To avoid this kind of quagmire, China went directly to the provincial level for its next project in Argentina, funding the government of Jujuy to build the solar park at Cauchari.

Push and Pull

China has found itself in tension with BRI host countries such as Argentina partly because of its focus on its own globalization goals. BRI contracts for projects such as Cauchari often stipulate that Chinese construction materials, technology, and even workers be used; in China’s view, that’s to streamline the project and maximize efficiency, as well as to achieve its goal to expand the reach of its companies.

Rebecca Ray, an economist with the Global China Initiative at the Boston University Global Development Policy Center, said China’s overseas projects are efficient partly because they’re centrally controlled by the Chinese government. “The fact that China’s able to easily coordinate between creditors and investors, contractors and insurers, [makes it] able to pull together a package much more easily than a market economy where each of these are separate sets of actors that you have to convince to be part of a project,” she explained.

Perhaps more important, said Qi Qi, a postdoctoral scholar at Tufts University who studies Chinese renewable energy technologies, China has mastered the development and mass production of renewable energy technologies.

In the 2000s, as the European Union (EU) in particular began subsidizing renewable energy, China increased its market share there simply by selling solar panels more cheaply than its European competitors, made possible largely by the lower labor costs in China and domestic subsidies from the Chinese government.

After the EU objected to what it saw as unfair competition in a 2012 trade dispute, China poured resources into research and development to cultivate its role as a supplier of high-quality solar components. Because China also brought its considerable manufacturing might to bear on scaling up the industry, streamlining the mass pro-

All construction on the Santa Cruz hydroelectric project was halted by China in 2023. Credit: Xinhua/Alamy Stock Photo

duction of renewable technology from solar cells to wind turbines, it was able to set a globally competitive price for its products.

Chinese companies acquired every link in the supply chain, including mining raw materials, shipping, and construction, while locating each link near the others to cut transportation costs.

As a result, China dominates the global market, supplying more than 80% of solar power equipment worldwide. Its investments in research and development have made solar cells both cheaper and more efficient. It has also pioneered the building of ultrahigh-voltage transmission lines, which are crucial to connecting remote renewable plants with population centers. (Brazil recently awarded Chinese utility State Grid a contract to build 1,500 kilometers of transmission lines connecting plants in the country's northeast with its southern cities after few other companies had the investment might or expertise even to bid.)

The streamlined approach can leave a technological and economic gap between China and its BRI partner countries, however. "Who benefits from that is not Argentinian solar power companies," said Uriburu. "So what is the incentive for the private sector to be involved in this?"

Juliana González Jáuregui, an international relations researcher at the Latin American Faculty of Social Sciences in Argentina, pointed out that when China was dependent on foreign investment to fuel its own development, it negotiated the transfer of technological knowledge that would allow it to rapidly build its own capacity for innovation. Without similar technology sharing between China and developing countries under the BRI, she said, "the worst scenario is Argentina becoming more dependent in terms of the provision of technologies, and also of financing."

China can supply affordable, quality technology to developing nations, but how it shares that technology and supports the institutional framework to make it work could determine whether those countries can make the transition to renewable energy in a way that's sustainable and profitable for them. These nations "need capacity building," said Qi. "They need outside help."

"Climate change is about inequality," Qi said. "Also, the energy transition is about inequality."

A New Administration

But Qi's research has found that the policy framework in partner countries, including political will, is often the major determining factor in the success of BRI projects.

In November 2023, Argentina's relationship with the BRI and its green energy projects was put on hold by a heated presidential election. Though China did not take a public stance, both Uriburu and González Jáuregui said they believe Chinese companies stopped moving forward on projects such as the Cauchari expansion while they waited for the outcome of the election.

Ultimately, Argentines elected Javier Milei, a climate change–denying economist who campaigned on a platform of cutting off long-standing government funding of the sciences and severing all ties with China.

The 300-megawatt Cauchari Solar Plant in Jujuy, Argentina, was built with financing and materials from the Belt and Road Initiative. Credit: Manuel arequipa/Wikimedia, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

Even Milei's own staff have tried to soften his comments on China, which Milei has called an "assassin," and analysts largely dismiss his promises to cut ties with the country as political grandstanding. China is Argentina's second-largest trade partner after Brazil—in 2022, more than 90% of Argentina's soybean exports and more than half its meat exports went there.

At least for now, the relationship is of existential importance to Argentina, and China knows it. After Milei's foreign minister allegedly met with a Taiwanese official last December, China, which does not recognize Taiwan's independence, threatened to begin buying both soybeans and meat elsewhere.

"China is our creditor of last resort," Uriburu said, largely because Western multilateral banks are wary of lending Argentina any more money. The country is the largest debtor to the International Monetary Fund, to which it owes $46 billion.

Although Milei's administration may reconfigure the terms, said González Jáuregui, "the long trajectory of Argentina's relationship with China includes trade and investments, as well as the provision of financing and swap agreements, no matter who has been in power." Still, she said, "since Milei has publicly denied the existence and effects of climate change, we can expect efforts [to counter] climate change not to be a priority."

Shortly after Milei's election, construction of the Santa Cruz hydroelectric dams was halted yet again as his government raised objections over the work agreement. If the project folds, Argentina will still have to repay the Chinese loans.

A new approach to the BRI may include allowing more time and flexibility for host countries to contribute their own materials and labor.

Read the article at Eos.org

An Uncertain Future

Both the Group of Seven (G7), led by the United States, and the European Union have proposed their own answers to the BRI, pledging to spend billions on sustainable infrastructure in poorer nations. But these efforts, nicknamed Build Back Better World and Global Gateway, are just getting started. Ideally, developing nations would benefit from having more choices in whom to partner with, Ray pointed out, "but it may be a bit Pollyanna-ish at this point to set expectations that we will see such a positive scenario unfold soon."

A downturn in China's own economy, exacerbated by the COVID-19 pandemic, has led Chinese firms to pour more equity into foreign infrastructure projects, hoping to turn a better profit abroad than at home. Chinese banks continue to slow lending directly to foreign governments, but President Xi announced at a 2023 BRI forum that the initiative is pivoting to "small yet smart" projects that yield strong development results, as well as increasing its focus on low-carbon industries and renewable energy and creating more training opportunities for partner countries.

"That indicates an intention for lending to rebound, but in a way that is more sustainable financially as well as environmentally and socially," said Ray.

Going forward, a new approach to the BRI may include allowing more time and flexibility for host countries to contribute their own materials and labor, Shen said. That would be "quite a significant institutional, even mindset, change" for Chinese companies.

And the world is watching, because a trillion dollars of Chinese funding may be a determining factor in whether the global community can meet its emissions reduction goals.

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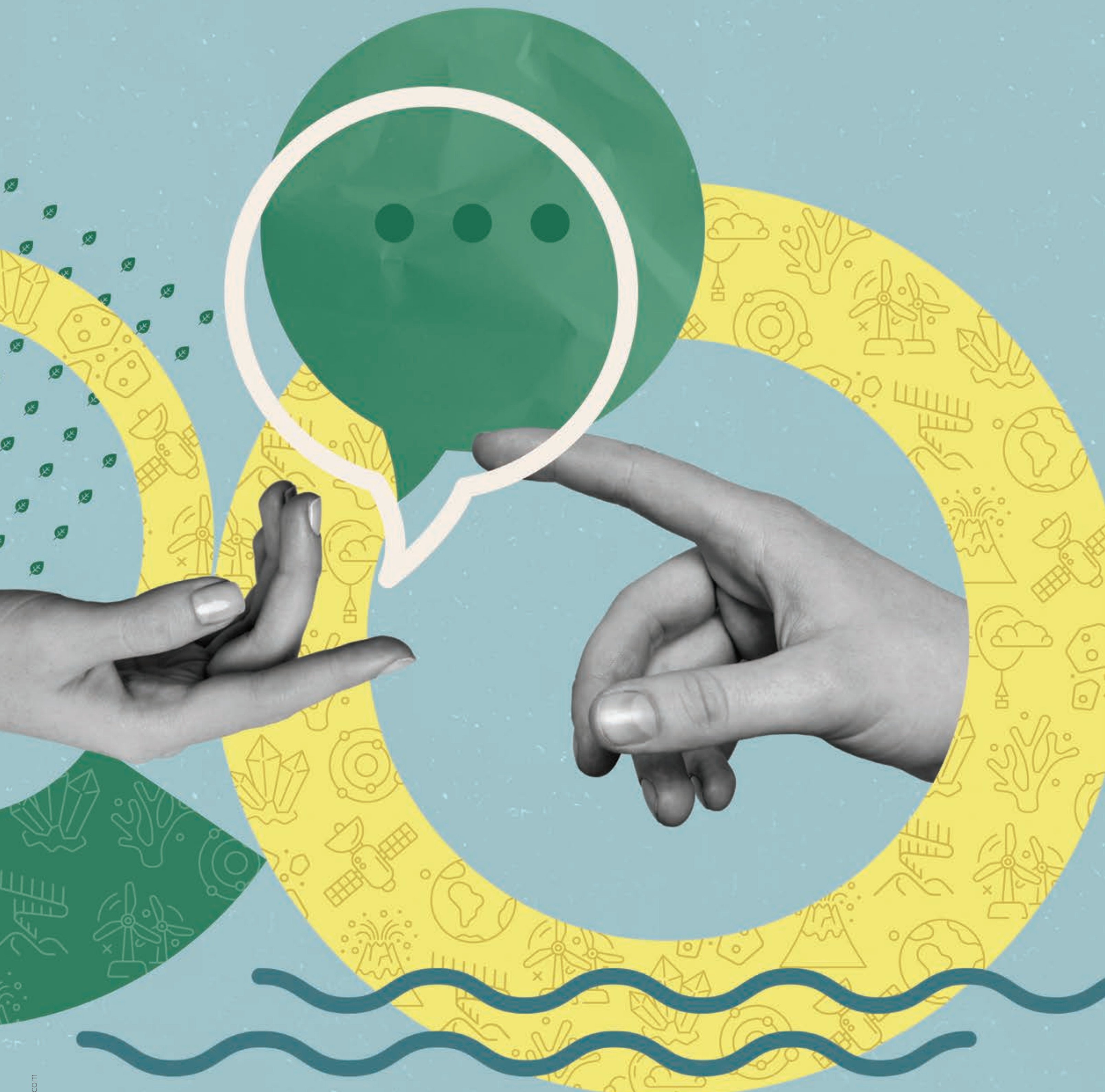
Crafting Signs for Geoscience's Future

By Kimberly M. S. Cartier

Deaf geoscientists are creating the language to communicate their science as well as helping the community grow and thrive.



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"This descriptive quality of sign language is unique and doesn't exist for most languages, not completely. Certain sounds are descriptive. Onomatopoeia, we call it. In sign language, it's much richer."

A Note About Terminology

Following best practices established by the Deaf community, all sources were asked whether and how they preferred to be identified with respect to deafness and the Deaf community and with identity-first or person-first language. Unless otherwise requested by a source, this article uses lowercase "deaf" to refer to a person's audiological status and uppercase "Deaf" to refer to members of the community, some of whom are hearing friends, family, and allies. The way a source communicated is specified upon first reference; "said" or something similar is used thereafter.

The geosciences have a steep language learning curve. Diving into a subfield requires learning jargon to describe a bevy of abstract concepts, niche meanings of otherwise familiar terms, and specialized laboratory and field equipment.

For Deaf geoscientists who primarily use American Sign Language (ASL), that learning curve is made even steeper by the fact that many scientific terms don't have ASL counterparts.

When Caroline Solomon was working toward her doctorate more than 2 decades ago, she didn't know any other deaf oceanographers.

In the classroom, in the lab, and out in the field researching biogeochemistry in Maryland's estuaries, "I was making up signs ad hoc for my field, you know, phytoplankton, dinoflagellates, diatoms, and so forth," Solomon signed. "I was just making them up as I went."

Years later, she finally met another deaf aquatic scientist. As the two shared their research, Solomon realized that they had developed some of the same signs completely independent of each other.

"It was really fascinating, because the way we sign is dependent on the concept we're expressing," Solomon said. She realized that "we're talking about these concepts, we're conceiving of them, in similar ways. I think that was the first 'Aha!' moment for me."

That encounter emphasized to her the need for Deaf geoscientists to share the ASL signs they had created for themselves and to standardize them so that other scientists, students, and interpreters could use them.

In the years since, "I've really seen the number of Deaf scientists increase, which is really wonderful to see," said Solomon, now an estuary biogeochemist, biology professor, and dean of the faculty at Gallaudet University in Washington, D.C.

In addition to their academic contributions, those scientists have worked hard to expand ASL dictionaries to include geoscience-related terms and standardize their use in classrooms and labs. Deaf scientists' work to literally redefine the language of geoscience is helping remove barriers to education and make science, technology, engineering, and mathematics (STEM) more accessible to everyone.

"When we focus on developing signs that can convey the entire picture, it gives deaf scientists and future deaf scientists a language with which they can begin to navigate the science and STEM world," signed Cooper Norris, a Deaf scientist and environmental laboratory technician at Pacific Northwest National Laboratory (PNNL) in Richland, Wash. "And then it helps our hearing colleagues to be able to communicate better with us as well."

Both a Word and an Idea

Signs don't just represent a spoken word but also seek to describe the word's meaning. For example, one ASL sign for "electron" involves the left hand making a fist in front of the chest while the right hand, signing the letter E, circles the left. The sign represents the movement of the electron (right hand) outside the nucleus (left hand).

Sign language's capacity to convey a complex or abstract concept succinctly with a few gestures, called iconicity, makes it well suited for teaching scientific jargon, particularly in the geosciences, where many of the processes at play can be hard to conceptualize, explained Richard Ladner, an emeritus professor of computer science at the University of Washington in Seattle and a child of Deaf adults.

"This descriptive quality of sign language is unique and doesn't exist for most languages, not completely," Ladner said. "Certain sounds are descriptive. Onomatopoeia, we call it. In sign language, it's much richer."

Historically, though, ASL dictionaries have lacked more than a handful of STEM-related words, requiring Deaf students and researchers either to fingerspell field-specific jargon or to invent their own signs for personal use.

"When you don't know the sign or if there is no sign, you have to fingerspell it," signed Annemarie Ross, an associate professor of chemistry at Rochester Institute of Technology's National Technical Institute for the Deaf (NTID) in New York. Just like writing out a new word on a blackboard, "fingerspelling works if you're trying to learn the word, but it doesn't teach the concept, and it doesn't necessarily represent the concept," said Ross, who is Deaf.

In a classroom, fingerspelling every instance of a science word can be cumbersome and physically demanding.

"You can imagine you're teaching a class and the word 'chromatography' or 'spectroscopy' comes up," said Todd Pagano, a

chemistry professor at NTID. "As you can imagine, spelling 'spectroscopy' or 'chromatography' 50 times in a single class period takes a lot of time."

Pagano, who uses ASL in his classes, often works with his students to create signs for classroom use. Not only does the process streamline his teaching and his students' learning, he said, "it helps students who may be native signers to teach something to their professor, take ownership of their learning, and at the same time show that they understand the concept."

"Signs can convey the concept directly without going through a second language, such as English," Michele Cooke, a Deaf structural geologist at the University of Massachusetts Amherst, wrote via email.

"For example, the sign for 'strike-slip fault' efficiently conveys the sense of movement of this kind of fault, takes a fraction of the time needed for spelling 'strike-slip,' and allows the recipient to directly connect the sign to the concept without the extra cognitive layer of using the English word 'strike-slip,'" Cooke said.

What's more, not all native signers speak the same language. ASL, mainly used in the United States and Canada, is just one of more than 300 sign languages in use around the world. When users create an ASL sign, it needs to follow ASL rules for grammar and the "five parameters": handshape, palm orientation, movement, location, and facial expression/nonmanual signals. A sign must also gain acceptance by widespread usage in the Deaf community—if the community doesn't like it, the sign can be lost as a common term.

Although English is often considered the international language of science, other English-speaking countries like the United Kingdom have their own sign languages, as do countries and cultures in which English is not the primary spoken language. Iconicity circumvents some of the variations between different sign languages and facilitates science communication within the international Deaf community.

Limited Usefulness of Ad Hoc Signs

Many newer ASL signs in the geosciences have come about organically as individual scientists realized that they needed them for their own research or classrooms, like Solomon did with "phytoplankton" and "dinoflagellates."

On a field trip with deaf high school teachers and educators, Cooke recognized the need for a sign for "outcrop" to streamline communication. "We agreed that signing 'out' and 'crop' doesn't convey the meaning and creates confusion," she said. "So we came up with a sign that is the equivalent of 'rock' and 'look at it' for 'outcrop.'"

Norris, who was a postbaccalaureate in a soil biogeochemistry lab at PNNL after studying at NTID, said that ASL's science vocabulary can be even more limited in a laboratory setting. The nomenclature of specialized instruments and analysis techniques isn't frequently taught in introductory geoscience classes, including those at NTID, Norris recalled. When he joined his new lab, "I realized all the experiences and the signs that I would need to learn. Developing those signs within the lab became a process, but it became a process that is rewarding," he said.

For example, his research required him to use a Shimadzu carbon analyzer, which has a component that spins like a carousel. Kaizad Patel, an Earth scientist and Norris's mentor at PNNL, said that after so many times fingerspelling "Shimadzu" or simply pointing to the device, the lab group decided to create a sign to represent that machine.

"You spell out a word so often that you're like, 'OK, enough of this. We just need something to express what we're talking about,'" Patel said. Their sign includes a movement that mimics the carousel-like function of the machine. Using the sign increased the team's efficiency and cut down on confusion.

Signs like "Shimadzu" are very niche, but even the more general geoscience-related signs might have limited effectiveness outside their originally intended setting. Like family nicknames or personal variations on signs, "home signs" or "lab signs" might be understood only by those who created them or use them.

"If your whole lab knows that sign," Pagano said, "it's OK to use that when you're in that lab. But outside of that lab, the sign hasn't necessarily been standardized or disseminated or known." Other Deaf professionals and interpreters might not know that sign, or it might mean something else in another context.

"There are very few deaf geoscientists, but with better access to geoscience signs, maybe we can see geosciences become more diverse."

Explore More

- ASL-STEM Forum and Dictionary: aslstem.cs.washington.edu/
- ASLCORE Dictionary: aslcore.org/
- Atomic Hands, Deaf STEM communications and networking: atomichands.com/
- Norris/Patel Dictionary: pnnl.gov/labsigns
- *Silence of the Spheres: The Deaf Experience in the History of Science* by Harry G. Lang, ISBN 0897893689
- STEM Sign Language Summit: bit.ly/sign-summit

The "Shimadzu" sign "might not work as well [in another lab] where you have other instruments that spin like a carousel," Patel said.

That potential for miscommunication can create additional barriers when deaf scientists attend professional events, like conferences and workshops, designed by and for hearing people.

"When I tried using ASL interpreters at conferences, I found that missed too much of the science," Cooke said. "Conference presenters speak quickly, and when the interpreters have to fingerspell (and guess the spelling of words they don't know), they can't keep up, so they skip things." In other cases, an interpreter might hear a word that has multiple meanings (as much science jargon does) and use the wrong sign for that context, causing confusion or an unneeded delay in understanding.

"If I went to a conference in a different town using different interpreters, each time I had to teach them my signs that I had developed for my own career," Solomon said. "If a hearing person goes to a conference, they can simply access the presentation." Oftentimes, deaf scientists who present their research in ASL at a conference have to alter or slow down their natural signing style so that interpreters can keep up.

"I have spent hours preparing interpreters, teaching interpreters, the science and the content," Solomon said. "That's a lot of invisible labor involved."

Standardizing and Increasing Access

The added burdens and extra work that go into navigating spaces designed for hearing people—classrooms, labs, field camps, conferences—underscore the need deaf geoscientists have for standardized and, most important, documented signs. For decades, scientist members of the Deaf community have worked to shore up the language gap by collating their science signs into STEM-specific ASL dictionaries. What started as printed pamphlets with sequences of hand gestures and arrows showing movements has evolved into massive online video dictionaries that help people find the signs they need.

"There are very few deaf geoscientists, but with better access to geoscience signs, maybe we can see geosciences become more diverse," Cooke said.

ASL-STEM, a community forum and video dictionary of more than 3,200 STEM signs hosted by the University of Washington, is one of the largest efforts to document and share science signs.

"It's a public place where people can put signs up for science," said Ladner, who cofounded ASL-STEM.

ASL-STEM has no entry for "geology" or "geoscience" ("geology" can be found elsewhere). Users have submitted signs for natural science, Earth and space sciences, and atmospheric sciences, but most of the entries are related to medicine, engineering, and technology.

ASL "is like any language," Ladner said. "New terms come into languages all the time. It's based on need; it's based on efficiency."

Anyone can submit a sign to ASL-STEM for consideration, but there's no guarantee that the sign has strong iconicity or that it follows ASL's grammar. But because the project is community driven, users can submit signs they see a need for or regularly use, and entries include niche terms like "bacteriophage," "fieldwork," and even many of Solomon's original marine biology signs.

ASLCORE, hosted by NTID, is another effort to document signs specific to professional fields. New signs are developed solely by Deaf users of ASL and go through a rigorous vetting process before being added to ASLCORE.

"It's really important that it's really led by the Deaf and hard-of-hearing community," said Pagano. He explained that most of ASLCORE's science entries are related to biology, chemistry, and physics for the simple reason that many of the scientists who have worked on the project, himself included, are biologists, chemists, or physicists.

"It's built upon a team of experts," said Pagano. "You have an expert in the discipline, for example, chemistry or geoscience, to make sure that the meaning of the sign is correct and make sure everyone understands the meaning. You have ASL linguistics experts. You have Deaf and hard-of-hearing individuals who are working in the field who use the signs. For ASLCORE, we also have interpreters who specifically interpret in that field."

Recently, ASLCORE developed a group of "sustainability" signs under a National Science Foundation grant. Ross, who was on the sustainability sign development team, explained that it was a difficult task because "sustainability" can mean different things to different groups of people. It could mean reducing fossil fuel usage or conserving natural resources or protecting Earth.

"Sustainability is one of the most complex ideas you can develop a sign for," Ross said. After much discussion, the team agreed on a three-part sign that conveys the idea of preserving Earth's natural resources by combining signs for environment, replacement of resources, and stability.

A three-gesture sign requires more practice to get right, Ross admitted, but the team felt that the complexity would help convey a fuller definition of the term. The group also developed simpler variations of "sustainability" for day-to-day use, as well as 59 other multipart signs for related terms like "air pollution," "climate change," "geospatial analysis," and "water security." These terms are arguably related to the geosciences even if they are not categorized as such.

"The lack of geoscience signs isn't due to a lack of need," Pagano said. Deaf geoscientists have existed for as long as people have studied geoscience. "It's really just that the field needs more scientists to develop and disseminate the signs."

Some, like Norris and Patel, have created subfield-specific dictionaries—in their case, environmental and applied biological sciences. They collaborated with members of the ASLCORE team to ensure that their signs for instruments, lab processes, and jargon met ASL's grammar and iconicity standards.

"In the geosciences, there isn't much out there," Patel said, "so we're trying to fill that niche."

"There's still a lack of access for our community," Norris added, "and the number of deaf students and deaf scientists out there [is small] because of the lack of access. If we can create more resources like this, we will hopefully see more students coming into our field."

Deaf-Led Progress

Some signed languages, like British Sign Language, already have robust science dictionaries. Indigenous Hand Talk, such as Plains Indian Sign Language and Inuit Sign Language, describes the natural world with vocabulary that predates both ASL and the colonization of North America. These languages could help braid Indigenous Knowledges and Western science together, also helping to decolonize the geosciences.

Other sign languages, like ASL, Mexican Sign Language, and Indian Sign Language, are still growing their science vocabulary. The increased awareness that ASL sometimes lacks the vocabulary for science has been both a boon and a cause for concern, Solomon said.

"There was this great excitement that everybody was coming up with these signs and developing them, but it got to the point where it felt like *anyone* was developing these," Solomon said. She saw an increasing number of grants that included a promise to develop new signs in their broader impact statement, and it worried her.

"Where are the standards for this development?" she asked. "Where are the values that underlie this process? What are the ethical implications here? And where are the linguistic principles in these signs? Who gets to develop them? Who owns them?"

And when the grant money runs out, who will pay to keep the dictionaries going?

The efforts to create science signs for ASL must be led and owned by Deaf users of the language, Solomon said. Alongside the development of new signs must be a push for standardization of science signs, she said, and that push needs to be led by the Deaf community.

Many more ASL dictionaries with science signs, including some geoscience-specific ones, exist now than several decades ago. But not knowing which dictionary, if any, has the sign you need is yet another barrier to overcome. The next step, Norris said, should be centralization.

"In the future," he said, "it would be nice to see more of them compiled into one place to help our community thrive."

"It's a learning process for everybody, including myself as a Deaf person," Norris added. "Hearing people are also on that learning journey. We're all trying to break down barriers."

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Read the article at Eos.org

"It's a learning process for everybody, including myself as a Deaf person. Hearing people are also on that learning journey."

Linguistic Colonialism

Efforts pushed by outsiders to cohere and standardize languages, including signed languages, can be a form of colonization that suppresses cultural identity and limits discourse. Around the world, Indigenous Hand Talk and other Indigenous languages remain under threat of extinction as a result of atrocities endured by Indigenous peoples, including forced relocation and cultural assimilation. Learn more about linguistic colonialism: **bit.ly/LinguisticColonialism**.

Over the next century, the Arctic will change and look much different than it does today. Just how different remains to be seen.

THE ARCTIC'S UNCERTAIN FUTURE

By Grace van Deelen

AI illustration by tynza — stock.adobe.com

As a doctoral student at the University of Colorado Boulder in the 1980s, Mark Serreze studied sea ice in the Beaufort Gyre, a current in the Arctic Ocean just north of Canada. He used a network of drifting buoys to track the movement of the ice pack, finding that floes of sea ice periodically opened in response to summer winds. He also studied the terrestrial St. Patrick Bay ice caps of Ellesmere Island in Nunavut, Canada.

Serreze now directs the National Snow and Ice Data Center at the University of Colorado Boulder, where he continues to study ice in a warming world. But the St. Patrick Bay ice caps he visited for his graduate work no longer exist—they've since melted away as climate change has advanced, mostly unabated.

Today Serreze sees "an Arctic that is losing its character, losing its soul, that soul being its snow and ice."

In the past few decades, sea ice—the engine of the Arctic climate—has diminished dramatically, with the total area of ice cover down about 50% from the 1980s. Precipitation patterns now bring more rain and less snow to the Arctic. Thawing long-frozen ground allows for more severe erosion. And vegetation is growing faster and farther north in response to rising air temperatures.

The Arctic is "drastically different from what it was," said Jennifer Francis, a climate scientist at the Woodwell Climate Research Center in Massachusetts.

THE ARCTIC IS "DRASTICALLY DIFFERENT FROM WHAT IT WAS."

Scientists use past climate data and estimates of future greenhouse gas emissions to simulate how these changes may continue in the future. But system complexity, natural variability, and limited data mean these forecasts can vary.

"All models are wrong," the saying goes, "but some are useful."

Combining simulations that have varying assumptions, initial climate conditions, and data into ensembles reduces—but doesn't eliminate—uncertainty. Ensembles agree that as long as we produce greenhouse gases (and even after we stop), the Arctic will continue to warm, creating a cascade of changes. The details of those predicted changes, however, range widely.

Arctic sea ice is in decline, and most research suggests that Arctic summers may be ice-free by mid-century. Credit: NASA/Kathryn Hansen

The Arctic over the next century could look like a slightly warmer version of today's Arctic. Or it could be unrecognizably altered. The farther into the century we forecast, the more uncertain its future becomes.

Just how much the Arctic changes depends on the steps humanity takes to halt or even reverse climate change, said Laura Landrum, a climate scientist at the National Center for Atmospheric Research. "It'd be good if we'd started yesterday," she said.

2040

Without major reductions in greenhouse gas emissions, the changes scientists currently see in the Arctic will greatly accelerate by 2040.

In just 15 years, permafrost thaw and increasing precipitation will mean some rivers in the Arctic will swell with water and erode their banks more quickly. The once-solid ground beneath some Arctic towns, especially those on the coast, may yield to the water.

Because of erosion and sea level rise, residents of places like Shishmaref, an Alaska Native community located on a highly vulnerable barrier island, may be forced to move. Indeed, officials in Shishmaref and in at least 12 other Native Alaskan villages are already exploring relocation plans.

Warmer ocean waters will also fuel ever more destructive storms. Events like Typhoon Merbok, which caused widespread flooding in coastal Alaska in 2022, will be more common.

The Arctic biosphere will also change. At least one species of algae, *Alexandrium catenella*, could take advantage of warmer oceans and spread northward from its habitats in temperate and subpolar waters, said Don Anderson, a biologist at the Woods Hole Oceanographic Institution in Massachusetts. These bloom-forming algae produce toxic compounds that contribute to "red tides" elsewhere in the world. In the Arctic, the algae could poison marine life and contaminate food such as clams, which some coastal Arctic communities rely on. Widespread blooms could kill other Arctic life such as seabirds, walruses, and whales.

Our incomplete understanding of the life histories of harmful algae in cold environments, as well as of the influence of competing species and potential predators, means we can't say for certain that warmer oceans will directly lead to more harmful algal blooms, however. "There will be winners and there will be losers" in the ecosystem, Anderson said.

By 2040, warming could thaw about 10%–40% of high-latitude permafrost, a process that emits greenhouse gases including methane and carbon dioxide (CO_2) as long-frozen remains of animals and plants are exposed to air and begin to decay. Scientists can't narrow in on exactly how much permafrost will thaw, or how the thaw will affect Arctic systems, Serreze said. That's because they aren't sure how much carbon dioxide and methane are present in Arctic permafrost or when and where it could escape.

Today the Arctic is warming anywhere from 2 to 4 times faster than the rest of the world in a phenomenon known as Arctic amplification. Calculating the Arctic amplification ratio is simple, Serreze said: Just pick a time period or season, determine how temperatures in the Arctic and elsewhere have changed, and divide. That amplification ratio is expected to increase, but scientists aren't sure by how much. That uncertainty can complicate climate projections, too.

Emergence

Some scientists think that a new Arctic climate will have emerged by 2040. No longer dominated by ice and snow, the Arctic will become something altogether different, warmer and wetter.

Landrum defined this emergence as a state when the Arctic climate no longer fits expected patterns based on the past 30 years of data, when "the idea of a climate normal doesn't really work anymore," she said.

The process of emergence diminishes scientists' ability to use records of a system's past to pinpoint specific changes to its future, such as the intensity of future heat waves or the number of future typhoons.

Instead, scientists modeling emerging systems rely more heavily on their understanding of the physics of those systems, for example, how heat transfer works between the ocean and the atmosphere.

If scientists had a complete understanding of Earth systems, emergence wouldn't pose a problem. But they don't, and they lack the resources and data to do so.

In a recent paper, Landrum and a colleague suggested that Arctic emergence has already begun. Minimum sea ice extents in the Arctic now lie well outside the ranges that modelers would expect when using data from the past 30 years. Landrum's conversations with Arctic residents indicate to her that regional air temperatures and precipitation patterns could deviate from climate normals relatively soon, too, if they haven't already.

Carbon dioxide stays in the atmosphere for hundreds of years. Even drastic cuts to emissions today won't prevent changes in the Arctic by 2040, because much of that warming is "baked in" to the system.

Geoengineering approaches such as carbon capture and marine cloud brightening could slow the changes, but only if the science is settled enough to prove their efficacy and the political will exists to implement such solutions. And geoengineering shouldn't be just an "excuse for continuing to consume and produce more fossil fuels," Landrum said.

Many people and communities have committed themselves to meaningful adaptations in the Arctic, from coastal resilience planning to implementing near-real-time monitoring and advanced warning for algal blooms.

But it may not be enough. "What we need to do is guess at what might be some of the worst-case events...and then try and plan to avoid those," said James Overland, an Arctic oceanographer for NOAA's Pacific Marine Environmental Laboratory.

2060

Thirty-five years from now, consistent summer sea ice will likely be a memory, much like reliable snow in the northeastern United States or summers without record-breaking heat waves. Some summer sea ice may still cling to the edges of Arctic shores, or the occasional summer will still have Arctic-wide sea ice. But most climate scientists agree: By mid-century, many Arctic summers will be virtually free of sea ice.

"Barring really dramatic carbon reductions that are probably not realistic," summer sea ice loss is probably inevitable, according to Walter Meier, a sea ice scientist at the National Snow and Ice Data Center.

And that loss will have widespread consequences for the Arctic, some of which we're already beginning to see.

Without sea ice, Arctic processes could break down.

Without ice as a barrier, more heat transfer occurs between the ocean and the atmosphere. As more moisture enters the air, it causes more precipitation and stronger storms, which scientists are already noticing, Francis said. Without sea ice to temper wave action, storms could fuel more powerful seas and more destructive coastal erosion. Coastal areas may also face worsening flood risk, and even more communities may be forced to move.

The temperature gradient between the once-cold Arctic and warmer, more southern latitudes will likely shrink. Though the science is still uncertain, that could create a less stable jet stream and more interaction between the polar atmosphere and the atmosphere at more southern latitudes. Warm air from the south could intrude more easily into the Arctic, exacerbating warming. A weakened jet stream could also lead to longer heat waves, rainy periods, droughts, and cold spells.

As a graduate student, Mark Serreze conducted research on the St. Patrick Bay ice caps on Canada's Ellesmere Island. The ice caps no longer exist. Credit: Mark Serreze

Variable Fates

Scientists' confidence in sea ice projections comes from the wealth of data and studies already done, as well as from the relative simplicity of the system: Sea ice responds to temperature changes in the atmosphere and ocean, as well as to wind patterns, Serreze said. But the extent to which its disappearance will affect the Arctic and global atmospheric circulation and weather is still unsettled.

"BARRING REALLY DRAMATIC CARBON REDUCTIONS THAT ARE PROBABLY NOT REALISTIC," SUMMER SEA ICE LOSS IS PROBABLY INEVITABLE.

"It's a complicated place, and there's still a lot we don't understand completely," Francis said.

Uncertainties in Arctic projections exist for a couple reasons, Serreze said. First, small variations in emissions scenarios can compound into widely diverging projections. Second, various climate models simulate Arctic processes differently. Notably, some are more sensitive to fluctuations in atmospheric greenhouse gases.

In addition, climate models are limited by a lack of long-term historical data, as satellites have collected climate data for only about 40 years. Some climate data from the 19th and 20th centuries exist only in the form of observational records and scarce, scattered measurements of ocean temperatures. They are useful data with which to make projections, but scientists must interpolate between records to complete a picture of conditions. That interpolation introduces uncertainties, said Niklas Boers, a climate scientist at the Potsdam Institute for Climate Impact Research and a professor at Technische Universität München, in Germany.

Improvements in modeling can do only so much without a thorough understanding of how a climate system works. More sophisticated models produce results with less uncertainty, said Greg Breed, a quantitative ecologist at the University of Alaska Fairbanks. "But they're still driven by a model that is ultimately an incomplete picture of the system we're trying to represent with it."

Breed described the changing Arctic climate as an experiment that's never before been done. "The thing about experiments is that they often completely contradict your models, because you didn't know some dynamic of the system. You just weren't aware of it," he said.

Scientists should expect to be surprised by how the Arctic will change, Breed said.

Because the formation of sea ice is a relatively simplistic process, some scientists think the ice could someday come back.

If governments have the political will to cut emissions, temperatures in the Arctic could eventually fall low enough to allow summer sea ice to form again. "One can easily imagine a scenario in which the efforts of these international bodies… managed to decarbonize the economy sometime in the next 40 or 50 years," said Robert Newton, an oceanographer at the Columbia Climate School, Columbia University.

"As CO_2 comes out of the atmosphere, either naturally or by engineering, the temperature should come down and the sea ice should return," he said.

IF WE HAVE THE MEANS AND THE TECHNOLOGY TO REDUCE THE CONCENTRATION OF CO_2 IN THE ATMOSPHERE, "THE FATE OF THE ARCTIC BECOMES A SOCIOECONOMIC QUESTION."

Paleontological data can give a glimpse of the Arctic's past. Fossils in and around this petrified forest on Ellesmere Island, for example, indicate that at one time, the Arctic climate was much warmer and more humid than it is today. Credit: Jaelyn Eberle

The extent of efforts to decarbonize remains an open question, of course—especially as receding sea ice provides more economic opportunities. In a 2016 paper, Newton and his colleagues outlined the many economic arguments for allowing sea ice to recede, including an increase in commercial activities such as fishing, oil and natural gas production, mining, and shipping. It's possible that those with an economic stake in an ice-free Arctic would prevent efforts to restore the ice.

If we have the means and the technology to reduce the concentration of CO_2 in the atmosphere, "the fate of the Arctic becomes a socioeconomic question," Newton said.

2100 and Beyond

In the absence of drastic cuts in emissions, the Arctic will transform even further by the end of the century. By 2100, the Arctic will be about 30%–60% wetter, its landscape dominated by the effects of rain. Most state-of-the-art climate models suggest that by this time, temperatures in the Arctic could rise by about 13°C–15°C (23.4°F–27°F), compared with a global temperature rise of up to 5°C (9°F). Summer sea ice will be long gone, and winter sea ice may decline in quantity and thickness.

It's unlikely that the Arctic will be ice-free year-round within the next century. Many scientists believe there will always be winter sea ice. But others, such as Newton, say such a scenario is not completely unfathomable. The Arctic has been ice-free year-round before—during the Eocene, 52 million years ago.

Paleontology and paleoclimatology can give a glimpse of what the Arctic climate and ecosystems could eventually become beyond 2100 if warming goes unchecked. Jaelyn Eberle, a vertebrate paleontologist at the University of Colorado Boulder, has spent much of her career searching for and analyzing fossils in the Arctic, particularly on Ellesmere Island, Canada's largest Arctic island and home to Serreze's now-vanished ice caps.

Eberle and her colleagues have shown that during the Eocene, Arctic flora and fauna resembled a contemporary cypress swamp. The global climate was warm and humid, allowing alligators, primates, tapirs, and animals similar to hippos and rhinos to live above the Arctic Circle. Average summer temperatures likely soared to 20°C–25°C (68°F–77°F), and winter temperatures probably hovered around freezing.

Projected temperatures in 2100 aren't quite at Eocene levels. But some models indicate that 23°C (41.4°F) of change is possible—and one study suggests that parts of the globe could reach an Eocene-like climate by 2130.

It's unlikely that Arctic temperatures will resemble the Eocene, Landrum said. But it's not impossible, and that fact is "truly scary," she said.

"We're not necessarily saying that when it warms, we're going to get a replay of the Eocene," Eberle said. Rather, paleontological data show what living systems in the Arctic can handle, and that the Arctic ecosystem could deviate wildly from how it looks today.

"I don't expect alligators in Hudson Bay," Landrum said. "But I do expect a really different system."

A huge source of uncertainty, according to Eberle and Breed, is the extent to which humans will alter the Arctic environment and ecosystems between now and 2100. Maybe we'll start relocating species northward. Maybe we'll plaster solar panels across Siberia. Maybe new Arctic cities will rapidly expand into Arctic species' territory.

Ecology introduces uncertainty, too: Living organisms have complicated life histories, and their interactions with one another could lead to many possible outcomes. For example, scientists aren't sure how bowhead whales—one of a handful of whale species that live almost entirely in the Arctic—will respond to warming. "They might be just fine without any sea ice and [with] warmer water, or they may decline, perhaps precipitously and unexpectedly," Breed said. That uncertainty comes from a lack of a complete understanding of the animal and its ecosystem. And forecasts of how organisms and ecosystems will respond to warming largely ignore evolution's potential to help species adapt at the pace of climate change, Breed said.

"A lot of the ecosystem models that we do kind of assume that the properties of each individual species are static," he said. But evolving is "absolutely what everything's doing." Breed emphasized that ecosystems are often more robust than we think and can hang on despite large changes in their habitats. He said he expects to see mostly gradual shifts of species' ranges punctuated by species' collapses brought on by natural disasters.

If sea ice does return, ice-dependent flora and fauna could, too. But hoping for a world where sea ice returns before ice-dependent species are wiped out is overly optimistic, Breed said. And if polar bears and seals go extinct, the emergence of similar species—for example, another white bear evolving from grizzlies—would take tens of thousands of years or longer.

In terms of wildlife, it is futile to look so far forward given the uncertainties that exist, he said.

In a sea of unknowns, one truth remains: A vastly altered Arctic cannot be avoided. Some of the possible changes could be reversed only if the political will to do so exists—and that's looking frustratingly unlikely, Breed said.

"We're going to have a different world, and we don't know what that world's going to be."

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Read the article at Eos.org

Volunteers Track Parisian Pollution with the Help of Tree Bark

Volunteers in Paris collect bark samples from the city's plane trees as part of the Ecorc'Air project. Credit: Aude Isambert

Along the streets of Paris, more than 40,000 tall, leafy plane trees provide picturesque backdrops, offer shade to city dwellers, and improve air quality, among numerous other benefits. Since 2016, some of these trees have also served as low-cost, passive biological sensors for Ecorc'Air, a crowdsourced science initiative that monitors levels of fine-particle pollutants associated with road traffic.

Motor vehicles emit numerous forms of particulate matter linked to health problems such as cardiovascular and respiratory conditions. Some of these pollutants settle out of the air onto the bark of plane trees and become trapped on its porous surface.

Because the trees shed their bark annually, a bark fragment collected just before shedding occurs holds a record of all pollution deposited during the past year.

Carvallo et al. report how Ecorc'Air is harnessing the pollutant-collecting properties of plane tree bark to track annual levels of traffic pollution at a finer scale than is currently feasible with electronic air quality monitoring tools. The initiative invites Parisian volunteers to collect small bark fragments from plane trees in their neighborhoods and send them in freezer bags to participating laboratories—along with information such as the trees' GPS coordinates and their proximity to the nearest road.

In the lab, researchers measure the magnetic properties of each bark sample, a proxy for levels of metallic particulate matter accumulated on the sampled tree. They then use these measurements to create detailed annual maps of estimated traffic pollutant concentrations in Paris.

The project is ongoing, but several findings from its first 8 years have stood out. For instance, the researchers have identified several areas in the city with consistently high concentrations of metallic particulate traffic pollutants. They also have identified trends in pollutant concentrations over time along the Pompidou Expressway, a major thoroughfare in Paris, demonstrating how Ecorc'Air can capture local-scale changes. Interviews with Ecorc'Air participants suggest that interest in environmental research is growing among Parisians, especially those who are involved in local associations.

Overall, the project's findings show how crowdsourced efforts such as Ecorc'Air can aid environmental research and potentially help inform policy and detailed urban planning. (*Community Science*, https://doi.org/10.1029/2024CSJ000084, 2024) **—Sarah Stanley,** *Science Writer*

All Eyes on Jupiter

Jupiter's striking appearance comes from its stormy atmosphere. Swirling clouds surround the gas giant, and their distribution reflects the planet's weather.

Scientists have used professional observatories such as the Very Large Telescope in Chile (whose construction in the 1990s cost more than 330 million euro, or US$366 million) and spacecraft such as the Juno orbiter (part of a US$1.13 billion mission) to study Jupiter's meteorology, but they lack some ongoing monitoring abilities. Amateur astronomers have filled in part of this gap by monitoring visible clouds and wind.

Now, *Hill et al.* show that the chemical tracers of Jupiter's weather can be observed using relatively inexpensive equipment, which may allow amateur astronomers to contribute even more to scientific knowledge of the planet's conditions.

Unlike Earth's water-based clouds, Jupiter's topmost clouds are thought to be primarily made of ammonia ice; the atmosphere's ammonia content is indicative of the planet's weather. Ammonia absorbs red light at a wavelength of 647 nanometers. Methane, whose abundance is both fixed and well known to scientists, absorbs orange light at a wavelength of 619 nanometers.

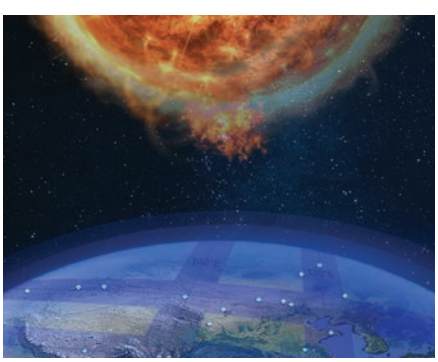
NASA's Juno spacecraft was a little more than one Earth diameter from Jupiter when it captured this mind-bending, color-enhanced view of the planet's tumultuous atmosphere. Credit: Enhanced image by Gerald Eichstädt and Sean Doran, CC BY-NC-SA 4.0 (bit.ly/ccbyncsa4-0), based on images provided courtesy of NASA/JPL-Caltech/SwRI/MSSS

Using a commercially available telescope priced at around US$4,000, the researchers took pictures of Jupiter and looked for spots where there was increased absorption at 647, relative to 619, nanometers, indicating increased ammonia abundance at those locations. They could then calculate the abundance of ammonia using the ratio of these absorptions and the known, unchanging abundance of methane.

This study showed changes in ammonia distribution over timescales ranging from weeks to years, but scientists need more data to understand what these changes mean. The authors say they hope amateur astronomers can use this method to help collect and share more data and that this increased workforce can allow for weekly or even daily monitoring of Jovian weather. (*Earth and Space Science*, https://doi.org/10.1029/2024EA003562, 2024) **—Saima May Sidik,** *Science Writer*

From Sun to Earth: A New Network for Comprehensive Space Weather Monitoring

There's a lot going on between Earth's atmosphere and the Sun. Accurately forecasting conditions in this area of space is challenging but critical to the safety of astronauts, satellites, and even ground-based systems such as power grids. Doing so requires using a combination of monitoring techniques to track specific aspects of the Sun, solar wind, the ionosphere, and more. A new large-scale network is set to enhance scientists' ability to watch and predict how events on the Sun will affect Earth.



The Chinese Meridian Project will integrate data from hundreds of ground-based instruments to monitor space weather between the Sun and Earth. Credit: Chi Wang et al.

Wang et al. introduce the Chinese Meridian Project (CMP), a comprehensive, ground-based space environment observation network that integrates data from about 300 instruments to monitor space weather as it travels from the Sun to Earth's atmosphere. The CMP is projected to provide continuous monitoring of multiple spatial layers of the solar-terrestrial space environment, enabling both more rapid detection and more accurate forecasting of events such as solar storms.

The CMP architecture is made up of "one chain, three networks, and four focuses," the authors write.

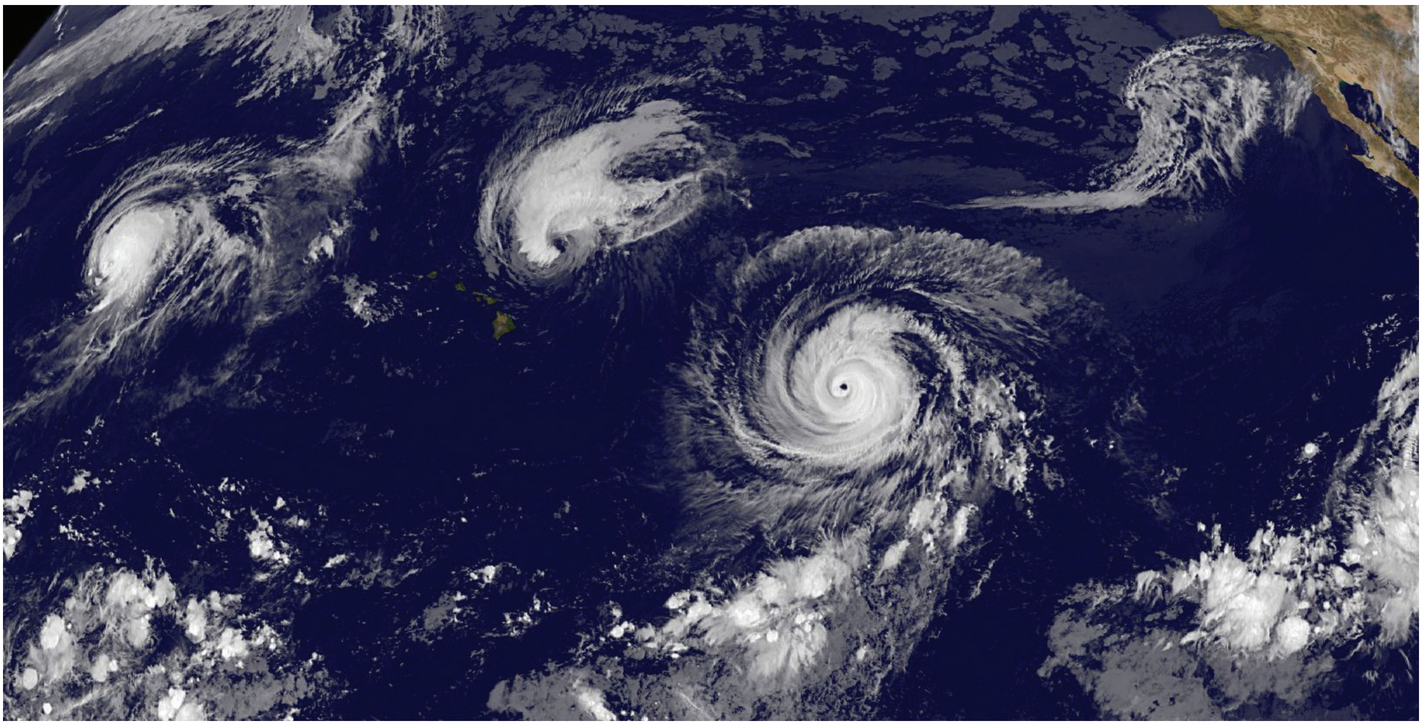
The "one chain" refers to a collection of optical, radio, geomagnetic, and other devices that monitor the chain of weather events that travel from the Sun to Earth.

The "three networks" cover three areas closer to home: Earth's ionosphere, geomagnetic field, and middle and upper atmosphere. They include radar, lidar, and geomagnetic and ionospheric instruments based in China that observe each of these levels.

The "four focuses" are four locations: the poles, middle- and low-latitude regions in China, and the Tibetan Plateau. Specialized tools and monitoring facilities, including telescope arrays, magnetographs, radar systems, and an aurora spectrometer, will offer more detailed views of geomagnetic and atmospheric disturbances.

The network also includes data transmission and storage capabilities, as well as a system for analyzing and sharing data from the CMP with the international research community. The CMP is expected to improve scientists' ability to gather data on the solar-terrestrial environment. This could enhance their ability to forecast events such as electromagnetic storms that imperil satellite networks and electrical grids. (*Space Weather*, https://doi.org/10.1029/2024SW003972, 2024) **—Nathaniel Scharping,** *Science Writer*

Physics Meets Machine Learning for Better Cyclone Predictions



Typhoon Kilo, Hurricane Ignacio, Hurricane Jimena, and Tropical Depression 14E are pictured here from left to right as they swirl over the Pacific in 2015. Credit: NASA/NOAA GOES Project

Time is of the essence in tropical cyclone prediction: The more warning time a community has, the better prepared its members will be when a storm makes landfall.

Currently, the forecasted path and nature of tropical cyclones are reliable up to only 5 days in advance. But new research by *Liu et al.* looked at a new way to forecast these storms that could increase that lead time to 2 weeks.

The researchers created a hybrid model for longer-range tropical cyclone forecasting, combining the strength and high resolution of the physics-based Weather Research and Forecasting (WRF) Model with the large-scale circulation and storm path modeling capabilities of a machine learning model called Pangu-Weather (Pangu).

WRF divides Earth's surface into a grid with squares as small as 2 kilometers on a side and simulates the processes at play in a tropical cyclone's evolution.

However, physics-based models like WRF have some limitations in predicting storm intensity levels because they don't always capture changing environmental factors such as sea surface temperatures or interactions with other storms. Machine learning prediction models are better at forecasting tropical cyclone paths, but the 25-kilometer resolution of Pangu means it can miss smaller-scale variability within a developing storm.

To reduce these limitations, the researchers combined the approaches of the WRF and Pangu models. They conducted six experiments over the course of 2 weeks to test their modeling design. After adjusting their models, they tested their approach on 2023's Freddy—the longest-lasting tropical cyclone on record—as a case study.

They found that the hybrid approach significantly improved the tracking and intensity forecasts compared with using only one modeling method. Their approach also extended accurate predictions from 5 to 7 days and closely matched the path and intensity of Freddy for the whole 2 weeks. The authors note that with more testing on tropical cyclone cases, their modeling approach could extend warning time to beyond 2 weeks, helping at-risk communities to better prepare in the face of major storms. (*Journal of Geophysical Research: Machine Learning and Computation*, https://doi.org/10.1029/2024JH000207, 2024)

—Sarah Derouin, *Science Writer*

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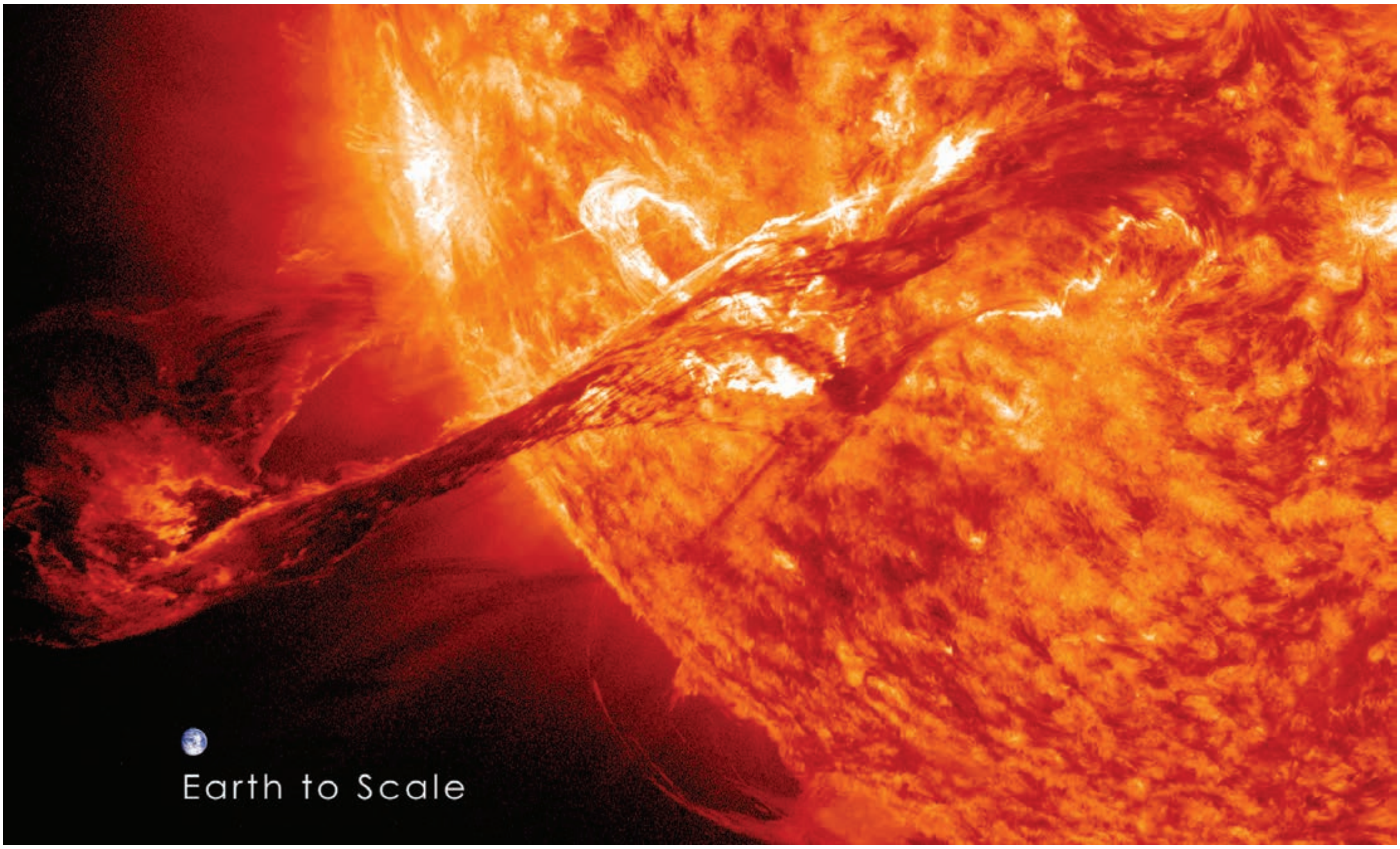
Coronal Mass Ejection Gives Earth's Magnetosphere Rare "Wings"



A coronal mass ejection (CME) in April 2023 caused Earth to grow Alfvén wings. The CME shown in this image, with Earth illustrated to scale, took place in 2021. Credit: NASA/GSFC/SDO

Like a supersonic jet being blasted with high-speed winds, Earth is constantly being bombarded by a stream of charged particles from the Sun known as solar wind.

Just like wind around a jet or water around a boat, these solar wind streams curve around Earth's magnetic field, or magnetosphere. On the sunward side of the magnetosphere, they form a front called a bow shock, and on the nightside, they stretch into a windsock shape with a long tail.

Dramatic changes to solar wind alter the structure and dynamics of the magnetosphere. An example of such changes provides a glimpse into the behavior of other bodies in space, such as Jupiter's moons and extrasolar planets.

Chen et al. report unprecedented observations of a rare phenomenon created during a coronal mass ejection (CME). CMEs typically travel faster than the Alfvén speed, at which vibrating magnetic field lines move through magnetized plasma, which can vary with the plasma environment. A CME in 2023 disrupted the normal configuration of Earth's magnetosphere for about 2 hours. The researchers analyzed observations from NASA's Magnetospheric Multiscale (MMS) Mission to learn what occurred.

On 24 April 2023, the MMS spacecraft observed that though the streaming speed of the solar wind was fast, the Alfvén speed during the strong CME was even faster. This anomaly caused Earth's bow shock to temporarily disappear, allowing the plasma and magnetic field from the Sun to interact directly with the magnetosphere. Earth's wind sock tail was replaced by structures called Alfvén wings that connected Earth's magnetosphere to the recently erupted region of the Sun. This connection acted as a highway transporting plasma between the magnetosphere and the Sun.

This unique CME event offered new insights into how Alfvén wings form and evolve, the authors write. A similar process could occur around other magnetically active bodies in our solar system and universe, and the researchers' observations suggest that the formation of aurorae on Jupiter's moon Ganymede may also be attributable to Alfvén wings. The authors suggest that future work could look for similar Alfvén wing aurorae occurring on Earth. (*Geophysical Research Letters*, https://doi.org/10.1029/2024GL108894, 2024) **—Nathaniel Scharping,** *Science Writer*

The Role of Community Conversation in Improving Air Quality

Researchers worked with organizations serving communities disproportionately affected by environmental hazards (including those in Boston, shown here). Credit: Robbie Shade via Flickr, CC BY 2.0 (bit.ly/ccby2-0)

Assessments of how transportation pollution affects health often fail to prioritize the needs or concerns of communities experiencing disproportionate exposure to environmental hazards, such as low-income areas or communities of color. As a result, even successful climate policies do not necessarily benefit these communities, and some policies even worsen inequalities.

Rick et al. suggest that one reason for this gap could be that academic researchers fail to engage directly with these communities or their advocates.

To address this, the group collaborated with several environmental justice organizations in the northeastern United States to develop transportation emission mitigation strategies and build a sense of trust and community.

The organizations were Alternatives for Community & Environment, in Boston; the Center for Latino Progress and the Connecticut Coalition for Environmental Justice, both in Hartford; Pittsburghers for Public Transit, in Pittsburgh; the South Ward Environmental Alliance, in Newark, N.J.; the Virginia Environmental Justice Collaborative, in Richmond; and WE ACT for Environmental Justice, in New York.

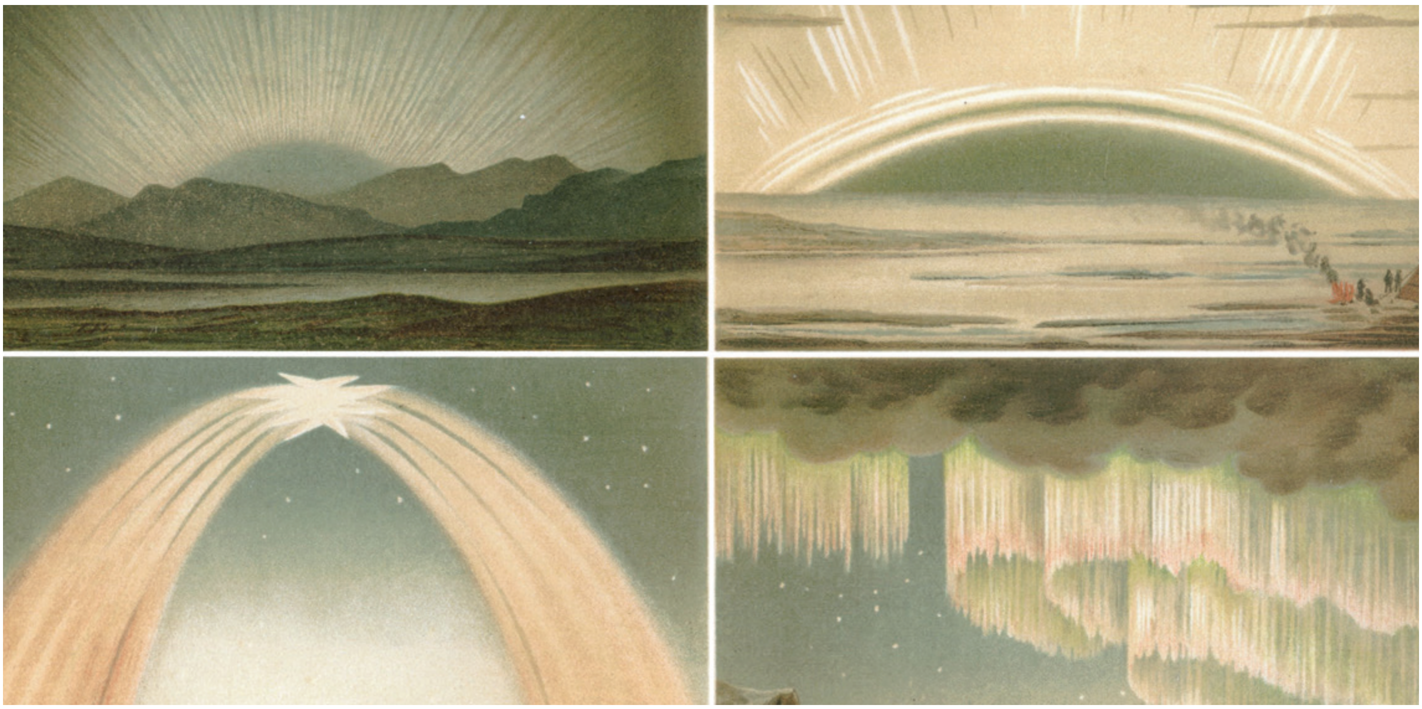
The researchers quantified emissions levels from automobiles; buses; and light, medium, and heavy trucks across 12 states. They also determined the number of asthma flare-ups in children and premature deaths associated with each transportation mode. At current pollution levels, they found that most premature deaths from transportation-related emissions are driven by automobile pollution.

Researchers and environmental justice representatives met to design and evaluate four emissions reduction scenarios: bus electrification, truck electrification, increased use of public transit, and increased active mobility (such as walking and cycling). The researchers then used computer modeling to see how the air quality improvements yielded by each scenario could affect premature deaths and asthma flare-ups.

They found that policies that reduce automobile and light truck use have the greatest health benefits, but that reducing medium and heavy truck and bus emissions also significantly improves air quality and health. In densely populated areas, bus electrification has appreciable health benefits.

Of the four organizations that participated for the full duration of the project and completed postproject reflection interviews, all reported that they found the results useful for their advocacy efforts. However, they offered some suggestions for more effective future collaborations, including holding discussion-based (rather than presentation-based) meetings, increasing hyperlocal air quality monitoring rather than relying on broader air pollution modeling, and linking quantitative results with ethnographic data. (*Community Science*, https://doi.org/10.1029/2023CSJ000041, 2024) **—Sarah Derouin,** *Science Writer*

Let's Get Geophysical: Tracking the Evolution of AGU Journal Article Titles



"Magnetic" was the most popular scientific word used in AGU journals in the early 20th century, a term reflecting the avid scientific interest of the time in the mechanisms behind the northern lights, pictured here in a 1908 German encyclopedia. Credit: Meyers Konversations-Lexikon, 6th ed., vol. 16, via Wikimedia Commons

Scientific studies have filled the pages of AGU journals for more than a century. These articles reveal how the study of geophysics has evolved alongside technology and societal interests, and they tell the story of our expanding knowledge of the Earth and space sciences.

To illuminate this story, *Wooden* catalogs the most frequently repeated words in the titles of AGU journal articles published between 1896 and 2023. (AGU was established in 1919, but *Terrestrial Magnetism*, acquired by AGU as the *Journal of Geophysical Research* in 1959, was founded in 1896.) The author grouped article titles into intervals by publication year: 1896–1949, 1950–1969, 1970–1989, 1990–2009, and 2010–2023. She also categorized words as either scientific terms or method and descriptor terms. Among method and descriptor terms, the names of months and the word "observatory" were most popular prior to 1950, "measurements" dominated from 1950 to 1969, and variations of "model" (e.g., "models", "modeling") took the top spot from then on.

The most frequently used scientific word in the 6,397 journal article titles published from 1896 through 1949 was "magnetic" (counted together with instances of "magnetism"); it was followed distantly by "Earth" and "water". The popularity of "magnetic", "magnetism", and "Earth" comes as no surprise given the topical focus of *Terrestrial Magnetism*; in fact, that journal's founding editor had ambitions of mapping Earth's entire magnetic field.

Most instances of "water" in the first half of the 20th century appeared in *Transactions, American Geophysical Union* (now *Eos*), which published many articles on water resources, especially groundwater. In subsequent years, geophysical research began to expand outward toward the Sun and inward toward Earth's ocean and core.

In the period 1950–1969, "wave"—used most frequently in "radio wave", "gravity wave", and "surface wave"—took the top spot among scientific terms. "Radio wave" in particular took off in the 1960s, in tandem with the rise of satellites and sounding rockets.

Between 1970 and 1989, AGU's collection of journals grew from 4 to 11, and annual output increased from about 1,300 articles to more than 2,300. "Wave" remained the most used scientific word, and "plasma" and "auroral" made their first appearance in the top 10 thanks to the discovery of the plasmasphere in the mid-1960s.

From 1990 to 2009, the AGU collection grew to 17 journals, and in that time the most common scientific words in article titles became "ocean", "sea", "surface", and "water". The word "Southern" was often associated with "ocean", indicating a growing awareness of El Niño.

The years 2010–2023 saw the addition of three new journals (including *Perspectives of Earth and Space Scientists*, in which this analysis was published) and the publication of 89,467 articles. "Wave" returned to the top spot among scientific terms, with "climate", "temperature", and "carbon" also appearing in the top 10, reflecting a growing societal focus on climate. (*Perspectives of Earth and Space Scientists*, https://doi.org/10.1029/2024CN000241, 2024) **—Rebecca Owen,** *Science Writer*

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UNIVERSITY OF GEORGIA

LECTURER

The Department of Geology at the University of Georgia (UGA) invites applications for the position of **Lecturer**, starting **February 1, 2025**. This is a 9-month position; however, the successful candidate will receive separate compensation for the summer months as they are expected to direct and operate the UGA Geology Field School in Canon City, Colorado each year. The 9-month academic year will be spent teaching introductory-level courses in Athens, GA (50%), as well as directing, planning, managing logistics, and developing the Field School Program (50%). Teaching during the academic year will typically be focused on large-enrollment geology courses and coordinating laboratory sections, whereas the summer field school instruction will be teaching in the field.

One of the longest-running in the nation, the UGA Department of Geology Field School program operates annually in Canon City, Colorado, offering hands-on geological fieldwork experience in a diverse and dynamic landscape. Students engage in practical training, including mapping, rock and mineral identification, and structural analysis, under the guidance of experienced faculty. This immersive program provides valuable real-world skills and insights into geological processes, preparing students for careers in geology and related fields.

Applicants must have a Ph.D. in geology or a related field. Please note we encourage applications from a wide range of disciplines.

Review of applications begins **November 15th, 2024**, and we will continue to review those received after this date until filled. Applications should include: **1)** cover letter that details fieldwork expertise and history, **2)** curriculum vitae, **3)** a teaching statement detailing their experience and philosophy in geoscience education, **4)** a copy of the graduate school transcript. Applicants should also provide names and contact information for at least 3 references using the online system.

Georgia is well known for its quality of life in regard to both outdoor and urban activities (**exploregeorgia.org**). Athens, Georgia is frequently ranked as one of the best places to live in the US: **https://www.visitathensga.com/media/rankings-press-coverages/**. The Franklin College of Arts and Sciences, its many units, and the University of Georgia are committed to sustaining a work and learning environment that is inclusive. The University of Georgia is an Equal Opportunity/Affirmative Action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, ethnicity, age, genetic information, disability, gender identity, sexual orientation or protected veteran status. Persons needing accommodations or assistance with the accessibility of materials related to this search are encouraged to contact Central HR (**hrweb@uga.edu**). To apply, go to **https://www.ugajobsearch.com/postings/402243**.

PRINCETON UNIVERSITY

POSTDOCTORAL RESEARCH ASSOCIATE

Improving Ocean Surface Boundary Layer Mixing Parameterizations with Langmuir Turbulence and Machine Learning

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a **postdoctoral or more senior research scientists** to develop machine learned parameterizations for vertical mixing in the ocean surface boundary layer and apply them to ocean climate models. Our previous work demonstrated that neural networks can learn to predict the vertical structure of vertical diffusivity and the networks can then be applied in an ocean climate model to improve simulations of upper ocean stratification (**https://dx.doi.org/10.1029/2023MS003890**). The successful applicant for this position will work to advance these ideas, specifically focusing on improving representation of the effect of ocean surface waves and Langmuir turbulence on the energetics and vertical distribution of mixing within the ocean surface boundary layer. This work will involve: **i)** contributing to design and run new Large Eddy Simulation experiments; **ii)** and analyzing the LES output to generate training data; **iii)** using Machine Learning techniques to learn improvements to the existing mixing parameterization; **iv)** implementing the new schemes in a global circulation model (MOM6); **v)** and finally, evaluating the impacts of the new parameterization on ocean climate simulation in a global climate model.

The work is part of a larger project, M2LInES, covering eleven institutions. The overall goal is to reduce climate model biases at the air-sea/ice interface by improving subgrid physics in the ocean, sea ice and atmosphere components of existing coarse (¼° to 1°) resolution IPCC-class climate models, and their coupling, using machine learning. The postdoc will be expected to collaborate with other postdocs at Princeton and with other members of the M2LInES project across multiple institutions.

In addition to a quantitative background, the selected candidates will ideally have one or more of the following attributes: **a)** familiarity with concepts of geophysical fluids, such as in atmospheric science or physical oceanography; **b)** experience with numerical modeling including Large Eddy Simulation, turbulence closure methods, and/or atmospheric or oceanic circulation/climate models; and **c)** experience, or demonstrated interest, in machine learning.

Candidates must have a Ph.D. or expect to complete a Ph.D. for an anticipated **start date in late 2024 or early 2025**. The Term of appointment is based on rank. Positions at the postdoctoral rank are for one year with the possibility of renewal pending satisfactory performance and continued funding; those hired at more senior ranks may have multi-year appointments. Complete applications, including a cover letter, CV, publication list, research statement (no more than 2 pages incl. references), and 3 letters of recommendation should be submitted by **November 15th, 2024, 11:59 pm EST** for full consideration.

Princeton is interested in candidates who, through their research, will contribute to the diversity and excellence of the academic community. Applicants should apply online at **https://www.princeton.edu/acad-positions/position/36662**. For additional information contact Dr. Brandon Reichl (**brandon.reichl@noaa.gov**) or Dr. Alistair Adcroft (**aadcroft@princeton.edu**).

The work location for this position is in-person on campus at Princeton University. This position is subject to Princeton University's background check policy which will include meeting the security requirements for accessing the NOAA Geophysical Fluid Dynamics Laboratory. 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.

ATM

Tenure-Track: Assistant Professor

The Department of Atmospheric Sciences in the College of Arts & Sciences at Texas A&M University invites applications for a full-time tenure-track assistant professor position with expertise in Boundary Layer Meteorology, Urban Meteorology, or Fire Weather. Exceptionally well-qualified candidates from other areas of the atmospheric sciences are also encouraged to apply. This position is a 9-month full-time academic appointment with an anticipated start date of August 1, 2025.

Information about the Department of Atmospheric Sciences can be found at atmo.tamu.edu Our department includes 22 faculty members, 147 undergraduate students, and 52 graduate students. Our department hosts the Office of the State Climatologist, the Center for Atmospheric Chemistry and the Environment, the Texas Center for Climate Studies, and the Southern Regional Climate Center.

Teaching and research facilities in the department include two undergraduate computer laboratories, a ClimaVision dual-polarization X-band radar, a micropulse lidar, the Houston Lightning Mapping Array, the Weather Center, automated surface weather stations, and radiosonde systems. The department is part of the College of Arts and Sciences, which offers an extensive array of degree programs and educational facilities. Additionally, the Texas A&M High Performance Research Computing Center maintains several supercomputing clusters that are easily accessible for faculty and student use.

Texas A&M University is a land-, sea-, and space-grant university, within a dynamic and international community. Our department, the College of Arts and Sciences, and Texas A&M University are committed to enriching the learning and working environment for all visitors, students, faculty, and staff by promoting a culture that embraces unique and varied experiences, perspectives, and talents. This is vital to accomplishing our mission and living our core values.

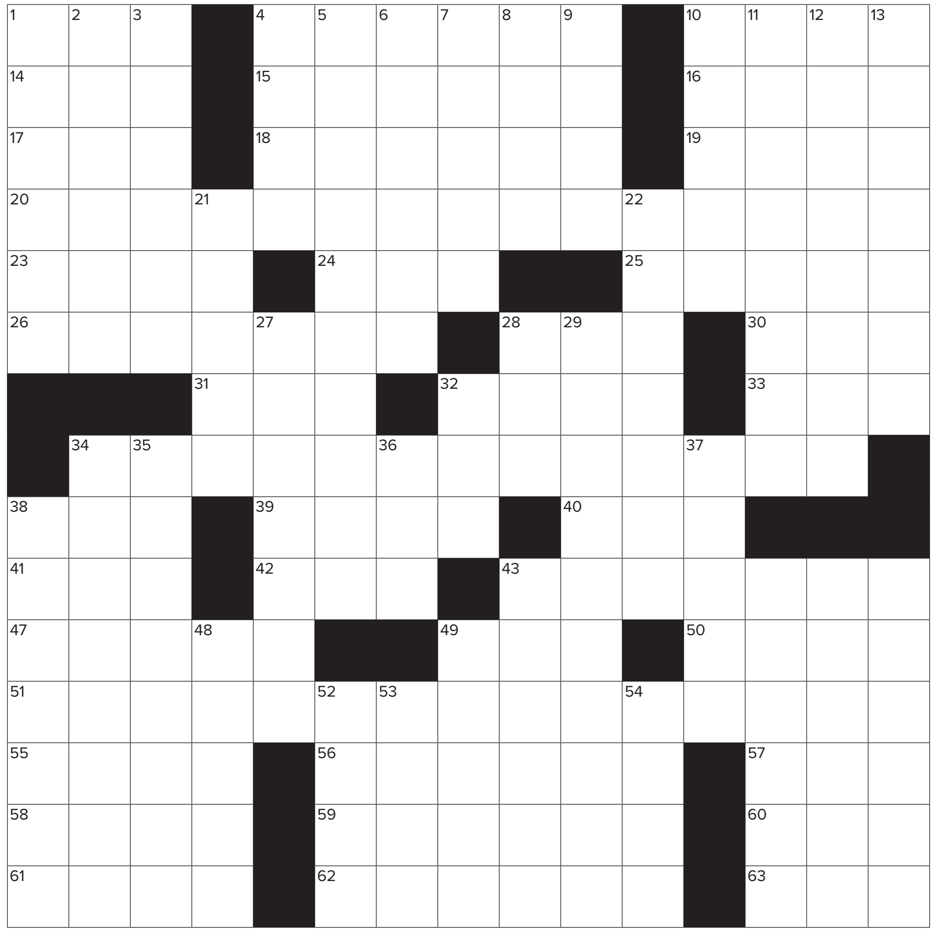
The successful candidate will be expected to establish and maintain an independent and externally funded research program, provide transformative teaching at the undergraduate and graduate levels, and contribute to the service mission of the department.

Qualifications
Applicants must have a Ph.D. in the atmospheric sciences or a related field at the time of hire. Postdoctoral experience is desirable but is not required.

Application Instructions
To apply, please upload a cover letter, a CV, a personal statement that includes your philosophy and plans for teaching, research, and service as applicable, and names and contact information for three references at the link below.
http://apply.interfolio.com/153380

Frontiers

By Russ Colson, Minnesota State University Moorhead



ACROSS

1 Precursor to the TLS security protocol
4 Snowman in the song *Winter Wonderland*, ____ Brown
10 Data storage devices once standard on desktop computers (abbr.)
14 Canadian province where *Anne of Green Gables* was set (abbr.)
15 Sumerian goddess of love and war
16 Opera solo
17 Sick
18 Silly actions
19 Goes before trap, blast, or dune
20 Results of research in the deep oceanic frontier can ____ to protect it (2 words)
23 Incan Sun god
24 Goofy laugh
25 Alternate spelling of a telescope's optical part
26 Capital of Iran (one spelling)
28 Mad cow disease (abbr.)
30 Batteries needed for most TV remotes
31 A way to take people for a ride?
32 Shindig
33 Astronaut Grissom,
34 Stars that were colored on plaster hundreds of years ago by a ____ prove the draw of the space frontier even in medieval times (2 words)
38 Start for nail, hold, or clip
39 They meet south of reps in the U.S. Capitol Building
40 Old-time seat of Christian and Jewish faiths?
41 Southernmost country in Africa (abbr.)
42 Prefix on many meteorological contour maps
43 Tart stone fruit often eaten dried
47 The largest known lifeform by mass
49 Fury
50 ____ Cola
51 In a way, a researcher at the science frontier becomes a ____ by sorting out flights of fancy from equally improbable truths (2 words)
55 Stately start for ida, or a Spanish bloom
56 Put down again, as in "they ____ the carpet"
57 Bumstead, for short
58 Asiatic songbird, or the heart of amelioration?
59 Sowed
60 Equivalent of 149,597,870,700 meters in astronomical units
61 The main elements of life, other than O and H
62 Plural closing for "ad-" or "helic-" or a scramble of repost, underlined as in the anagrams for 20, 34 and 51 across
63 A pioneering plane that broke barriers (abbr.)

See p. 40 for the answer key.

DOWN

1 ____ and Opportunity, pioneers on the space frontier
2 Greek goddess of the Moon
3 Female figure from Mesopotamian mythology, or Frasier's ex
4 French singer Edith
5 Irritations
6 Shortcut between major roads, or a laboratory maze?
7 Minor cut (which means the same if you remove the first letter)
8 Beginning of a fairy tale
9 Agency with a New Frontiers program
10 What makes waste?
11 Goal of tiling a field
12 Favorite childhood source for 34 down
13 Sorrow
21 Your daughter's cousin
22 Detergent or janitor
27 Composer of The Barber of Seville
28 Sheepish sound?
29 As the field geologist learns, smectitic gumbo is ____ than sandstone after a rain
32 Navigation aid
34 Petrified bone (2 words), or a really old oper. syst.?
35 Harvest maize (2 words)
36 Yoko
37 [The quality of Mercy] is ____ blest (Shakespeare)
38 Can be heavy and produce a jam
43 A place for token games?
44 Complex homes?
45 Earth's ____ remain frontiers of science
46 A goal, or a particular chain of stores
48 What over-users of technology might fall into?
49 Small bit of land in the keys, say
52 About-ish
53 Turnip
54 Terminal degrees in education