Eos
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Himalayan Majesty, Myth, and Mountainside Development

Mapping the Martian Ionosphere

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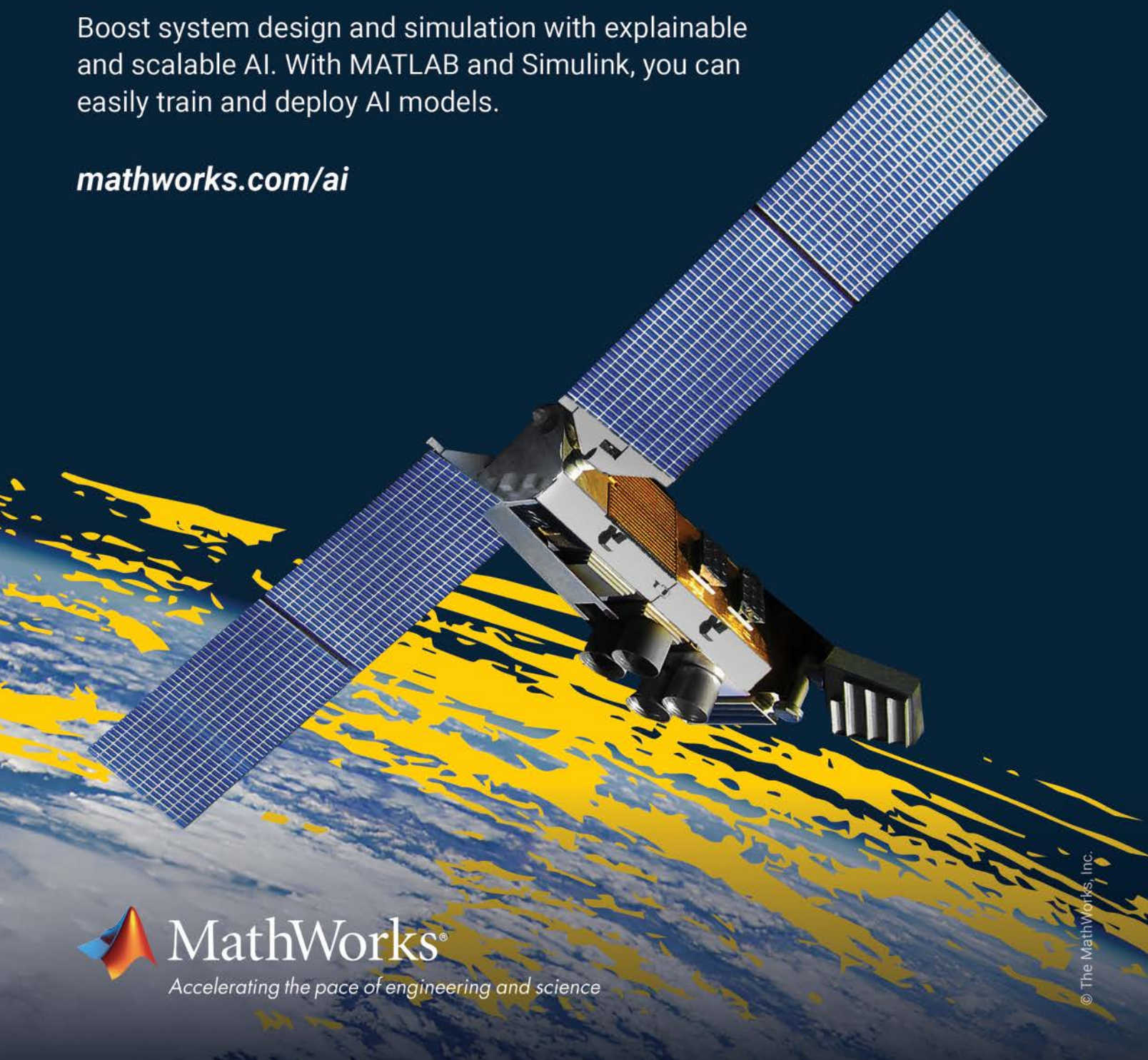

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From the Editor

CubeSats, those boxy satellites that float above Earth alone or in miniature constellations, are emerging as little engines (without engines) of accessible education and affordable engineering.

"The goal from the get-go" of CubeSat education programs "is to give students hands-on experience, not just in building…but in the full life cycle of a mission," says space scientist Noé Lugaz in Kimberly Cartier's forward-looking feature "Small Satellites, Big Futures" (p. 20).

Other goals of CubeSat programs include the pursuit of economic and ecological sustainability. Wooden satellites, like the ones profiled in Grace van Deelen's "A New Satellite Material Comes Out of the Woodwork" (p. 2), might just do the trick.

This month's articles offer a good reflection of Earth and space scientists in these uncertain times: excavating down-to-earth opportunities, reaching for the stars. I think I can, I think I can…

On the Cover

An atmospheric balloon lofts into the air a CubeSat prototype built by Ghanaian students. Credit: STEMbees

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Janice Lachance, Executive Director/CEO

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A New Satellite Material Comes Out of the Woodwork

More than a thousand years after they were built, wooden shrines in Kyoto, Japan, inspire engineer and former astronaut Takao Doi.

"If we can use wood in space, we might be able to have sustainable space development forever," said Doi, now a visiting professor at Ryukoku University in Kyoto.

The idea of a wooden space age gained traction last year with the launch of LignoSat, the world's first wooden satellite to reach orbit. LignoSat, developed by Doi, a group of Kyoto University scientists, and logging company Sumitomo Forestry, is a CubeSat—a type of minisatellite that is relatively inexpensive and easy to construct. LignoSat's structure is meant to reduce its environmental impact: Wood is a renewable material and creates less pollution when it burns up on reentry into Earth's atmosphere.

LignoSat was deployed from the International Space Station (ISS) by the Japan Aerospace Exploration Agency (JAXA) and stayed in space for 116 days.

Doi and his colleagues are using what they learned to develop LignoSat-2, which they expect to launch in 2028. And they're not alone in exploring the extraterrestrial potential of timber—at least one other group is also developing a wooden satellite.

Raphaela Günther, an aerospace engineering Ph.D. student at Technische Universität Dresden in Germany who is not involved in the LignoSat project, said she considers the work of the Kyoto University team to be a "small breakthrough" in renewable space materials research.

"We think wooden satellites orbiting around the Earth are the future," Doi said.

Lessons Learned

LignoSat was a 10-centimeter cube made of magnolia panels assembled with traditional woodworking joinery. An aluminum frame reinforced the structure.

The LignoSat mission had five goals:

- to measure strain on the wooden structure
- to measure temperature inside the satellite
- to demonstrate how permeable wood is to magnetic fields in space
- to analyze the effects of space radiation on wood
- to establish two-way communication with scientists on the ground.

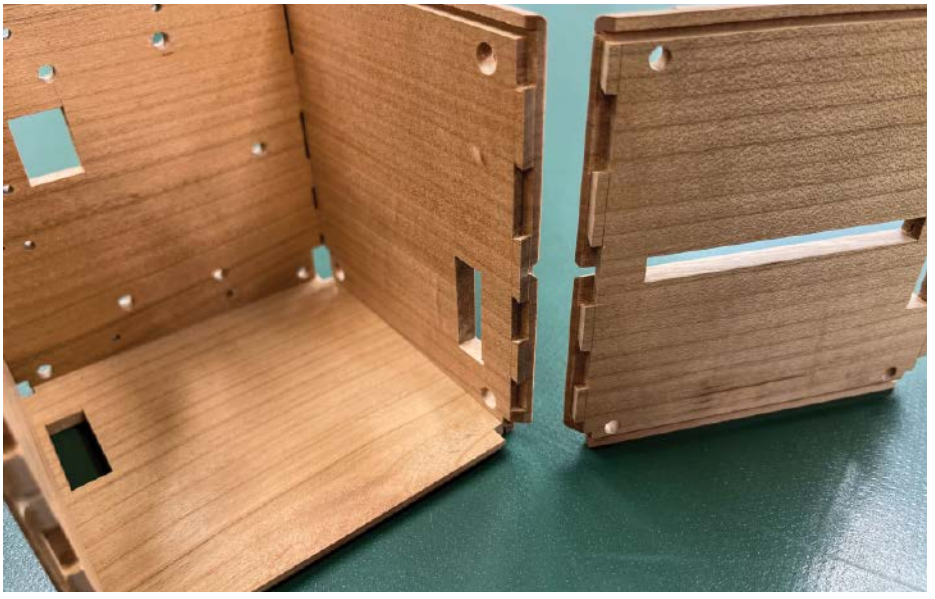
Orbital data from the U.S. Department of Defense show that the satellite stayed in one piece during its time in space, proving that wooden satellites can work, Doi said.

But after the satellite was deployed from the ISS on 9 December 2024, scientists in Kyoto weren't able to communicate with it, and without the ability to communicate, the mission couldn't complete its other four goals, either.

In 2024, LignoSat was the first wooden satellite launched into space, but its communications system failed, so scientists are trying again with LignoSat-2. Credit: Kyoto University

"Unfortunately, we didn't receive any of the information we wanted to know about," Doi said.

An analysis indicated that the loss of communication could have been caused by two failures: First, any or all of the three switches needed to activate the satellite system and deploy its antenna may not have turned on, and second, the computer program used in the system may not have started up as expected.



LignoSat was constructed using a traditional joinery method called the blind miter dovetail joint. Credit: Kyoto University

"We think wooden satellites orbiting around the Earth are the future."

Despite the lack of communication, Doi pointed to considerable achievements in the LignoSat mission. It demonstrated that a wooden satellite can exist in orbit without falling apart, and it streamlined the review process for wooden spacecraft. NASA must complete a safety review of all satellites that head to the ISS, he explained, and now that such a review has been completed for Ligno-

LignoSat-2 will have both an external and internal antenna and will be twice the size of the first LignoSat. Credit: Kyoto University

The WISA Woodsat contains a suite of sensors to measure how outer space will affect its materials. It also has a selfie stick. Credit: Arctic Astronautics/ Flickr, CC BY 2.0 (bit.ly/ccby2-0)

Sat, reviews for subsequent wooden satellites will be simpler.

The Kyoto University team plans to build LignoSat-2 to be twice the size of LignoSat, with two communication systems (one inside the structure and another attached to its exterior).

Installing the antenna inside the satellite body reduces the drag, Doi said. "Even if the antenna is not deployed, which might have been the cause of LignoSat 1's communication problems, we may be able to use this second communication system to communicate with [LignoSat-2]," he said.

A Cubical Niche

A Finnish space technology company is also thinking about wood in space. In 2021, Arctic Astronautics and Finnish company UPM Plywood began developing the WISA Woodsat, a 10-centimeter birch plywood CubeSat. The satellite contains a suite of sensors meant to gather information about how outer space affects wooden spacecraft. It has a deployable camera, a "selfie stick" meant to take photos of itself in space and allow the team on the ground to monitor it visually.

"There is a niche for these kinds of satellites, and the basic research is extremely interesting," said Jari Mäkinen, a cofounder of Arctic Astronautics and the initiator of the WISA Woodsat project. "It's totally possible that when we see these satellites flying, we realize important information [about how plywood acts in space]."

The WISA Woodsat itself is nearly ready for launch, Mäkinen said, but Arctic Astronautics still needs permitting from Finnish space authorities to proceed. He hopes that the launch will take place next year.

"We will fly as soon as possible," he said.

A Sustainable Space Industry

For Doi, wooden CubeSats are just the beginning.

"Let's create a space timber industry" reads the translation of the bio of the research team's X (formerly Twitter) account. Doi said he imagines a future in which wood overtakes aluminum as the primary material for satellites.

Wood is cheaper, easier to use, and lighter than conventional spacecraft materials. Its use could both push the space industry toward using more wood and make space development more accessible to countries with fewer resources, Günther said.

A wooden space age could shrink the environmental footprint of the space industry, too. When aluminum satellites burn as they fall back into Earth's atmosphere, they create aluminum oxide particles. These particles, sometimes smaller than 1 micrometer, may destroy ozone, disrupt atmospheric processes, and even alter Earth's magnetic field, some scientists have suggested (bit.ly/conductive-particles). When wood burns, it generates only carbon dioxide, biodegradable ash, and water vapor.

And scientists don't fully understand all the possible ways in which particles from decomposing metal or wooden spacecraft interact with the upper atmosphere. The decomposition products of wood are easier to assess because they have already been extensively studied, as they are major drivers of atmospheric processes, Günther said.

With a few hundred tracked objects returning to Earth each year, reentering metal spacecraft are not currently a major environmental problem. But because the space industry is growing quickly, it's crucial to look for more ecofriendly materials, Doi said. Replacing even a small portion of parts on future satellites with wood could significantly reduce pollution, Mäkinen agreed.

"It's not a question [of whether] we do or…we don't" begin to use more sustainable spacecraft materials, Günther said. "I think we have to."

Wood poses challenges for spacecraft engineers, however. Because it's grown naturally, it has defects and doesn't behave homogeneously, meaning that "the behavior of the material in three different directions is not the same," Günther said. Her own research is in creating spacecraft materials made of wood fibers and binding material that behave more consistently.

Mäkinen agreed that wood provides many environmental and technical advantages but said that large space companies have probably invested so much in their current manufacturing processes that a large-scale shift to wood as a satellite material is unlikely without some sort of regulation, legislation, or financial incentive from space authorities. "I hope that I'm wrong," he said.

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

Policy Success: Fees and Bans on Plastic Bags Reduce Beach Trash

New research indicates that legislation aimed at limiting distribution of single-use plastic bags is effective in reducing such pollution on beaches. Credit: iStock.com/Bilanol

Shoppers may use a plastic bag for only a few minutes before tossing it in the trash. Inefficient waste disposal, however, may allow that bag to find its way into streams and, ultimately, coastal ecosystems. There, plastic pollution can imperil marine plants and animals as well as the economic value of beachfront businesses.

"Plastic bags are designed to be single use. They're designed to be lightweight. Even if we're trying to properly manage them, they just get into the environment more easily than other plastics," said Erin Murphy, ocean plastics science and research manager at the Ocean Conservancy.

Though many states and municipalities have plastic bag bans or require fees for customers who want a bag, no national policy exists to reduce the number of plastic bags used in the United States.

But a study published in *Science* showed that in places with bag bans and fees, the number of plastic bags found on local beaches and shorelines has dropped significantly (bit.ly/bag-ban-results).

"A lot of the time, communities don't feel like they can implement policy that will directly impact their communities and directly benefit their communities. This study showed that whether it's a town or state, these [plastic bag bans] are effective policies, regardless of the scale of governance in which you implement them," said Murphy, who was not involved in the research.

Analyzing the Trash

Study authors Anna Papp and Kimberly Oremus examined data collected from 45,067 shoreline cleanup events between 2016 and 2023. During these events, organized by the Ocean Conservancy, participants collected trash along a beach and logged their findings into the Trash Information and Data for Education and Solutions (TIDES) database.

Plastic bags are the fifth most common item found during these shoreline cleanups, making up 4.5% of all cataloged trash. Cigarettes and food wrappers take the top spots, and some of the more unusual items logged include golf balls, Mardi Gras beads, and fake nails.

Papp and Oremus cross-checked the cleanup data with 182 plastic bag policies around the United States that were enacted between 2017 and 2023. The discrepancy between the dates of the cleanup data (starting in 2016) and the policy data (starting a year later) allowed the researchers to use the 2016 data as a control to evaluate how trends in plastic bag litter may have changed in response to local or state-level regulation.

"Comprehensive data on plastics in the environment can be challenging to find, so the cleanup data offered a new way of measuring plastic bag litter in the environment. This, combined with the wide reach of bag policies in the U.S. in recent years, made our study possible," said Papp, an environmental economist at the Massachusetts Institute of Technology.

A Broad Spectrum of Bans

Legislation managing plastic bag waste is a hodgepodge of strict bans (like the ones implemented in New Jersey, where single-use paper bags are also limited), partial bans (like the ones in California, targeted at large retailers), and required fees (as in Oregon, where retailers must charge at least 5 cents for a thick, presumably reusable plastic bag). In addition to statewide legislation, hundreds of municipalities have their own plastic bag policies.

"During our data collection phase, I was initially surprised by the reach of plastic bag policies. We estimate that now one in every three Americans lives in an area with some bag policy," said Papp.

Papp and Oremus were able to document the effectiveness of such policies, regardless of their reach. In places where some form of plastic bag legislation exists, data showed a 25%–47% decrease in the proportion of plastic bags recovered in coastline cleanups.

Although all policies aimed at reducing plastic bag litter were effective, the pair of researchers found that those implemented at the state level correlated most strongly to reducing the amount of plastic bag waste found during beach cleanups.

"In some ways it's like, well, of course, if you use fewer plastic bags, you're going to find fewer plastic bags on the beach, but it's good that [researchers] documented that in a quantitative way," said Susanne Brander, an ecotoxicologist at Oregon State University who was not involved in the study. "We need those data in order to convince additional lawmakers and agencies to take this seriously and to think not just about plastic bags, but about other single-use items as well."

By **Rebecca Owen** (@beccapox.bsky.social), Science Writer

Artificial Light Lengthens the Urban Growing Season

Artificial light and higher temperatures in cities may lengthen the growing season by up to 24 days, according to a new study in *Nature Cities.*

Previous studies have observed that plant growth starts earlier and ends later in cities than in rural areas. But these studies haven't concluded whether this difference depends more on heat or on light, both of which regulate the growing season and are amplified in urban centers.

The new study's authors used satellite data to estimate nighttime light pollution in cities and pinpoint the start and end of the growing season (bit.ly/ALAN-plants). They found that the amount of artificial light at night plays a bigger role in growing season length than temperature does, especially by delaying the end of the season.

"This study highlights artificial light at night as a powerful and independent force on plant phenology," said Shuqing Zhao, an urban ecologist at Hainan University in China who was not involved in the research. "It marks a major step forward in our understanding of how nonclimatic urban factors influence plant life cycles."

City Lights Trick Plants

"Plants rely on both temperature and light as environmental cues to regulate their growth," explained Lin Meng, an environmental scientist at Vanderbilt University and a coauthor of the study.

In the spring, warmer temperatures and lengthening days signal to plants that it's time to bud and produce new leaves. In the fall, colder, shorter days prompt plants to drop their leaves and prepare for winter.

But in cities, these essential cues can be disrupted. Cities are typically hotter than surrounding rural areas—the so-called urban heat island effect—and much brighter because of the abundance of artificial light.

These disrupted cues "can trick plants into thinking the growing season is longer than it actually is," Meng said. "Plants evolved with predictable cycles of light and darkness—now, cities are flipping that on its head."

To assess how heat and light are affecting urban plants, Meng and her coauthors used satellite data from 428 cities in the Northern Hemisphere, collected from 2014 to 2020. For each city, the researchers analyzed correlations between the amount of artificial light at night (ALAN), air temperature, and the length of the growing season.

The scientists found that on average, the growing season started 12.6 days earlier and ended 11.2 days later in city centers than in rural areas. ALAN apparently played an important role in extending the growing season, especially in the autumn, when ALAN's influence exceeded that of temperature.

Anna Kołton, a plant scientist at the University of Agriculture in Krakow who was not part of the research, highlighted the significance of this result. "The impact of climate change, including increased temperatures on plant functioning, is widely discussed, but light pollution is hardly considered by anyone as a significant factor affecting plant life," she said. The new study is among the first to bring ALAN's effects into the spotlight.

"Every Day Needs a Night"

"The extension of urban vegetation may at first glance appear positive," said Kołton.

But this perception is deceiving. In reality, an extended growing season "poses a

In this image, the cities of Paris, London, and Amsterdam can be identified from left to right by their clusters of lights—which affect the length of the growing season. Credit: International Space Station (ISS) Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit, Johnson Space Center

threat to the functioning of urban greenery."

Delaying the end of the growing season may be especially disruptive. In the fall, shortening days prompt plants to reduce their metabolic activity, drop their leaves, and toughen up their cell walls to withstand the coming winter. But if they are constantly stimulated by artificial light, Kołton pointed out, urban plants may miss their cue and be unprepared when the cold hits.

"Every day needs a night, and so do our trees, pollinators, and the rhythms of nature we all depend on."

Longer growing seasons also affect animals and people. "Flowers might bloom before their pollinators are active, or leaf-out might not align with bird migration," said Meng. "And for people, a longer growing season means earlier and prolonged pollen exposure, which can make allergy seasons worse."

As cities become bigger and brighter, their growing seasons will likely continue to lengthen unless the impacts of ALAN are addressed.

"The good news is that unlike temperature, artificial light is something we can manage relatively easily," said Meng. She and Zhao both suggested that swapping blue-rich LED lamps for warmer LEDs, which are less stimulating to plants; introducing motion-activated or shielded lights; and reducing lighting in green spaces could limit light pollution in cities.

"Every day needs a night," Meng said, "and so do our trees, pollinators, and the rhythms of nature we all depend on."

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

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Scientists Spot Sputtering on Mars

NASA's MAVEN spacecraft, seen here in an artist's concept, has been orbiting Mars since 2014. Credit: NASA/GSFC

Mars's current atmosphere is downright tenuous (it confers less than 1% the pressure of Earth's) but there's good evidence that it was substantially thicker in the past.

A hitherto unobserved process, known as atmospheric sputtering, may have facilitated Mars's transition from a watery planet to the arid world it is today, researchers reported in *Science Advances* (bit.ly/Mars-sputtering).

Since the early 2010s, planetary scientist Shannon Curry of the University of Colorado Boulder has pored over data from Mars, looking for signs that the Red Planet's atmosphere is eroding.

It's been a long journey, she said. "I've been looking for this since I was a postdoc." Colleagues even took to ribbing Curry that her search might be folly. "Every year, I would run my code, and I would look for it," she said. "We started joking that it was like a unicorn."

But Curry, the principal investigator of NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission, now has reason to celebrate: She and her colleagues believe they've finally captured the first direct observations of sputtering on Mars.

"I've been looking for this since I was a postdoc."

Escaping via Kicks

Planetary atmospheres are constantly changing; everything from solar eclipses to volcanic eruptions to fossil fuel burning can alter their composition, density, and structure.

One way atmospheres erode is photodissociation, in which photons break apart molecules, creating lighter constituents that can escape.

Sputtering is another. That process occurs when high-energy ions, accelerated by the

Sun's electric field, plow through a planet's upper atmosphere and collide with neutral atoms. Those energetic kicks impart enough energy to the neutral particles that they go on to escape the planet's gravitational field.

Sputtering plays only a minor role in the escape of Mars's atmosphere today—the rate of sputtering is several orders of magnitude lower than that of photodissociation.

"But we think billions of years ago, it was the main driver of escape," Curry said.

Thanks to nearly a decade's worth of MAVEN observations, Curry and her collaborators had access to detailed records of the Sun's electric field and neutral particles in Mars's atmosphere.

They focused on neutral argon, a heavy noble gas. It's generally difficult to remove argon from the Martian atmosphere in other ways, said Manuel Scherf, an astrophysicist at the Space Research Institute at the Austrian Academy of Sciences in Graz who was not involved in the research. "The only really efficient escape mechanism at the moment is sputtering."

Follow the Darkness

The researchers used simulations of Mars's atmosphere to home in on where they might find a signal of sputtering. Looking above an altitude of roughly 360 kilometers seemed to be key, the modeling revealed. The team furthermore knew that it was critical to look at the nightside of Mars. That's because photodissociation dominates the dayside.

"We have to get out of the sunlight in order to detect sputtering," said Janet Luhmann, a space scientist at the University of California, Berkeley and a member of the research team.

The researchers compared the abundances of argon in the Martian atmosphere in two altitude bins: 250–300 and 350–400 kilometers. They also compared periods during which the Sun's electric field pointed either toward or away from Mars. Sputtering should preferentially occur in the higher-altitude bin when the Sun's electric field points toward Mars because that's when ions are accelerated toward the planet's atmosphere. Indeed, Curry and her colleagues found statistically higher densities of argon in that group of data.

"We have to get out of the sunlight in order to detect sputtering."

The team calculated that argon was being sputtered at a rate of about 1,023 atoms per second. That might seem like a large number, but it's actually about 100 times lower than the current rate of photodissociation, Luhmann said.

But billions of years ago, the Sun's electric field was likely far stronger than it is today, and sputtering rates could have been much higher; sputtering could have been the dominant contributor to the eroding of Mars's atmosphere.

Such a shift could help explain what happened to Mars's water.

Copious evidence shows that liquid water once existed on the surface of Mars. River valleys, dried lake beds, and other water-carved features persist to this day. This means that Mars's atmosphere must have once been thick enough to support liquid water. "You need that atmospheric pressure pushing down on water to make it a liquid," Curry said. But the Red Planet today is an arid world devoid of visible water. Sputtering could explain, at least partially, how the loss of pressure occurred.

And because liquid water is intimately tied to our conception of life, these results have important meaning, Scherf said. "You cannot know whether life can exist somewhere if you don't understand the atmosphere and how it behaves."

The team hopes to use MAVEN data for years to come, but Curry and her colleagues recently learned that they may not have that opportunity: The mission is slated to be canceled in the proposed 2026 federal budget. That's been a huge blow emotionally, said Curry, but the team isn't giving up yet. "The United States right now is number one in Mars exploration," Curry said. "We will lose that if we cancel these assets."

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

Surface Conditions Affect How Mosses Take to Former Well Pads in Canada's Boreal Fens

Boreal peatlands in Canada provide crucial ecosystem services, from flood mitigation and water purification to storing colossal amounts of carbon and providing a habitat for species such as caribou.

Over the past several decades, more than 36,000 hectares of well pads have been constructed to house oil and gas drilling platforms in these landscapes, destroying underlying vegetation and disrupting the flow of water through the ground.

Once drilling operations are finished, operators are required to return pads to a state similar to what they were before construction. Though restoration efforts have historically focused on tree planting, reintroducing the right mosses is crucial for restoring functional peatlands. A study in *Ecological Engineering* outlines a new approach to reintroducing these keystone plant species, tested for the first time at the scale of a full well pad in Alberta, Canada (bit.ly/well-pad-moss).

"We want to get as close to the original state as is possible and realistic, given the very long timescales that peatlands develop over," said Murdoch McKinnon, a graduate student at the University of Waterloo in Ontario and the lead author of the study.

The challenge is providing the right hydrological conditions for mosses to thrive.

A well pad located near the town of Slave Lake, Alberta, is still brown immediately after researchers introduced moss. Credit: University of Waterloo

Removing Fill

Well pads are constructed by heaping crushed mineral fill onto a section of peat to create a harder, level surface.

Traditionally, researchers in the region have reintroduced moss by first completely removing the fill, which lowers the surface so that it is closer to the water table. In some cases, they would bury some of the fill under the newly exposed peat, a technique referred to as inversion.

This process has been successful in establishing the *Sphagnum* mosses typical of bogs, which have acidic soil that is low in nutrients. It's been less successful in reintroducing the *Bryopsida* mosses characteristic of fens, the nutrient-rich wetlands that make up almost two thirds of peatlands in Canada's Western Boreal Plain.

To reestablish a moss community that could eventually turn into a fen, McKinnon and his colleagues left some of the fill on the surface, which provided the minerals that *Bryopsida* mosses rely on for growth. The team then roughed up the surface with an excavator to create different microsites, which promotes species diversity.

After introducing mosses from a nearby donor fen and closely monitoring the site for two growing seasons, the researchers found that conditions for the reestablishment of *Bryopsida* mosses were best when the water table was within 6 centimeters of the surface. That was often the case along the edges of the pad, which received water from adjacent peatland, whereas the mosses in the interior of the pad struggled with drier conditions.

Introducing moss is one of the methods scientists are using to restore well pads in boreal peatlands in Canada. Credit: University of Waterloo

"I think it's a good approach, but maybe the surface of the pad was not low enough to have flowing water, which you need in a fen," said Line Rochefort of Université Laval in Quebec, an expert in peatland restoration who was not involved in the study.

"Without addressing that, it's hard to introduce and establish peatland vegetation on mineral substrate," said Bin Xu, a peatland ecologist at the Northern Alberta Institute of Technology (NAIT) who worked on the project. "On the flip side, when you do have good hydrobiological conditions, it's really easy to support peat-forming vegetation, which is encouraging."

An important takeaway from the study is the importance of decompacting the surface by roughing it up to allow for not only hydrological flow across the pad but also the natural vertical fluctuation of the water table, Xu said.

He and colleagues at NAIT have now applied these lessons to three additional well pads in Alberta, and industry experts have used a similar approach on around a dozen more, Xu said. "Through informing policy and sharing the learnings with industry, we can together address the need to reclaim well pads built in peatland across the province."

By **Kaja Šeruga,** Science Writer

First Species-Level Assessment Reveals Extinction Risk in Mesoamerica

Reforestation is more complicated than just planting trees. It includes evaluating habitats and ecosystems, identifying the health and sustainability of different species, and assessing strategies for establishing new stands of trees.

In regions like Mesoamerica, where forests are highly threatened by human activities and climate change, conservationists interested in reforestation need to prioritize species whose populations are shrinking.

To help with this task, a group of researchers evaluated the conservation status of all 4,046 tree species endemic to Mesoamerica and described in the Global Tree Assessment. They found that 46% of these trees are at some risk of extinction.

The study, published in *Plants, People, Planet*, is the first to evaluate the status of all endemic trees in Mesoamerica (bit.ly/Mesoamerican-trees).

Emily Beech, the study's lead author and head of conservation at Botanic Gardens Conservation International, emphasized the importance of focusing on this region because of its high levels of biodiversity. Central American countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama), Beech said, are rarely listed as being among the most biodiverse or home to the highest number of endangered species.

This underrepresentation is not due to a lack of biodiversity, she explained. The countries' small sizes cause them to be overshadowed by large countries with bigger forests, such as Brazil and the Democratic Republic of the Congo. But together with Mexico, Central America is home to 10% of the world's plant diversity despite accounting for less than 1% of its land surface.

To address this gap, the scientists first identified endemic Mesoamerican trees from assessments submitted to the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species. Then, to evaluate the trees' conservation status, they overlaid distribution maps of the selected tree species on maps in the World Database on Protected Areas.

They found that of the 4,046 tree species analyzed, 1,867 are under threat of extinction. Mexico was the only country to have tree species in the database that were extinct or extinct in the wild. Of extant trees, Mexico and Costa Rica had the highest numbers of threatened species, with 888 and 227, respectively. The most common threat overall was habitat loss due to agricultural expansion.

Most species (3,349) had at least one data point inside a protected area. Nevertheless, 72% of Mesoamerican species in protected areas are threatened.

A Tailored Approach

Neptalí Ramírez Marcial was not a part of the new research, but as head of the restoration group at El Colegio de la Frontera Sur in Mexico, he works with tree species that are under different threat categories. The forests of Chiapas, where he and his colleagues are based, used to be filled with oak trees, which supported high levels of biodiversity. Owing to human influence, pines now outnumber oaks, and the climate is less favorable to the sensitive species on the IUCN Red List.

Despite Ramírez Marcial's use of the Red List, he remains critical of the tool and its use in research.

For example, he pointed out that the new assessment of Mesoamerican trees lists *Furcraea macdougallii* (MacDougall's century plant) as extinct in Mexico. Ramírez Marcial believes that this plant is similar to an agave and should not be considered a tree at all—and thus should not be included in the survey.

Nelson Zamora, a researcher at the National Herbarium of Costa Rica, plants a Platymiscium curuense *tree, a threatened species indigenous to the country. Credit: Ian Rock/Osa Conservation*

He also pointed out that the new study considers the entire country of Mexico to be part of Mesoamerica. From an ecological point of view, he said, the Mesoamerican biogeographic region extends only through central Mexico and excludes the northern part of the country, which has discrete ecosystems not shared with Central America.

Ramírez Marcial agreed with the conclusions reached in the new study, however—that restoration strategies must consider the biodiversity of the areas they want to protect. For example, he pointed out that Mexico's government programs prioritize distributing pines for reforestation efforts across the country instead of designing "tailored suits" for each region.

This study is the first to evaluate the status of all endemic trees in Mesoamerica.

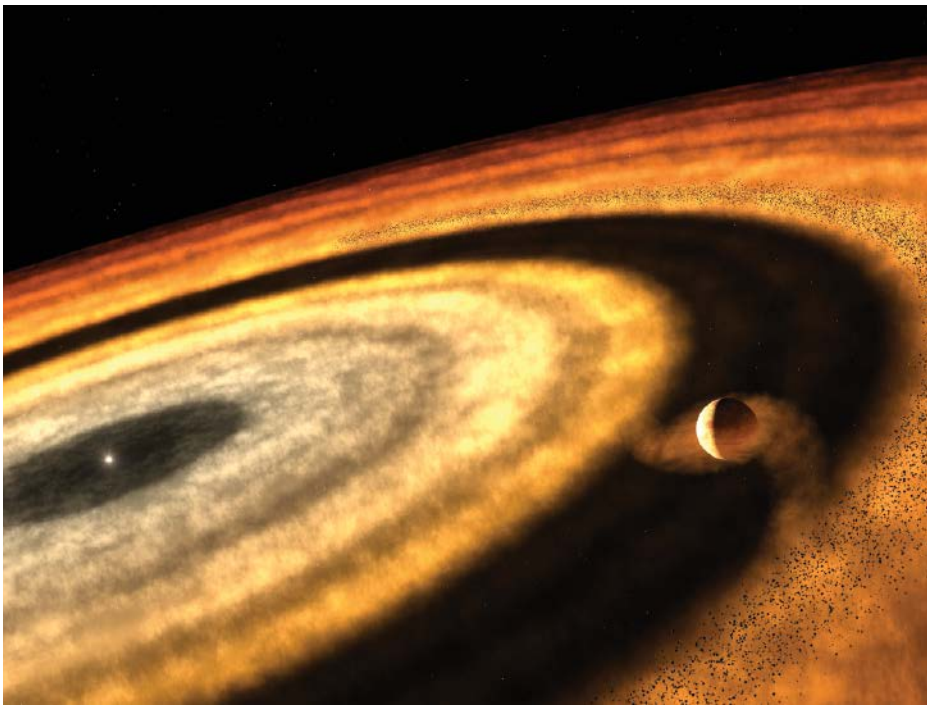
Daniela Quesada, a conservationist at the Monteverde Institute in Costa Rica, said the new study offers a more comprehensive view of the state of trees in Mesoamerica than was previously available. However, like Ramírez Marcial, she considers information from the IUCN Red List to be a starting point for research. The accuracy of the Red List, she explained, depends on the amount of information submitted to it.

Quesada said that the next step for tree conservation in Mesoamerica is for scientists to "take a closer look at each species that appeared" in the new study. A rigorous analysis of the presence and influence of each species in each region could influence the development of tailored conservation projects.

As an example, she mentioned the case of *Ocotea monteverdensis*, a tree that "went from not even being listed to being in the most vulnerable conservation category" (critically endangered), thanks to the work of ecologist John Devereux Joslin Jr. This recognition led to the development of a targeted, ongoing community conservation program for the tree.

By **Roberto González** (@perrobertogg.bsky.social), Science Writer

This Exoplanet May Have Grown Stranger as It Journeyed Starward



New evidence suggests that WASP-121b formed in the icy outer regions of its solar system, depicted in this artist's impression, before migrating to a tight orbit around its host star. Credit: T. Müller (MPIA/HdA), CC BY-SA 4.0 (bit.ly/ccbysa4-0)

A strange planet orbiting a distant star may be even weirder than we realized. Already thought to have "iron rain" and an unusual polar orbit, this ultrahot Jupiter might also have begun life far away from its star before diving into a tight 30-hour orbit.

The planet, WASP-121b, or Tylos, is about 850 light-years from Earth and was discovered in 2015. Observing the planet in October 2022 with the James Webb Space Telescope (JWST), researchers found that it hosted a surprising amount of methane and silicon monoxide. Their observations mark the first time silicon monoxide has been conclusively found on another world.

The presence of methane and silicon monoxide, researchers say, might mean that WASP-121b initially formed much farther from its star—as far away as 30 astronomical units, about the same distance Neptune lies from our Sun. (One astronomical unit is the average distance between the Sun and Earth.) The findings were published in *Nature Astronomy* and *The Astronomical Journal* (bit.ly/WASP-121b-SiO, bit.ly/WASP-121b-H2O).

"Something weird happened dynamically in its past," said Tom Evans-Soma, an astronomer at the University of Newcastle in Australia and the lead author of the *Nature Astronomy* paper. "And it may be a big factor in how it moved from far out to close in."

"Something weird happened dynamically in its past."

Iron Rain

Hot Jupiters are a class of gas giant planets that orbit extremely close to their stars and have temperatures exceeding 1,500 K (2,200°F). Ultrahot Jupiters are even closer

and hotter, sometimes reaching temperatures above 2,000 K (3,100°F).

WASP-121b is one such ultrahot world, orbiting its star (WASP-121) within 2 times the star's radius. At this proximity, the planet is tidally locked to the star, the way the Moon is to Earth, so the same face always points to the star.

Atmospheric temperatures on WASP-121b can reach more than 3,000 K (4,900°F) on the dayside and 1,100 K (1,500°F) on the nightside.

This discrepancy in temperature may help explain the concept of iron rain on WASP-121b. Metals are likely to vaporize on the fiery dayside, and as these particles blow to the nightside, the drop in temperature creates conditions for droplets of liquid metal to form and fall from the planet's atmosphere. "The nightside temperatures drop low enough for a whole bunch of these materials to condense," possibly within seconds, said Evans-Soma.

The planet's proximity to its star has also stretched the world into an oblong shape, and it orbits in a strange 90° orientation, almost pole to pole above and below the star. The planets of our solar system, in contrast, orbit in a flat plane.

A Distant Origin

These characteristics alone had already painted WASP-121b as an unusual world, but the latest observations further add to its mystery.

The researchers used JWST to observe the planet for 40 hours and pick apart its light, revealing the presence of water, carbon monoxide, and silicon monoxide on the dayside. These compounds may have been pulled from the nightside by a powerful equatorial jet with wind speeds of up to 10 kilometers per second.

The team also detected methane in the planet's nightside—a surprising result because methane shouldn't survive WASP-121b's high temperatures at all. "People have been looking for methane in exoplanets, but generally focusing on much cooler planets," said Evans-Soma.

The team detected methane in the planet's nightside—a surprising result because methane shouldn't survive WASP-121b's high temperatures.

The presence of methane suggests that the planet has a source of the compound replenishing its atmospheric supply. The team thinks the source might be trapped methane pulled up from the planet's interior by strong convection currents.

The presence of methane also suggests that WASP-121b formed much farther from its star. At a greater distance, icy pebbles of the methane were more abundant. Here, too, the gas giant may have consumed 21 Earths' worth of rocky material during its formation, which would explain the presence of silicon.

A Starward Migration

Richard Booth, a planet formation expert at the University of Leeds in the United Kingdom who was not involved in the research, said that in general, scientists think hot Jupiters migrate inward over time. It is unlikely that they form close to their stars, he explained, because the stars' gravity would be too strong for planets to coalesce.

"Hot Jupiters definitely don't form in situ," said Booth.

But finding "evidence for migration is hard," he continued, because migration can happen quickly (at least on planetary timescales)—in just millions or even thousands of years.

The WASP-121 system is thought to have formed about 1.1 billion years ago, with its migration possibly happening as a result of a gravitational nudge from a passing star or other planets in the system. Such a nudge might also explain the planet's odd orbit.

Future work could tell us how this seemingly strange exoplanet compares with other ultrahot Jupiters. "It's not clear that it is particularly unusual," said Evans-Soma. "It just happens to be one of the planets we can study in really exquisite detail."

By **Jonathan O'Callaghan,** Science Writer

Biomass and Biodiversity Were Coupled in Earth's Past

Scientists have traditionally described long-term changes to Earth's marine ecosystems by measuring biodiversity—the number of different species that show up in ancient rock samples.

Until now, no one had measured how marine biomass—the sheer amount of organic material—fluctuated over hundreds of millions of years. A new study published in *Current Biology* does just that, using limestone samples to show for the first time that marine biomass and biodiversity trends aligned over the past 541 million years (bit.ly/marine-biomass-flux).

The results may help answer questions about how ecosystems evolve over geologic time and how humans are driving a mass extinction in the modern world.

"[Biomass] patterns really followed the biodiversity curve, at least on macroevolutionary timescales," said Pulkit Singh, a paleobiologist at Stanford University and the first author of the new study. Singh's graduate research formed the basis of the new analysis.

"This provides a new type of data that allows us for the first time to test some very influential ideas about the causality of long-term biodiversity changes," said Seth Finnegan, a paleobiologist at the University of California, Berkeley who was not involved in the new study.

Counting Skeletons and Shells

As organisms living in shallow marine environments die and settle to the seafloor, their calcium carbonate shells and skeletons are preserved as fossil-filled limestone. Successive layers of limestone serve as an inventory of the diversity and abundance of life in the oceans over millions of years and are especially valuable to paleontologists because of their high shell content as well as the fact that limestone deposition rates likely stay stable over time, even in the absence of shells and skeletons.

To get a comprehensive picture of biomass over the Phanerozoic eon, Singh and the research team collected troves of data from previous studies that included counts of skeleton and shell fragments in marine limestone samples. In all, the team found data for more than 7,000 samples from 111 studies and conducted point counts for 73 new samples, too.

The data collection required a lot of "intellectual courage" from Singh, said Jonathan Payne, a paleobiologist at Stanford University and a coauthor of the new study. "It took a lot of hard work with no guarantee that we'd get anything informative in the end."

The gamble paid off: Results showed that "shelliness," as Payne calls it—a proxy for biomass—generally increased over the past 541 million years alongside recorded trends in marine biodiversity, with dips in biomass aligning with known major extinction events.

The study "provides a link that has been missing until now" that connects long-term biodiversity processes to biomass trends, Finnegan said. The data appear to confirm what many paleobiologists expected but did not have the data to demonstrate—that marine animal biomass and biodiversity aligned over Earth's history, he said.

Singh and the team performed a series of analyses to ensure that the trends they were seeing weren't due to other factors, such as depositional environment, latitude, ocean depth, and ecosystem type. No matter how they sliced up the data, the results showed the same trends.

"It's really rare to get the first chance to document a pattern about life across long histories of time," Payne said. "There's theory, but in the end, theory is meaningful when you can compare it to real data."

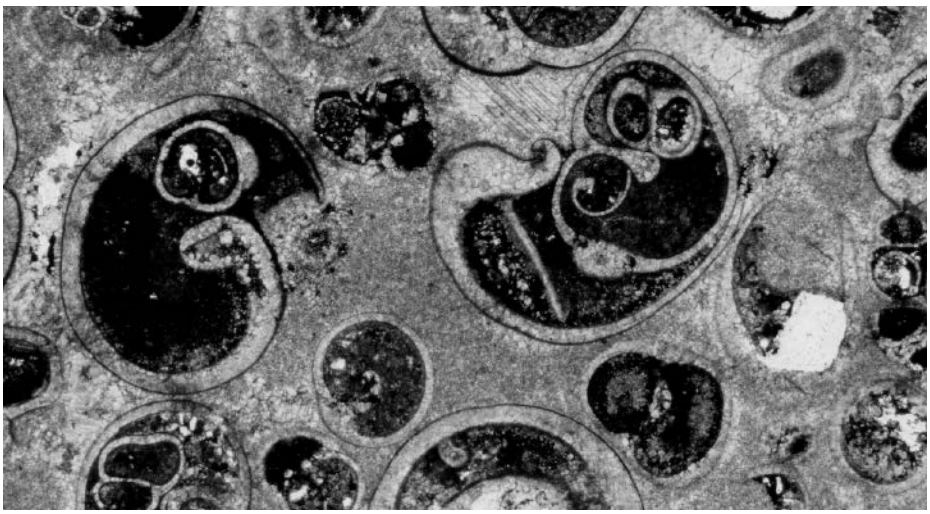
The patterns the team uncovered in the limestone were reflected, too, in language past researchers used to describe their samples: An analysis of nearly 16,000 abstracts that included descriptions of sedimentary carbonate rock over geologic time showed that the "shelliness" of words used to describe limestone samples increased alongside biomass trends. Words like skeletal and fossiliferous showed up at higher ratios compared with nonskeletal words in descriptions of samples from times in Earth's history when biomass was higher.

"It was an interesting, independent confirmation of the rest of the study," Payne said.

"When there is more stuff to eat at the base of the food chain, ecosystems can support more and larger individuals, and maybe they can also support more different kinds of organisms."

What Biomass Tells Us

Biomass indicates how much energy is available in an ecosystem. For animals, the ultimate source of that energy is created via



The number of shell and skeleton fragments found in ultrathin slices of limestone, like these Early Triassic gastropods, was used as a measure of biomass in the new study. Credit: Jonathan Payne

the primary productivity of photosynthetic organisms such as plants and algae. Understanding the relationship between biomass and biodiversity can provide insight into how ecosystems evolve, how diversity arises and collapses, and what the ultimate factor is that limits biodiversity in an ecosystem.

"It has been suggested for a long time that the long-term increase in biodiversity is a response to higher primary productivity," Finnegan said. "When there is more stuff to eat at the base of the food chain, ecosystems can support more and larger individuals, and maybe they can also support more different kinds of organisms."

In the ecology of the modern world, scientists have evidence that this is true. But modern scientists live in a "thin little time slice" in which any observations of ecosystems occur on very short timescales relative to Earth's history, Finnegan said.

Scientists don't know whether ecosystems work the same now as they did for all of Earth's history. Long ago, biodiversity may have dictated biomass instead, or the relationship may have been a feedback loop. "Really understanding biodiversity processes means understanding them on the million-year timescale," he said.

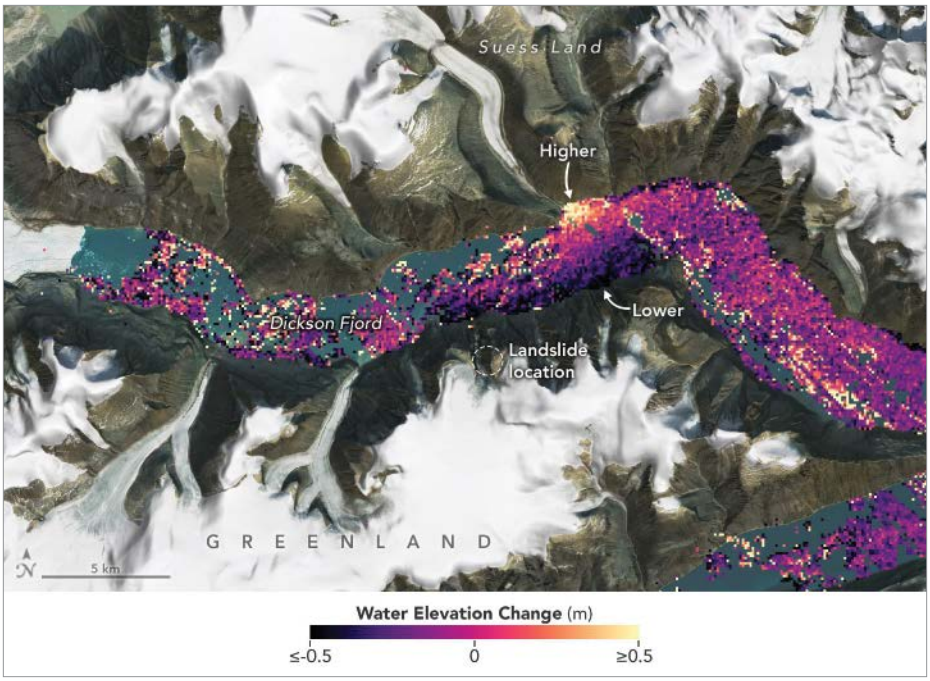
Since humans started to dominate ecosystems, biodiversity has plummeted. Biomass, however, has increased significantly, mostly as a result of animal husbandry and pet ownership. "We have a lot of humans, and a lot of cats and dogs but not a lot of diversity," Singh said. The world's oceans are also "very likely in the early stages of a significant extinction event," Finnegan said.

Deeper knowledge of how biomass and biodiversity have related over geologic time could help scientists better understand the effects of human-caused ecosystem changes and the drivers of what has been called a sixth mass extinction. Humans are altering the planet in a "massive experiment," Payne said. And the only way to understand planetary-scale experiments is to use the geologic record, he said. "It is the only source of information at the same temporal and spatial scales."

For the vast majority of the Phanerozoic, biomass and biodiversity seem to have been coupled, according to the new study. The results provide a coarse, but robust, picture, Payne said, though "there's a lot more to learn."

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

New Satellite Adds Evidence of an Earth-Shaking Wave



A sloshing tsunami in Dickson Fjord shimmied seismometers for 9 days starting on 16 September 2023. This data visualization of the fjord on 17 September shows the sloshing water and adds direct observational evidence to earlier models. Credit: NASA Earth Observatory

On 16 September 2023, a low hum began swaying seismometers around the world. Unlike during the short and jagged frenzy of an earthquake, this signal wobbled every 92 seconds and continued for 9 days. About a month later, while seismologists were still puzzling over the incident, the hum started again and lasted roughly a week.

Researchers traced the confusing signals to East Greenland, where satellite imagery revealed the scars of recent rockslides in Dickson Fjord. They deduced that millions of cubic meters of rock and ice had suddenly fallen into the sea on 16 September, creating a 200-meter tsunami and a long-lasting wave called a seiche. Rather than ricochet out to sea, the tsunami kept sloshing back and forth between the fjord's parallel walls, trapped by crooked topography. The later hum was from a second, smaller rockslide and seiche.

The area is unpopulated, meaning that no one was threatened by the initial wave—but no one observed the event either.

Seiches typically need a continuous energy source such as a windstorm to persist, but the long-lasting waves in Dickson Fjord appeared to be self-sustaining. Two teams independently developed simulations showing that Dickson Fjord could support a long-lasting seiche. A new study in *Nature Communications* builds on that work, using satellite data to provide the first direct observations of the seiche (bit.ly/seiche-observations).

"To really robustly be able to say, 'This is what was shaking the Earth at this time,' we needed that observational evidence," said Thomas Monahan, an oceanographer at the University of Oxford and the first author of the new paper.

As Above, So Below

East Greenland is remote, and the seiche mostly dissipated before the Danish military arrived 3 days after the initial wave to investigate the collapsed mountain face in Dickson Fjord. By then, the amplitude of the wave was already too small to detect from the boat.

Before (left) and after images show the obvious collapse of a glacier in Dickson Fjord. Credit: Søren Rysgaard

"They're sort of perfect partners, satellite and seismic data."

However, the shift in sea surface elevation was visible from space thanks to the international Surface Water and Ocean Topography (SWOT) satellite, launched in 2022. SWOT uses two altimeters spaced 10 meters apart to triangulate small changes in water height.

Prior to SWOT, satellites had one altimeter and could offer a 1D picture of the ocean. Now, Monahan said, researchers can obtain precise, high-resolution imagery of the sea surface, even between the deep walls of a distant fjord.

"We've never had the capability to do things in these regions at this level before," Monahan said.

The satellite passed over Dickson Fjord several times during the main event and the smaller rockslide that followed. Monahan and his colleagues examined SWOT data from four transits, tracking the sea surface slope along the same transect each time.

SWOT verified that water was sloshing back and forth between the fjord walls, and researchers extended their search to rule out other causes. The timing of the waves did not match the timing of winds recorded by a weather station in the fjord or the pattern of tides recorded by SWOT over the next 13 months. The magnitude of the wave did, however, match the seismic signal, further suggesting that the fjord's geometry had trapped a wave.

A vessel cruises past a glacier in Greenland's Dickson Fjord. The glacier would later collapse, triggering a tsunami that shook Earth for 9 days. Credit: Søren Rysgaard

"Science at Its Best"

The study further confirmed the seiche and also showed the early utility of SWOT, which had finished calibrating just 2 months before the initial rockslide.

"It's a nice surprise to see the result," said Yao Yu, a physical oceanographer who works with SWOT data at the Scripps Institution of Oceanography. The satellite is built for oceans, rivers, and lakes, she said, but the new study shows that it can also collect good data from high-latitude fjords in areas unreachable by prior satellites. "A lot of things we never expected, SWOT can do; it's actually working very well," she said.

SWOT's spatial resolution is especially important in the Arctic, where seismometers are sparse. The satellite provides only intermittent observations, but it can access remote locations. That fills a gap, said Stephen Hicks, a seismologist at University College London and a coauthor of one of the original seiche papers.

"They're sort of perfect partners, satellite and seismic data," Hicks said. The new study backs up and builds upon the original research, he added, and "that's sort of science at its best."

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

Beyond Majesty and Myth: Facing the Realities of Mountainside Development

The dramatic rescue of 41 workers trapped for 17 days in a collapsed Himalayan tunnel in India made global headlines in November 2023. The collapse occurred during work on part of the Char Dham highway project, an Indian federal initiative aimed at linking pilgrimage sites and supporting increased regional tourism.

From its inception, the project faced strong opposition from environmentalists and local residents because of its circumvention of environmental impact assessments (EIAs) in the ecologically fragile Himalayan region. Nongovernmental organizations and activists protested that by law, highway expansions exceeding 100 kilometers in length must undergo an EIA, but the highway ministry avoided the requirement by dividing the project into 53 smaller segments.

The mountainside town of Joshimath in Uttarakhand, India, seen here prior to a large subsidence event in 2022–2023, is a popular gateway to pilgrimage sites, hiking trails, and expeditions in the Garhwal Himalayas. Credit: iStock.com/DanielPrudek

Scientific evidence consistently underscores the fragility of Himalayan ecosystems and the risks posed by large-scale infrastructure development.

Environmental concerns over the Char Dham project prompted the country's Supreme Court to establish a High-Powered Committee to oversee these issues. Although the committee recommended limiting road widths to 5.5 meters (18 feet) to mitigate landslide risks in the landslide-prone region of Uttarakhand state, the Supreme Court overruled the recommendation in 2021, allowing widths of 10 meters because of the roads' strategic importance as feeder routes to the India-China border [*Rawat and Semwal*, 2023].

The incident is not an isolated example of the sidelining of local concerns in favor of development in India's mountain ecosystems. In another case, climate activist Sonam Wangchuk and his supporters were detained in New Delhi in October 2024 after demanding more local autonomy for another Indian Himalayan state, Ladakh, to protect its landscape from large-scale infrastructure and mining projects.

Scientific evidence consistently underscores the fragility of Himalayan ecosystems and the risks posed by large-scale infrastructure development. For example, researchers have warned of increased cloudbursts and flash flooding—and their effects on erosion and safety—along the Indian Himalayas [*Dimri et al.*, 2017], and numerous studies have linked increased landslide activity in the region to construction projects and development [*Ives and Messerli*, 1989; *Singh et al.*, 2014]. Indeed, a global analysis of fatal nonseismic landslides from 2004 to 2016 revealed that India accounted for the highest percentage of construction-triggered landslide events (28%), followed by China (9%) and Pakistan (6%) [*Froude and Petley*, 2018].

India's mountainous regions provide evidence of how rapid and extensive development amplifies impacts seen by local communities especially. Uttarakhand, for example, has experienced roughly 40% decadal urban population growth in recent decades, leading to an unplanned surge in urban infrastructure that has resulted in large-scale deforestation and other detrimental environmental changes. Although economic growth is essential for the region, balancing it with sustainable and safe development is crucial—a challenge also faced by other mountain communities worldwide, such as those in parts of the United States and Africa.

These examples prompt critical questions about the environmental injustice of imposing the interests and resource demands of broader society on mountain landscapes while neglecting the vulnerabilities of mountain communities. They also raise questions about the thinking and policies that led us to this juncture and about what measures we can adopt to safeguard these communities and ecosystems for future generations.

Mysticism Around the Mountains

Humankind's fascination with mountains has long been immortalized in cultural histories, literature, and art. Especially for those living far from these rugged terrains, perceptions and depictions of mountains are often idealized and shaped by romantic

notions of their majesty and mythical stature that fail to capture their complex realities and are far removed from the truth.

In South Asia, these depictions—portraying mountain ranges, escarpments, ridges, and valleys as the abodes of rishis, yogis, and deities—often overshadow the harsh realities that local inhabitants face.

As the philosopher T. R. V. Murti once noted, "The Himalaya of the rishis and the yogis is more important as an ideal to us than are the actual rocks and the miserable huts of the people there" [*Bharati*, 1978, p. 78].

Smaller mountains and hills also have lasting cultural and spiritual significance. An ancient Hindu tale set in Mathura, where I was born, tells of how the deity Krishna urged villagers to nurture their lands and honor the nearby Govardhan Hill, which provided the fertile soil that sustained their cattle, rather than solely relying upon and worshiping the god of rain [*Anand*, 2023]. When the enraged god of rain punished the villagers by flooding the village, Krishna came to their rescue by lifting Govardhan Hill and providing shelter for 7 days, ultimately humbling the god of rain.

Though the divine aura of Govardhan Hill—which has attracted countless pilgrims for generations, including me as a 12-year-old—is central to this timeless tale, Krishna's lesson about nurturing and protecting the landscapes that sustain both ecosystem health and human survival is often forgotten. Another hidden, but highly relevant, message is that local communities and voices must be centered when environmental and economic policies affecting mountain regions are crafted.

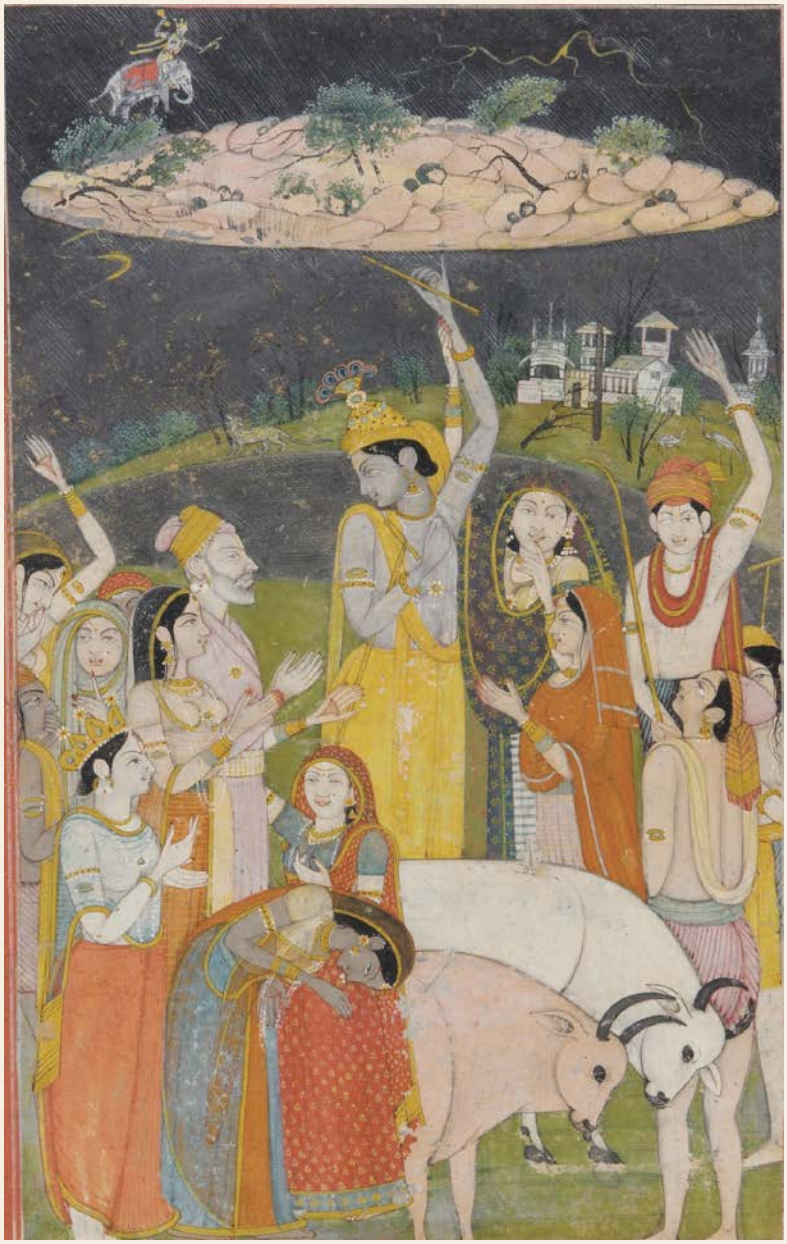
It took me nearly a decade to fully appreciate these insights as my relationship with mountains evolved. Today, though I still respect the spiritual essence of the story of Govardhan Hill, I deeply value Krishna's timeless message about preserving the connections between mountains and their inhabitants.

My own perspective notwithstanding, entrenched popular perceptions of homogeneous, picturesque mountain ranges, as well as the interests of the broader public, often drive conservation and development policies in mountain regions without acknowledging the heterogeneity of mountain landscapes and the communities that rely on them [*Bharati*, 1978]. As development progresses rapidly and the gap between idealized perceptions and the lived realities of mountain environments widens, the resulting ecological damage and increasing risks to habitats and local communities become more urgent. This concern is amplified as questions are raised about the dilution of conservation laws in India and elsewhere.

A Mountainous Reality Check

By virtue of their high relief, weather, and position atop an active tectonic boundary, India's mountainous regions are inherently highly vulnerable to natural disasters—and some hazards are becoming more unpredictable because of climate change [*Dimri et al.*, 2017].

Much development in these regions—home to roughly 52 million people, or just 3%–4% of India's population—is guided by the fact that they supply large portions of the water, natural resources, and energy that support more than 1 billion people living elsewhere. Thus, despite its effects on mountain ecology and communities, this



Krishna holds up Govardhan Hill to provide shelter for villagers in this painting from circa 1790. Credit: Attributed to Mola Ram/Public Domain

The author looks out at the Garhwal Himalayan Range from a hotel rooftop in Joshimath in 2015. Credit: Courtesy of S. K. Anand

development is often seen as vital to wider interests and public well-being across much of the country.

However, communities in mountain regions are also increasingly being strained by overtourism and related growth and development. This surge has been fueled by policies looking to promote and capitalize on tourism and, in the past decade, by social media, which often sensationalizes mountain locations, drawing even larger crowds. The issue affects areas from the high-altitude mountains of Ladakh to the biodiversity hot spot of the west coast mountains and the scenic ranges of northeastern states such as Arunachal Pradesh, Assam, Meghalaya, and Sikkim.

Whether for religious tourism or geotourism, influxes of visitors place immense pressure on local inhabitants. Although short-term economic gains are possible, the long-term sustainability of local economies is put at risk because of limited employment opportunities and rising living costs. Moreover, the ecological and environmental tolls are significant, as indicated by a multitude of development policy–induced disasters in the Himalayas [*Shugar et al.*, 2021].

For example, unchecked development can lead to land subsidence, which jeopardizes the safety of infrastructure as the ground sinks. I vividly recall a trip I took to Joshimath, Uttarakhand—a gateway to Himalayan pilgrimage sites, trekking trails, and expeditions—in January 2015. Amid the beautiful towering peaks of the Garhwal Himalayan Ranges, I couldn't help but notice fine cracks in some buildings and the generally poor infrastructure of the town, which left me with a lingering sense of unease.

The effects of climate change are exacerbating the challenges and costs created by rapid and poorly planned development.

When news broke in 2023 of alarming subsidence in Joshimath, causing large cracks to form in roads and buildings and forcing residents from their homes—with lasting mental health impacts—I revisited photos I had taken 8 years earlier and was reminded that the signs of impending problems were already there. Years of large infrastructure projects and poor drainage had destabilized the town [*Awasthi et al.*, 2024], which is in India's most earthquake-prone zone.

The Garhwal commissioner issued an official scientific report 50 years before subsidence in Joshimath became a crisis. It warned of these geological dangers and recommended strictly regulated construction because of the high seismic risk. Unfortunately, that warning went unheeded.

The effects of climate change are leading to more frequent and unpredictable extreme-weather–driven events and are exacerbating the challenges and costs created by rapid and poorly planned development. For example, Indian Himalayan states have repeatedly faced devastating flash floods in parts of Uttarakhand and Sikkim. As such incidents become alarmingly common, they raise serious concerns about the toll on inhabitants of mountain communities and how they will cope with limited resources.

What Must Be Done

Land use changes and human disturbances can accelerate erosion, degrading landscapes within decades and vastly outpacing natural soil formation. A recent global assessment

found that cropland, covering just 11% of the studied land, accounts for nearly half the total predicted soil erosion around the world [*Borrelli et al.*, 2017]. Cropland erosion rates are estimated to be 77 times higher than rates in forests, because replacing native vegetation with crops or bare soil increases exposure to precipitation and makes the land highly susceptible to erosion.

Such erosion can increase risks from natural hazards, and the loss of soil fertility threatens biodiversity, water and soil health, and long-term ecosystem functioning. History offers stark warnings. In early 20th century South Carolina, for example, unsustainable cotton farming led to severe soil erosion and gully formation. By the 1930s, entire farming communities, such as one in Calhoun County, were displaced and never returned [e.g., *Anand*, 2023].

Similar mechanisms come into play in development projects that remove or replace native vegetation in fragile ecosystems, such as the Char Dham project in Uttarakhand, which has involved extensive deforestation.

Even more concerning is that the natural processes that stabilize degraded hillslopes may take thousands of years to restore these terrains [*Anand*, 2023]. The disparity between the rapid pace of human-induced change and the prolonged timeline for natural restoration underscores the urgent need for proactive measures to protect fragile environments.

For Earth scientists such as myself, modeling landscape evolution under varying hydroclimatic conditions and human disturbances, as well as monitoring for early signs of intensified erosion and land degradation on decadal timescales, is a multifaceted challenge and a pressing need [*Tucker and Hancock*, 2010; *Anand et al.*, 2022]. Such research could improve quantitative assessments of change and predictions of disasters, enabling communities to act before irreversible damage occurs.

Scientists must also communicate beyond academia and collaborate with local communities to address their priorities. These communities know best the challenges and changes in their regions, whereas scientists can bring their knowledge, networks, and skills to bear on understanding the reasons for these changes and suggest viable solutions.

Collaborations organized through AGU's Thriving Earth Exchange program, which connects scientists with local communities facing environmental challenges, offer prime examples of success in turning science into action. Adapting that model to create similar programs in India and elsewhere could help address the unique challenges faced in vulnerable mountainous regions, ensuring that scientific knowledge and community expertise lead to resilient solutions.

We must be mindful of how romanticizing mountain environments in India and other vulnerable areas around the world can lead us to overlook their harsh realities.

For their parts, governments and administrative authorities must approach development in mountainous landscapes with deep consideration of local conditions and the problems and aspirations of the resident communities. Including and prioritizing local voices in decisionmaking processes and heeding expert scientific assessments and warnings about environmental impacts are crucial to ensuring sustainable development. These necessities hold whether development projects are related to tourism or to other economic, industrial, or energy interests.

Industrial infrastructure projects in mountain regions may be considered vital to national interests but still must be undertaken carefully to preserve the ecological integrity of these fragile environments. If they are unregulated and unscientific, mining activities, for example, can generate debris that increases hillslope vulnerability, potentially leading to catastrophic landslides or other incidents.

Climate activist Wangchuk has highlighted this issue, pointing out that local people do not reap the benefits of extracted resources but bear the brunt of such disasters. In October 2024, Wangchuk and his supporters went on a 16-day hunger strike and were detained while advocating for empowering local communities in Ladakh in decisionmaking related to environmental protections. This episode is a wake-up call that organizations and activists in the environmental advocacy and policy realms can play crucial roles in pressuring governments and corporations to prioritize sustainable practices over short-term financial gains.

On an individual level, we must be mindful of how romanticizing mountain environments in India and other vulnerable areas around the world can lead us to overlook their harsh realities and contribute to their degradation through overdevelopment. We must also be clear-eyed in confronting the genuine challenges in mountain regions, where poorly planned incursions in the name of profit or popularity can amplify disasters that, especially amid the relentless global climate crisis, drastically disrupt the ecosystems and communities that inhabit them.

Bridging this gap in perception is no easy task, but it is essential to helping these areas endure the pressures we place upon them.

Read the article at Eos.org

References

Anand, S. K. (2023), Representing the form and formation of Earth's topography under natural and anthropogenic drivers, Ph.D. dissertation, Princeton Univ., Princeton, N.J., bit.ly/Anand-dissertation.

Anand, S. K., et al. (2022), Inception of regular valley spacing in fluvial landscapes: A linear stability analysis, *J. Geophys. Res. Earth Surf.*, *127*(11), e2022JF006716, https://doi.org/10.1029/2022JF006716.

Awasthi, S., et al. (2024), Analyzing Joshimath's sinking: Causes, consequences, and future prospects with remote sensing techniques, *Sci. Rep.*, *14*, 10876, https://doi.org/10.1038/s41598-024-60276-3.

Bharati, A. (1978), Actual and ideal Himalayas: Hindu views of the mountains, in *Himalayan Anthropology*, edited by J. F. Fisher, pp. 77–82, De Gruyter Mouton, Berlin, https://doi.org/10.1515/9783110806496.77.

Borelli, P., et al. (2017), An assessment of the global impact of 21st century land use change on soil erosion, *Nat. Commun.*, *8*, 2013, https://doi.org/10.1038/s41467-017-02142-7.

Dimri, A. P., et al. (2017), Cloudbursts in Indian Himalayas: A review, *Earth Sci. Rev.*, *168*, 1–23, https://doi.org/10.1016/j.earscirev.2017.03.006.

Froude, M. J., and D. N. Petley (2018), Global fatal landslide occurrence from 2004 to 2016, *Nat. Hazards Earth Syst. Sci.*, *18*, 2,161–2,181, https://doi.org/10.5194/nhess-18-2161-2018.

Ives, J. D., and B. Messerli (1989), *The Himalayan Dilemma: Reconciling Development and Conservation*, U.N. Univ., London.

Rawat, A. S., and M. M. Semwal (2023), Unveiling the Himalayan nexus: Unraveling anthropogenic triggers and pursuing sustainable development in Uttarakhand, *J. Mt. Res.*, *18*, 101–115, https://doi.org/10.51220/jmr.v18i1.11.

Shugar, D. H., et al. (2021), A massive rock and ice avalanche caused the 2021 disaster at Chamoli, Indian Himalaya, *Science*, *373*, 300–306, https://doi.org/10.1126/science.abh4455.

Singh, R., R. K. Umrao, and T. N. Singh (2014), Stability evaluation of road-cut slopes in the Lesser Himalaya of Uttarakhand, India: Conventional and numerical approaches, *B. Eng. Geol. Environ.*, *73*, 845–857, https://doi.org/10.1007/s10064-013-0532-1.

Tucker, G. E., and G. R. Hancock (2010), Modelling landscape evolution, *Earth Surf. Processes Landforms*, *35*(1), 28–50, https://doi.org/10.1002/esp.1952.

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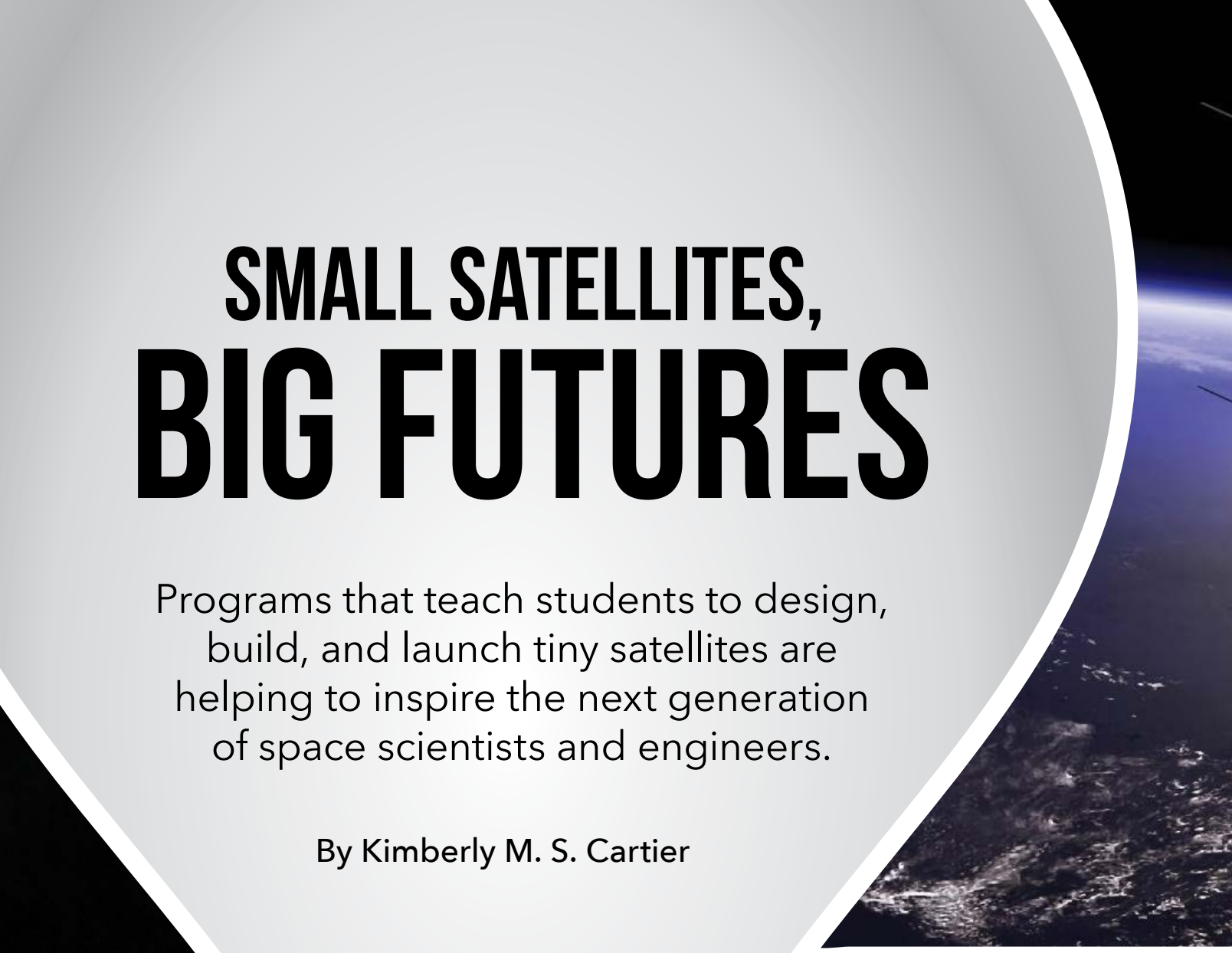
WHERE SCIENCE CONNECTS US

SMALL SATELLITES, BIG FUTURES

Programs that teach students to design, build, and launch tiny satellites are helping to inspire the next generation of space scientists and engineers.

By Kimberly M. S. Cartier



(clockwise from top center) Illustration of the Picosatellite for Atmospheric and Space Science Observations (PICASSO) CubeSat in orbit. Credit: BISA; An Infinity Girls in Space participant stands beneath her now-launched CubeSat. Credit: STEMbees; An Infinity Girls in Space participant displays her CubeSat prototype before launch. Credit: STEMbees; Participants of Space Prize's NYC CubeSat Challenge collect data from their CubeSat prototype. Credit: Space Prize; Two 2U CubeSats launched from the International Space Station. Credit: NASA

When Devin Phyllides graduates from college next year, she'll be able to boast something few students can: She'll have helped launch a satellite into space.

"It's probably my favorite job I've ever had," she said.

Phyllides, a senior undergraduate physics student at the University of New Hampshire (UNH) in Durham, is a research assistant for the 3UCubed CubeSat project, a collaboration between UNH, Howard University in Washington, D.C., and Sonoma State University in Rohnert Park, Calif.

CubeSats are small satellites first developed in 1999 as a platform for education and space exploration. They are measured in "units" or U, where a 1U CubeSat is a cube measuring 10 centimeters per side. A 2U CubeSat is equivalent to two 1U CubeSats stacked together, a 3U CubeSat is three cubes stacked together, and so on. The NASA-funded 3UCubed satellite is the size of a 1-quart milk carton.

Dozens of people from the three universities have helped design, build, and test the satellite ahead of its planned October 2025 launch, and most of them are university students.

"The goal from the get-go of this CubeSat is to give students hands-on experience, not just in building…but in the full life cycle of a mission," said Noé Lugaz, a space scientist at UNH and colead of the 3UCubed project.

Students around the world—high schoolers, undergraduates, and graduate students—have participated in CubeSat missions. Student-focused satellite programs not only provide important science in multiple fields but also inspire and engage the next generation of space scientists and engineers.

Why Build a CubeSat?

An entire aerospace industry has been developed around CubeSats, but the tiny satellites also remain a cornerstone of science, technology, engineering, and mathematics (STEM) education for all ages. Today, many of the satellites' components, such as the chassis, navigation systems, cameras, and scanners, can be purchased off-the-shelf, and most don't require advanced technical skills to assemble.

Building a CubeSat "still provides the challenge of putting everything together, and making sure the software works, and making sure that it does exactly what needs to be done," said Floor Bagchus, a master's student in aerospace engineering and the educational manager for the Da Vinci satellite at Delft University of Technology (TU Delft) in the Netherlands. But because so many of the components come ready to install, "it's really a very accessible way for engineering students to learn how to make an actual satellite," she said.

Some CubeSats are space-ready and are launched into orbit or released from the International Space Station. Others are not designed to leave the atmosphere and are lofted by atmospheric balloons for a short time before descending. Their small size and light weight make CubeSats ideally suited for doing science in the upper atmosphere or in low Earth orbit, such as studying Earth's magnetosphere, atmosphere, and surface conditions.

CubeSats aren't the only type of small, budget-friendly space mission in the game, Lugaz said, but in his opinion, they offer the most science per dollar and a realistic space mission experience.

In comparison with a CubeSat, "a balloon, for example, would be cheaper, faster, and maybe scientists can do faster turnover and reach more students," Lugaz said. "A CubeSat is obviously a longer program. But the positive side of this is that the science you can do with a CubeSat is much more [varied and] is also better training for some of the jobs in industry."

Their size also helps make the idea of space and satellites approachable, especially for younger students, Bagchus said.

"I think people are a bit scared of space, and teachers are scared of space, because they think that space is so gigantic, dark, vast, and complex," she said. "How can you make sense of such a difficult thing? How can you make students not be so scared of it, and show them that you can actually work in space, do things in space, and overcome very difficult hurdles by very basic principles? I think it's a very important thing to do in primary schools and high schools to show that you can actually do challenging things."

"I NEVER REALLY THOUGHT I'D BE ABLE TO SAY THAT I LAUNCHED A SATELLITE TO SPACE IN MY HIGH SCHOOL YEARS."

Building STEM Pathways for High Schoolers

The simplicity of a CubeSat means that students with limited or no technical experience can learn how to select the satellite components, install the scientific payloads and navigation systems, design the software, and analyze data. In this way, CubeSats can be an entry point into STEM careers.

In 2022, the Israel Space Agency launched the TEVEL CubeSat constellation, a program designed to provide high school students with a chance to build and launch satellites. Avigail Anidjar learned about the program when she was in eighth grade. When she started at Ulpanat AMIT Givat Shmuel High School near Tel Aviv the following year, she was excited to learn that the school was participating in the program's second iteration. She joined TEVEL 2 in 2023, at 15 years old.

"I never really thought I'd be able to say that I launched a satellite to space in my high school years," Anidjar said.

TEVEL 2 gave nine teams of Israeli high school students the opportunity to build and launch a 1U CubeSat. Building a satellite exposes students to an array of STEM fields, including atmospheric science, computer science, engineering, physics, and robotics.

The child of two engineers, Anidjar had taken introductory classes in physics and coding. Still, she learned a lot of hands-on skills in data analysis, computer programming, and problem-solving while working on her school's CubeSat.

"I've always known that I want to go into this kind of field…but now I know that dealing with more space things and satellites is something that's very interesting, and maybe I want to focus more on that," she said.

Nine TEVEL 2 satellites, one from each participating school, launched in March 2025 and will operate together to measure the flux of high-energy particles and solar cosmic rays over roughly the next 2 years. The satellites also feature a transponder for ham radio communication.

Anidjar said the launch was "really stressful" but also very rewarding. "We saw our whole work actually come to life. And after a few days, we also got a beacon from

it [showing] that it actually works and that it's alive, and not just a piece of metal in space. It was really exciting."

Anidjar recently graduated but remains on the satellite's data analysis team.

Student-built CubeSats can be a tool for educational empowerment, said Maryam Sani, a STEM educator and advocate, and the education lead for the Space Prize Foundation, a U.S.-based nonprofit dedicated to promoting space education and innovation.

In October 2024, Space Prize sponsored the NYC CubeSat challenge, during which 38 high school– and college-age girls and gender minority students from Colombia Saudi Arabia, the United Kingdom, and the United States spent three intensive days in New York City (NYC) learning what it takes to create a satellite.

The students were split into teams with others they had never met. Some had interest and prior knowledge about space or engineering from school or programs such as Space Camp. Others joined out of curiosity.

"And that was brilliant," Sani said. "To quote one student, she said, 'I just thought it would be something nice to do…I can't believe how much I learned and how much this has made me more interested in finding out about the space industry.' Which is exactly what we wanted."

Throughout the program the students learned basic physics, circuitry, and coding. Each team brainstormed a problem in New York City that a CubeSat could help solve, designed the system, and then built it. Weather prevented the launches, but the participants collected and analyzed data from their creations on the ground.

Sani said that some of the students from Saudi Arabia extended their project after they went home, eventually launching their CubeSat and incorporating the data into an undergraduate project for electrical and computer engineering degrees.

The CubeSat challenge "was a surreal experience," wrote one participant in her feedback form. "It made me feel more confident that being a woman in STEM was a possibility."

Space for All

CubeSats can lower the barrier to entry for students around the world who can't join rocketry programs or other STEM opportunities. CubeSat education programs can foster international participation and collaboration in science, even when pan-

Participants of the 2024 Space Prize NYC CubeSat challenge gather data from their satellites—and pose for photos—while standing on the deck of the museum ship USS Intrepid *in New York City. Credit: Space Prize*

demic lockdowns prevent in-person meetups.

In 2021, FIRST Global, a U.S.-based nonprofit that promotes international youth STEM education and engagement, hosted a CubeSat Prototype Challenge that enabled students from 176 countries to build and launch CubeSats. Among its initiatives, FIRST Global has organized annual Olympic-style robotics competitions for national youth teams since 2017. The competitions are typically held in-person, but the COVID-19 pandemic prevented the 2021 gathering. Organizers realized that a CubeSat challenge, which they had never done before, could be the answer if it were held remotely.

"We're trying to connect the world, but we couldn't do that physically," said Matt Stalford, the communications director of FIRST Global. "We certainly could do that symbolically, and CubeSats were a huge part of that."

For the challenge, each national team—made up mostly of teenagers—defined a mission of importance to their community and designed a CubeSat to collect the data needed to solve it. For example, team Japan studied residual airborne radiation near the Fukushima nuclear site, Team Seychelles collected environmental data to improve local weather forecast accuracy, and Team Argentina studied how local atmospheric conditions obstruct radio transmissions. FIRST Global shipped each team a standardized CubeSat prototype assembly kit.

"WE ASKED THE STUDENTS, 'WHAT WOULD YOU LIKE TO DO IN SPACE?' AND THE ANSWER WAS, 'I WANT TO PLAY IN SPACE.'"

"Then they had to do the hard part of building it, launching it, taking that data, and writing a report on what that data produced," Stalford said. Using balloons, the teams launched 90 CubeSats into the lower atmosphere.

Stalford said that asking students to design a satellite that could help solve a problem in their community made the CubeSat challenge more meaningful to them.

"Kids were built to care about the world," he said. "When you can spark the imagination, when you can get them asking questions like, 'How can I be part of the solution?', that's where kids come alive, and that's how you spark that love of STEM."

Each FIRST Global CubeSat challenge team received a standardized CubeSat prototype assembly kit, from which they built their CubeSats. Credit: FIRST Global

As part of the Infinity Girls in Space Project, cohorts of high school girls across Ghana build and launch CubeSat prototypes. Credit: STEMbees

Reaching Even More Students

FIRST Global's CubeSat Prototype Challenge inspired the creation of other CubeSat programs, including one run by STEMbees in Accra, Ghana. STEMbees is a nonprofit organization whose mission is to increase the visibility and participation of girls and women in STEM in Ghana and to close the STEM gender gap across Africa.

A STEMbees expert mentored the eight girls from Team Ghana in the 2021 FIRST Global challenge. Team Ghana members built and launched their CubeSat during the challenge and wanted to launch another one after the contest ended. They took their blueprints, customized them with 3D printing, and built a new one. The group went to nearby Academic City University for a launch that attracted the attention of the university students and local community.

"We saw the impact that it created," said Benedict Amoako, a robotics engineer and STEM instructor with STEMbees. "We had basically half the university students come out to see what these high school girls were trying to do on their large football pitch, and [they] were very impressed."

Seeing the success of Team Ghana's second launch made the STEMbees team want to expand its CubeSat program to reach even more students across Ghana, Amoako said. The organization partnered with AIMS Ghana and the U.S. Embassy in Ghana to create the Infinity Girls in Space Project. By

August 2023, more than 110 girls from 37 schools across the country had learned about and helped build CubeSat prototypes.

Aerospace engineering and satellite imagery analysis are not commonly taught in primary or high school in Ghana, explained Lady-Omega Hammond, STEMbees product and start-up growth strategist. Unless a student goes into one of a few specific careers—for example, the military, telecommunications, or land surveying—"you might not find yourself, as a young person, wanting to think about what's going on beyond the skies," Hammond said. "CubeSats gave us a very interesting angle to pique the interest."

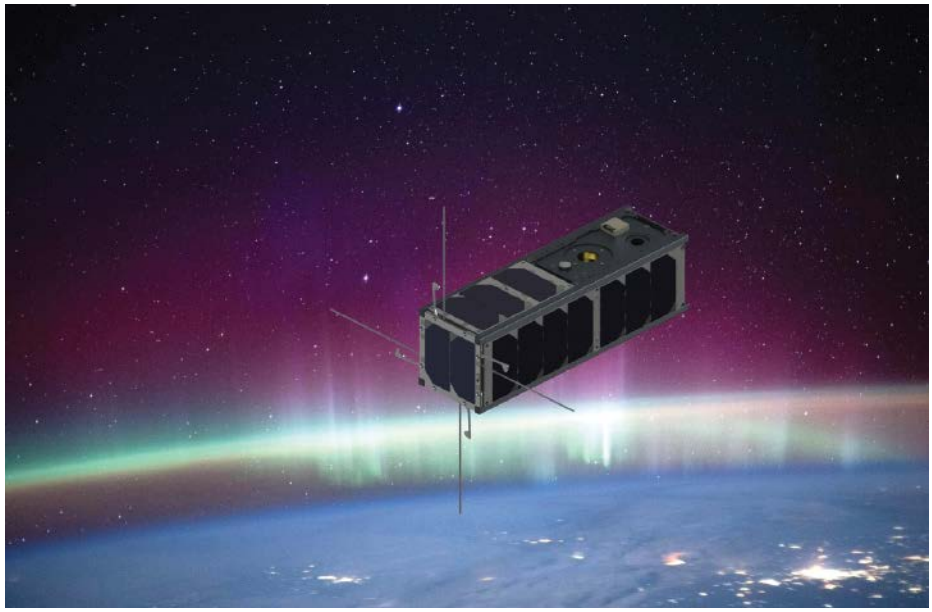
During Infinity Girls in Space, STEMbees provided CubeSat prototype training modules, lesson plans, assembly kits, and technical resources to teachers and students at more than 3 dozen high schools across Ghana. Students learned 3D printing, satellite assembly, coding, and basic physics and atmospheric science. Cohorts from several nearby schools, joined in person by STEMbees experts, worked together for the builds and launches. The eight cohorts lofted 10 CubeSat prototypes into the lower atmosphere by balloon, and they collected images and basic atmospheric readings before their teams retrieved them.

Although some students struggled initially because the concepts were new to them, "I think it all came together when they were working as a team" and supporting one another through the learning process, Amoako said.

"The pride and joy that you see when the parents are coming to see the end result of what their girls have created is always very heartwarming," Hammond said. Some participants have graduated and gone on to study engineering.

At the university level, students who participate in CubeSat missions can explore more complex technical and science skills such as payload design, spacecraft assembly, launch testing, and data pipeline development. They can then leverage this hands-on experience into academic or aerospace industry jobs. Postdoctoral researchers and senior graduate students gain experience mentoring newer team members and also experience a space mission's life cycle.

3UCubed has been in development for several years. After launch into low Earth orbit, the satellite will measure how particle precipitation affects the polar thermosphere and the lifetime of satellites at this altitude.



The 3UCubed satellite, shown here in an artist's rendering, is only 30 centimeters long. Credit: University of New Hampshire

To date, 68 undergraduate students and two graduate students have been part of the 3UCubed team. They have gone through all stages of mission development, Lugaz said, from concept and design reviews, to building, programming, and testing. After launch, students will be involved with collecting and analyzing data and publishing the results.

Teaching Future Teachers

TU Delft's Da Vinci CubeSat offers those same experiences and skill development opportunities to its student team members, Bagchus said, and it also provides opportunities for those who want to become STEM educators.

"The goal of the satellite is, very simply put, purely educational," Bagchus said. "We want to provide STEM education to inspire the future generation for STEM and also make them aware that space is literally all around them."

Da Vinci is planned to launch in 2027 through a partnership with the European Space Agency. The 2U CubeSat will have two educational payloads: one geared toward primary schoolers and one for secondary schoolers. The team is writing and testing free lesson modules for each payload so that teachers and independent learners around the world can learn from the satellite. Members of the satellite team who want to become teachers themselves are gaining experience in developing lesson plans that incorporate satellite technology.

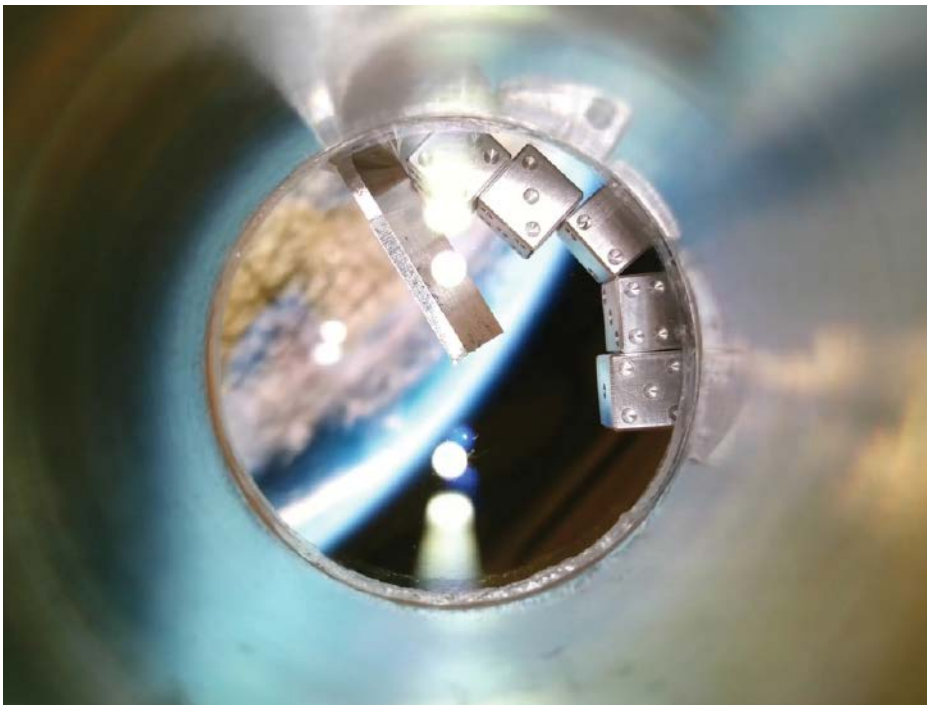
"We did a primary school competition, and we asked the students, 'What would you like to do in space?'" Bagchus explained. "And the answer was, 'I want to play in space.'"

The team designed a payload that will allow students to roll dice in space. The satellite will send them pictures and videos of the dice rolling, so they can make statistical calculations and play chance games. The design involved figuring out the technical aspects of controlling a space-based dice roll from the ground and delivering the results in a way that's accessible to primary schoolers.

The payload for secondary schoolers teaches them about how radiation in the space environment degrades digital photos when cosmic radiation strikes a pixel. One lesson plan for this payload guides students in developing computer code to restore image quality, similar to the Hamming codes used to process space telescope images—another practical lesson for students interested in space science.

The lesson plans and master classes for both modules will be available in-person and virtually.

"Not all people have the same access to education or can have their true potential



The Da Vinci CubeSat will have an educational payload tailored for primary school students that will allow them to roll dice in space. Credit: Da Vinci Satellite/TU Delft

achieved through education, because of where they were born, or maybe some personal issues they are facing," Bagchus said. The Da Vinci satellite is "a beautiful initiative to at least try to help a little bit in that aspect."

Launching into the Future

Some CubeSat prototypes are quick to develop. Others take years to complete. Case studies have found that lack of student training, time commitment constraints, and turnover from graduation can be challenges to CubeSat programs with longer lifespans. But using prototype kits and satellite simulators as well as dedicating time to hands-on training can overcome time and training issues, and turnover can provide an opportunity to get more students involved.

"You don't find this in your everyday secondary school or even in university," Hammond said. The long-term influence of a CubeSat on its student team members might not be immediately clear, she said, "but I believe in a couple of years, it will definitely influence their thinking into why they chose a career in STEM or not."

Phyllides, who joined 3UCubed last year, said she got involved with the program through a friend and had no experience with satellites when she started. Now, after more than a year calibrating the onboard instruments and analyzing test data, she's eagerly awaiting the satellite's launch.

"I want to see if the code that I've been writing will work and actually show our data," she said. She hopes to analyze 3UCubed data as part of her senior project. "That would be like a huge, huge goal of mine."

Last year, she presented on the 3UCubed mission at AGU's annual meeting and found networking with other students involved with space missions to be a valuable experience. She's still figuring out what she wants to do after graduation, but her work with 3UCubed has expanded her horizons.

"It's really, really awesome," she said. "I'm very, very lucky."

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These antennas at the High-frequency Active Auroral Research Program (HAARP) facility in Alaska send powerful radio signals into Earth's ionosphere so that scientists can learn more about it. Credit: UAF Geophysical Institute

Nudging Earth's Ionosphere Helps Scientists Learn More About It

Between 50 and 1,000 kilometers above our heads is the ionosphere, a layer of Earth's upper atmosphere consisting of charged particles: ions (atoms that have gained or lost a negatively charged electron) and loose electrons. The ionosphere alters the path of electromagnetic waves that travel through it, including radio and GPS signals, so studying it is helpful for understanding communication and navigation systems.

One way to study the ionosphere is to "nudge" it with powerful radio waves sent from the ground to see how it reacts. Where the waves hit the ionosphere, they temporarily heat it, changing the density of charged particles into irregular patterns that can be detected from the way they scatter radio signals. By studying these irregularities, known as artificial periodic inhomogeneities (APIs), scientists can learn more about the ionosphere's composition and behavior.

However, factors such as space weather and solar activity can inhibit both the formation and detection of APIs. *La Rosa and Hysell* sought to enhance the reliability and utility of the API research technique by examining API formation in all three main regions of the ionosphere, the *D*, *E*, and *F* regions. Past studies focused on API formation only in the *E* region.

To do so, the researchers revisited data from an experiment conducted in April 2014 at the High-frequency Active Auroral Research Program (HAARP) facility in Alaska. HAARP's radio transmitters created small perturbations in the ionosphere, and the facility's receivers captured the resulting scattered radio signals.

Initial analysis of the 2014 data revealed some APIs in the *E* region, but this team of researchers reprocessed the data at higher resolution. This reanalysis allowed them to document, for the first time, simultaneous APIs across all three regions, all triggered by a single radio nudge.

API formation in each of the three regions is dictated by a different set of mechanisms, including chemical interactions, heating effects, and forces that change the density of charged particles; this variability has made it difficult to develop a stand-alone model of API formation across the ionosphere.

To address that challenge, the researchers extended a model previously created to capture API formation in the *E* region by incorporating the relevant mechanisms for the *D* and *F* regions. In simulation tests, the model successfully reproduced the behavior observed in all three regions. This model could help deepen understanding of the physics at play in the ionosphere. (*Radio Science*, https://doi.org/10.1029/2025RS008226, 2025) **—Sarah Stanley,** *Science Writer*

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Coherent, Not Chaotic, Migration in the Brahmaputra-Jamuna River

Compared with single-channel meandering rivers, multichannel braided rivers are more often found in environments with sparse vegetation and coarse, shifting bars of sediment. Past research has called the way in which the paths of braided rivers shift over time "chaotic" because their migration depends on many factors, including river shape and changing water levels.

Because the migration of individual channel threads can affect the likelihood of hazards like flooding or erosion, understanding this migration is critical to protecting the residents, structures, and ecosystems surrounding these complicated waterways.

Li and Limaye examined a 180-kilometer length of the Brahmaputra-Jamuna River in Bangladesh, whose channels have been well resolved through satellite imagery.

Scientists—and many of the 600,000 people living on the islands among the channels—already know that the river's water levels are high during the summer monsoon season and low but consistent from January to March. But the researchers used a statistical method called dynamic time warping to map long-term changes in the river channels' sizes, shapes, and routes between 2001 and 2021. The technique allowed them to calculate how much and how quickly the centerlines of channel threads shifted. They then applied an existing model developed for meandering rivers to see whether it could also predict the movement of braided channel threads.

The research team found that the movements of the Brahmaputra-Jamuna River were more predictable than previously realized. About 43% of the channels moved gradually, rather than abruptly, during the study period. On average, these channel threads migrated more quickly than most meandering rivers, at a rate of about 30% of their width per year. In some cases, the rate of this migration was closely related to the curvature of the channel thread, and across the board, it was weakly related to channel thread width.

These findings have important implications for future research on braided river channels, the authors say. Knowing that at least some channel threads migrate coherently might inform erosion and flooding mitigation efforts for braided river regions, especially those in densely populated areas. (*Journal of Geophysical Research: Earth Surface*, https://doi.org/10.1029/2024JF008196,2025)

—Rebecca Owen, *Science Writer*

Part of the Brahmaputra River in Northeast India is seen in this photo taken from space in May 2020. Credit: ISS Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit, Johnson Space Center

Bubbles have a big impact on how much carbon dioxide gets dissolved in ocean water or released into the atmosphere. Credit: Allan LEONARD/Flickr, CC BY-NC 2.0 (bit.ly/ccbync2-0)

More Bubbles Means More Variation in Ocean Carbon Storage

The ocean absorbs carbon from the atmosphere, but exactly how much is uncertain. Estimates from the 2023 Global Carbon Budget ranged from 2.2 billion to 4 billion metric tons of carbon per year. One source of uncertainty may be that the effects of bubbles have not been incorporated into air–sea carbon flux estimates, according to *Rustogi et al.*

When waves break, they create multitudes of tiny bubbles that carry gases such as carbon dioxide back and forth between the atmosphere and the water. Models used to evaluate how fast this exchange occurs typically rely on measurements of wind speed, assuming that wind speed directly relates to the prevalence of bubble-forming waves. However, waves can be affected by other factors as well, meaning that this assumption doesn't always hold.

To assess the role of bubbles in air–sea carbon exchange in more detail, scientists applied a recently developed "bubble-mediated gas transfer theory" to the ocean. As with other models, the bubble-mediated approach incorporates wind strength, but it is unique in also accounting for wave conditions that form gas-carrying bubbles.

The researchers compared the results from their new model with those from a simpler, wind-only model that ignores the effect of bubbles. The two models yielded similar estimates for total annual ocean carbon storage, but the bubble-mediated model showed much higher variability, both seasonally and regionally; in some instances, local fluxes differed by 20%–50% from the wind-only model.

The bubble-mediated model also suggested that intense wave activity in the Southern Hemisphere leads to much higher carbon storage than in the relatively calm Northern Hemisphere—a difference that's not obvious in the wind-only model. That north–south difference could have implications for interpreting and projecting carbon cycle dynamics in a changing climate. With average wind speeds and wave heights likely to increase with global warming, it is essential to anticipate accurately how these changes will influence ocean carbon storage, the authors say.

The work is also important for marine carbon dioxide removal projects aiming to enhance carbon uptake to mitigate climate change effects, they note. A prerequisite for these efforts is quantifying how much carbon the ocean takes up naturally. Without a comprehensive understanding of the processes affecting uptake, the impacts of such interventions may be vastly under- or overestimated. (*Global Biogeochemical Cycles*, https://doi.org/10.1029/2024GB008382, 2025) **—Saima May Sidik,** *Science Writer*

Orbiter Pair Expands View of Mars's Ionosphere

Like Earth, Mars is surrounded by an ionosphere—the part of its upper atmosphere where radiation from the Sun knocks electrons off of atoms and molecules, creating charged particles. Mars's ionosphere is complex and changes continuously over the course of the day, but its role in atmospheric dynamics and effect on radio communication signals means understanding it is key for Mars exploration.

One way to study Mars's ionosphere is with radio occultation, in which a spacecraft orbiting Mars sends a radio signal to a receiver on Earth. When it skims across the ionosphere, the signal bends slightly. Researchers can measure this refraction to learn about Martian ionospheric properties such as electron density and temperature. However, the relative positions of Mars, Earth, and the Sun mean conventional radio occultation cannot measure the middle of the Martian day.

Now, *Parrott et al.* deepen our understanding of Mars's ionosphere using an approach called mutual radio occultation, in which the radio signal is sent not from an orbiter to Earth but between two Mars orbiters. As one orbiter rises or sets behind Mars from the other's perspective, the signal passes through the ionosphere and refracts according to the ionosphere's properties.

The researchers analyzed 71 mutual radio occultation measurements between two European Space Agency satellites orbiting Mars: Mars Express and the ExoMars Trace Gas Orbiter. Thirty-five of these measurements were taken closer to midday than was ever previously achievable, in effect allowing scientists to see a new part of the ionosphere.

The new data enabled the research team to calculate how the ionosphere's electron density changes throughout the day. They were also able to learn more about how the altitudes of the upper and lower layers of the ionosphere—called M2 and M1, respectively—vary daily. The new data suggest that the peak electron density of the M2 layer changes less dramatically during the day than has been suggested by prior research. The data also show that the M1 does, indeed, still exist during the midday, contradicting previous assumptions.

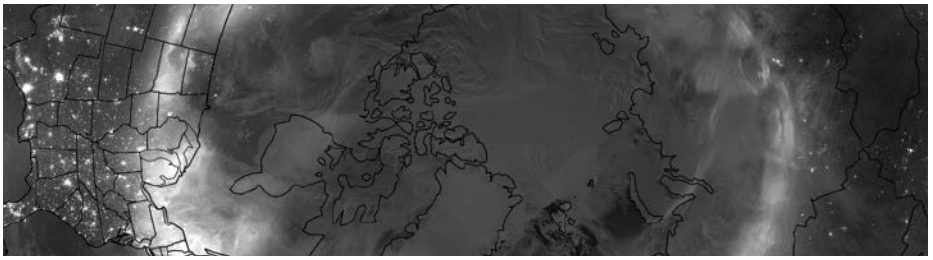
The researchers also used the new data to calculate ionospheric temperatures. They found that instead of being hottest at midday, temperatures in the ionosphere rise as the Sun reaches Martian sunset. Simulations using a Mars climate model suggest that it is likely winds transporting air, rather than the Sun's direct heat, that control these temperature dynamics. (*Journal of Geophysical Research: Planets*, https://doi.org/10.1029/2024JE008854, 2025) **—Sarah Stanley,** *Science Writer*

U.K. Space Weather Prediction System Goes Operational

The impacts of space weather such as extreme solar winds and magnetic waves are not limited to outer space. Bursts of plasma emanating from the Sun, for instance, can temporarily intensify electric and magnetic fields on the ground when they arrive at Earth's surface, causing geomagnetically induced currents (GICs) to flow into infrastructure such as power lines, pipelines, and railways. GICs can cause widespread equipment failures, leading to blackouts and safety concerns.

To improve monitoring, modeling, and forecasting of GICs in the United Kingdom, *Beggan et al.* developed a set of 14 models that better predict space weather hazards and track them in real time, allowing scientists and forecasters to warn operators of critical infrastructure. They also installed three new variometers to measure magnetic field changes at locations across the country. The work was a part of the United Kingdom's Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) program called SWIMMR Activities in Ground Effects, or SAGE.

The SAGE system can estimate changes in the subsurface electric field during geomagnetic storms, then calculate the size of GICs flowing into grounded infrastructure networks—which have known electrical resistance properties—in real time. SAGE also uses real-time data from satellites to predict the probability of magnetic substorms occurring and the magnitude of a storm at different U.K. ground observatory sites.



The northern lights cast a wide ring around Earth's North Pole in this composite view of images taken by NOAA Joint Polar Satellite System satellites during the May 2024 geomagnetic storm. Proximity of the aurorae to city lights hints at the potential effects of severe space weather on power networks. Credit: CSU/CIRA and NOAA/NESDIS

A major test of the new system occurred in early May 2024, when significant solar activity triggered the largest geomagnetic storm to hit Earth in the past 30 years. SAGE successfully provided real-time information on how the storm was affecting infrastructure. The system also provided two forecasts of GIC magnitude 30 minutes ahead of time; the real-time magnitude that SAGE later identified was between those two predictions.

More work must be done to continue improving SAGE, the authors write. For example, better monitoring of space weather conditions in space and on the ground would provide the system with more robust data on impacts, further improving its prediction capability. (*Space Weather*, https://doi.org/10.1029/ 025SW004364, 2025) **—Saima May Sidik,** *Science Writer*

What's Changed—and What Hasn't—Since the EPA's Endangerment Finding

EPA officials are reconsidering the agency's 2009 finding that greenhouse gas emissions endanger human health. Climate change caused by such emissions was a factor in the January 2025 Los Angeles wildfires, the effects of which can be seen here. Credit: James Keller

In 2003, several states and environmental groups sued the U.S. EPA for violating the Clean Air Act by not regulating emissions from new vehicles.

When the case eventually reached the Supreme Court, a group of climate scientists contributed an amicus brief—a legal document in which a third party not directly involved in the case can offer testimony—sharing data demonstrating that rising global temperatures were directly caused by human activity. This led the Supreme Court to decide that greenhouse gases constitute pollutants under the Clean Air Act and, ultimately, to the EPA's 2009 finding that greenhouse gas emissions endanger human health.

The endangerment finding became the basis for governmental regulation of greenhouse gases. Sixteen years later, the Trump administration is poised to repeal it, along with other environmental protections.

In a new commentary, *Saleska et al.*, the authors of the amicus brief, reflect on the brief and the damage the endangerment finding's repeal could cause.

Today, many of the climate scientists' concerns from the early 2000s have become reality, the authors say. Earth's 12 warmest years on record all occurred after 2009. The ocean is growing hotter and more acidic, and Arctic sea ice is retreating. Sea level rise is speeding up—from 2.1 millimeters per year between 1993 and 2003 to 4.3 millimeters per year between 2013 and 2023. Continued warming is also affecting human health. Direct heat-related deaths are on the rise, and so too are wildfires, precipitation extremes such as flooding and drought, climate-enabled spread of disease, and disruptions in agricultural productivity.

The authors also note that attribution science, the field that links specific weather events to climate change, has advanced since 2009. Today, they are even more firm in their stance that climate change poses a serious threat to society.

A reversal of the endangerment finding would require a lengthy legal process and compelling evidence that climate change does not pose a risk to human health and well-being. But the possibility of a repeal implies a worrying lack of trust in science and increasing politicization of climate issues, the authors say. If the role of climate science in policymaking is weakened, it will harm scientific progress and the national well-being of the United States, they warn. (*AGU Advances*, https://doi.org/10.1029/2025AV001808, 2025) **—Rebecca Owen,** *Science Writer*

Dear *Eos*:

The ocean around Antarctica is critical to ocean circulation, climate, and ecosystems. There, vast quantities of heat and anthropogenic carbon are drawn down from the atmosphere and stored at depth, thus moderating the rate of global climate change.

Key processes that control this drawdown occur during Antarctic winter and are governed by sea ice. But data from this time of year are still extremely sparse because of the hostile conditions that prevail then.

On our expedition in May–June 2025, we experienced the power of Antarctic winter. The photo shows the United Kingdom's polar research vessel, RRS *Sir David Attenborough*, breaking through sea ice at night and in blizzard conditions to transit between ocean sampling sites.

The skill and professionalism of the officers and crew were truly impressive and enabled the collection of a remarkable and priceless dataset.

—Michael Meredith, British Antarctic Survey, Cambridge, U.K.

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