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EOS

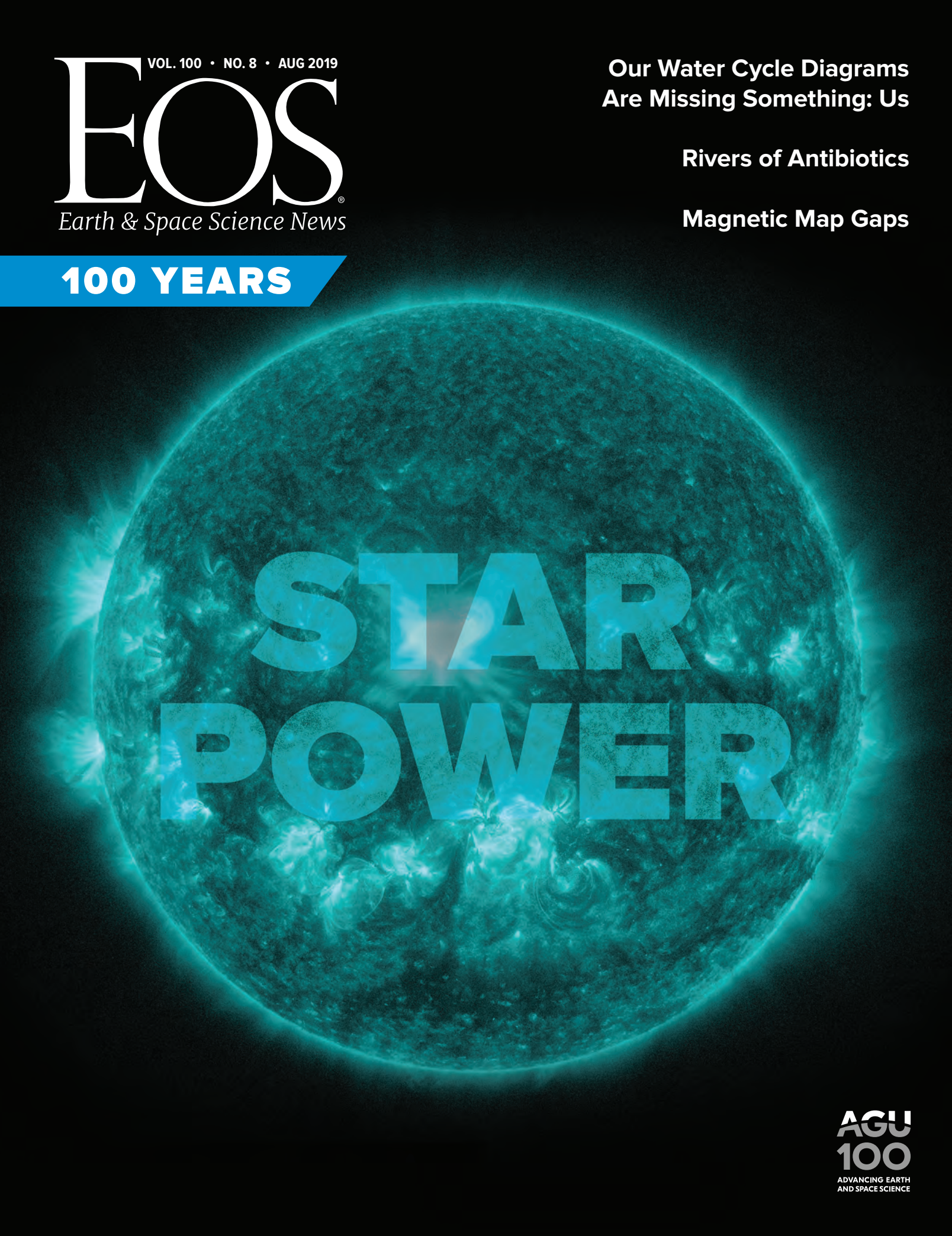
Earth & Space Science News

100 YEARS

Our Water Cycle Diagrams Are Missing Something: Us

Rivers of Antibiotics

Magnetic Map Gaps



STAR POWER

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Here Comes the Sun

One year ago this month, NASA's Parker Solar Probe launched from Cape Canaveral in Florida on a mission to the center of the solar system. Passing closer to the Sun than any mission before it, the spacecraft is now taking the first in situ measurements of the corona. Soon, we may have insight not only into the baffling coronal heating problem but also into the complex Earth–Sun relationship—the theme for this month's issue as part of our yearlong AGU Centennial celebrations.

Humans have surely been studying our closest star for as long as we could look up at the sky, though the modern era of heliophysics hit its stride in the 1950s. During the 1957–1958 International Geophysical Year (IGY), physicist James Van Allen played a key role in turning interest to the particles coming from space and interacting with our planet. He'd already been launching instruments with his University of Iowa students to study cosmic rays and probe aurorae. At the end of the IGY, an instrument package designed by Van Allen launched aboard Explorer 1, which collected data confirming the existence of the radiation belts that now carry his name, composed of charged particles carried to Earth by solar wind. (AGU awarded Van Allen its prestigious William Bowie Medal in 1977, and he later served as president of the organization from 1982 to 1984.)

In our cover story on page 18, a team of scientists show how far we've come in understanding the Earth–Sun relationship and what challenges remain. Their group studies the response of Earth's climate to solar variability, which involves an intricate statistical analysis to extract its actual effects from natural variability and anthropogenic effects. They suggest that modern analysis should use a newer observation data framework that takes into account variations at specific wavelengths, but these observations must be made from space from multiple well-calibrated instruments, making it a challenge even in an age when we can send spacecraft to make observations within spitting distance of the Sun's surface.

Solar physicists around the world are collaborating to create these data sets, as the team reports, and the result will eventually be a deeper understanding of how the Sun's variability can affect us over the long term here on Earth.

The thermosphere is particularly sensitive to this variability, and another team of scientists recently published results from a study of how infrared power from two solar cycles affected this outer layer of Earth's atmosphere (p. 42). Because this radiative energy can cause the thermosphere to change density, this relatively new field of study can provide helpful information for spacecraft, including the International Space Station, that orbit through it.

Eos reports on a particularly intriguing result on page 5, in which scientists offer evidence that planetary alignment in the solar system may be what regulates the Sun's 11-year sunspot cycle. They were able to match up, with decent regularity, sunspot minima with the alignment of Venus, Earth, and Jupiter in their orbits. Using simulations, these researchers "showed that even a weak tidal tug of 1 meter per second every 11 years forced unstable magnetic twists to pulse with that same period," and indeed, the simulation showed the solar dynamo's polarity flipping every 22 years, just as it does on the Sun.

We hope the Sun continues to shine on these studies explaining the unique give *and* take between our planet and the star it formed around over 4 billion years ago.

Heather Goss, Editor in Chief

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Christine W. McEntee, Executive Director/CEO

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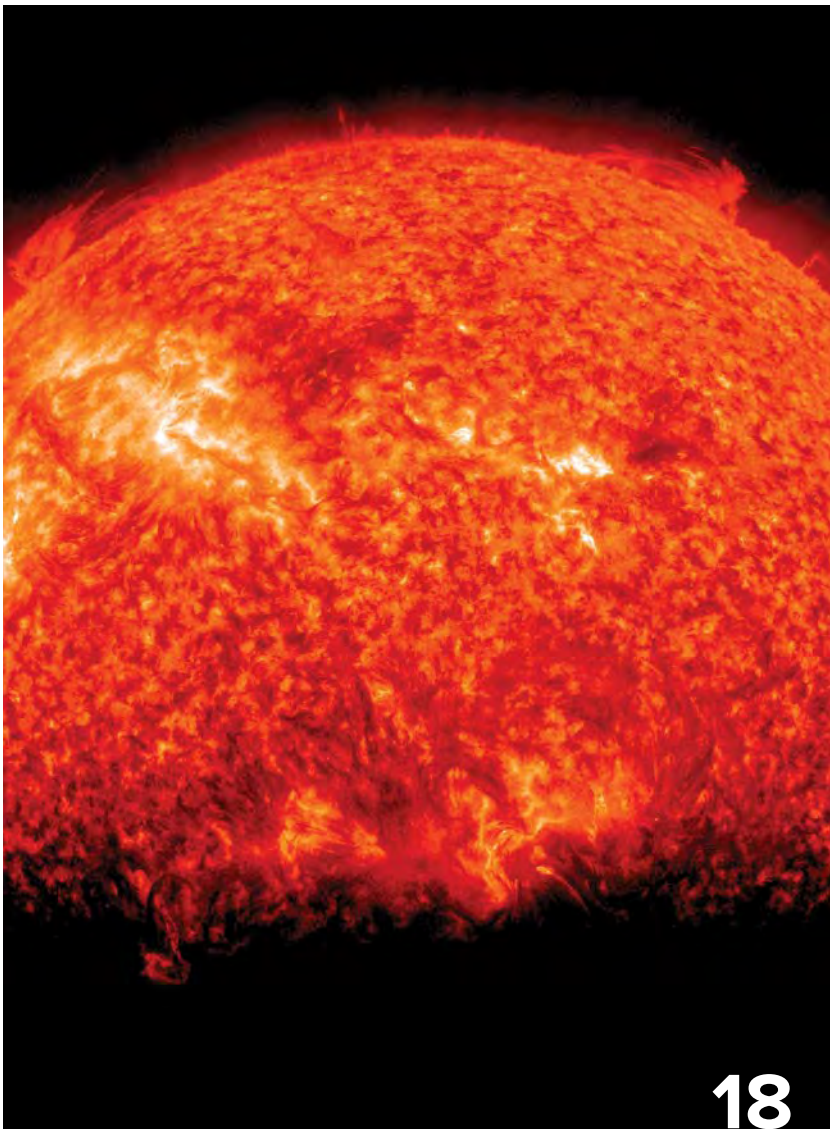
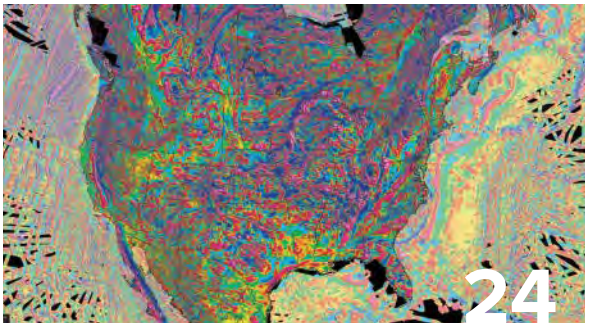
AN ENVIRONMENTALLY FRIENDLY INK SYSTEM AGRIWEB



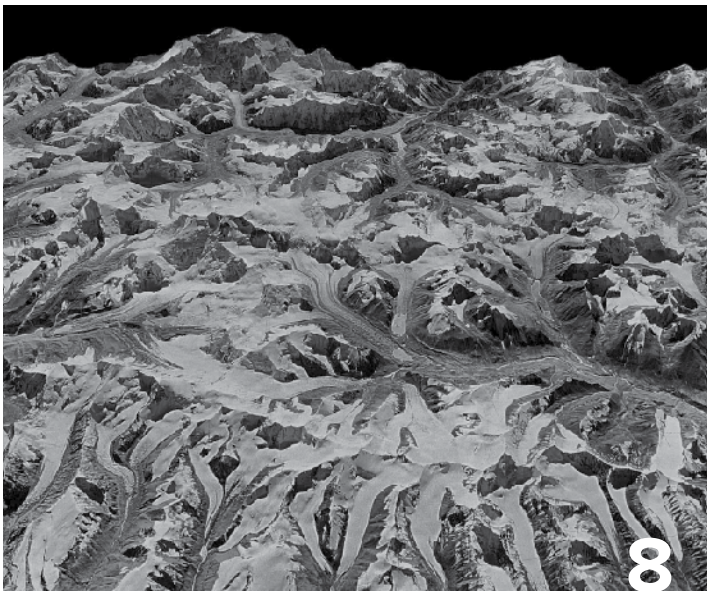


Cover Story

On the Cover

The Solar Dynamics Observatory observed this X1.6 class solar flare in 131 Angstrom wavelength light in 2014. Credit: NASA/SDO

Features



Columns

Antibiotics Are Flooding Earth's Rivers

Steam rises from garbage at the Odaw River in Ghana. Credit: Richard Marchant

In the photograph above, steam rises from a pile of garbage that sits by a river. The river is the Odaw, in Ghana, near the country's capital city of Accra, and in the photo the Odaw's water is black.

"They refer to it as a dead river," said Alistair Boxall, an environmental chemist at the University of York in the United Kingdom.

The photo was taken by ecologist Robert Marchant, also of the University of York. Marchant was at the river to take a sample of the water as part of a global campaign, led by Boxall, to study concentrations of pharmaceuticals in the world's rivers. Boxall, along with his colleague John Wilkinson, coordinated an international team that sampled rivers like the Odaw.

"We wanted to try and get a better understanding of what the levels of pharmaceuticals, including antibiotics, were around the globe," Boxall said.

> "They refer to it as a dead river."

Boxall and Wilkinson sent their collaborators a box that contained sample vials, syringes, filters, and freezer packs. The collaborators sampled 711 river locations in 72 countries and then sent their samples back to Wilkinson and Boxall for analysis.

The researchers found that 470 of those sites contained antibiotics, which come from sources including human excrement and drug manufacturing activity. Many of these antibiotics occur at concentrations above what the Antimicrobial Resistance (AMR) Industry Alliance, a group of private-sector companies that aims to address the threat of antibiotic-resistant bacteria, says is safe. Here, "safe" refers to those levels above which the alliance says that bacteria can start to develop antibiotic resistance. According to Boxall, those levels can range anywhere from 20 to 32,000 nanograms per liter of water, depending on the antibiotic.

Doctors use antibiotics to treat a raft of bacteria-caused ailments, from tuberculosis to staph infections. Some bacteria can become antibiotic-resistant when exposed to the drugs, which can make treatment next to impossible for doctors. In the United States alone, according to the Centers for Disease Control and Prevention (CDC), 23,000 people die each year from antibiotic-resistant bacterial infections.

At the Odaw, concentrations of antibiotics like metronidazole, used to treat things like skin and mouth infections, exceeded safe levels by a factor of 68. The Odaw, though, is not the worst-off river. More than 110 of the 711 sampled sites have concentrations that exceed safe levels by factors of up to 300. Rivers in Bangladesh, where concentrations hover around 40,000 nanograms per liter, are among the worst of that group.

> People who use the rivers are more likely to be exposed to the resistant bacteria.

"People are using these rivers to clean in, clean their clothes in. They're sourcing their water from those sites," said Boxall, who presented results from the campaign in June at the Canadian Chemistry Conference and Exhibition in Quebec City. This means that people who use the rivers are more likely to be exposed to the resistant bacteria.

The campaign helps address the threat that such bacteria pose by revealing the prevalence of pharmaceuticals in rivers around the world, something that should help prioritize which drugs merit the most attention when it comes to cleanup efforts.

Acquiring such data, however, would not have been possible without the global, standardized campaign conducted by Boxall and Wilkinson, according to environmental engineer Viviane Yargeau of McGill University in Canada, who was not involved in the study. "You know that you're comparing apples and apples," she said.

By **Lucas Joel,** Freelance Journalist

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EOS CENTENNIAL COLLECTION

Planetary Low Tide May Force Regular Sunspot Sync Ups

For more than 1,000 years, the number of sunspots hit a minimum within a few years of a major planetary alignment. A recent study showed that tides created by this alignment every 11 years are strong enough to tug on material near the Sun's surface and synchronize localized changes in its magnetic field.

"We noticed from historical data that there is an astonishing degree of regularity" in the sunspot cycle, Frank Stefani, lead author of the study, told *Eos*. Stefani is a fluid dynamics research fellow at Helmholtz-Zentrum Dresden-Rossendorf in Dresden, Germany. "We definitely have a clocked process," he said. "But then the question was, What is the clock?"

The study expands upon the commonly accepted model for the solar dynamo and supports a long-held theory that planetary configurations are responsible for the sunspot cycle and magnetic solar cycle.

> Other planetary systems might have tidally dominant planets that resonate with their suns, but it's not likely that we'll be able to prove it.

Wound, Twisted, and Unstable

As a giant spinning ball of plasma, the Sun's magnetic field is extremely complicated. Its magnetic field lines start as parallel lines running from the north pole to the south. But because the Sun rotates faster at its equator than at its poles, those pole-to-pole magnetic field lines slowly wind and wrap around the Sun, stretching like taffy from the middle of the line to become horizontal.

In addition to the rotational motion of solar plasma, convection moves material from the equator to the poles and back again. This twists the field lines around each other into loops and spirals.

The winding and twisting of the Sun's magnetic field lines are described by the alpha-omega dynamo model. In that model, alpha represents the twisting, and omega represents the wrapping. Tangled field lines can create instabilities in the local magnetic field and cause sunspots, flares, or mass ejections.

This model is the commonly accepted explanation for the behavior of the Sun's magnetic field, but it's not perfect, Stefani explained. It predicts that the instabilities' twistedness will oscillate randomly every few years. But the model can't explain why the number of sunspots waxes and wanes on a roughly 11-year cycle or why the Sun's magnetic field flips polarity every 22 years.

Low Tide, Low Activity

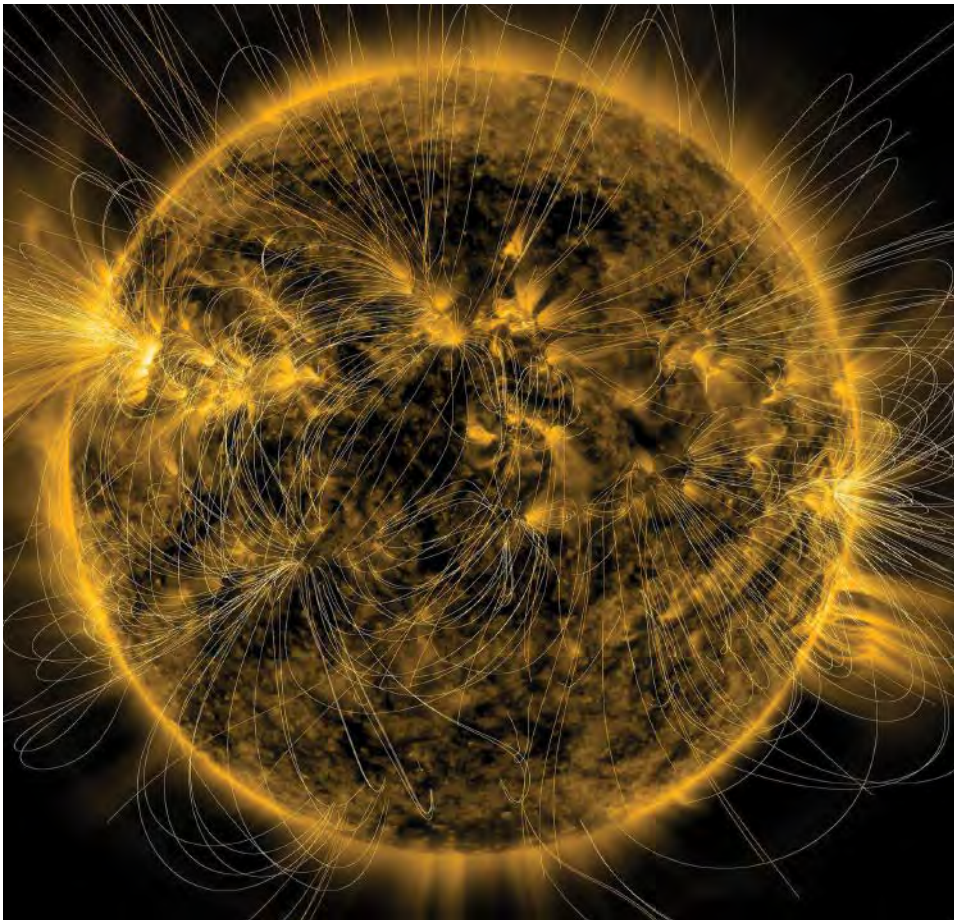
Another solar system phenomenon happens every 11 years: Venus, Earth, and Jupiter align in their orbits. These three planets have the strongest tidal effect on the Sun, the first two because of their proximity to the Sun and the third because of its mass. Past observational studies have shown that minima in the sunspot cycle have occurred within a few years of this alignment for the past 1,000 or so years.

"If you look at the trend, it has an amazing parallelism," Stefani said.

The researchers wanted to test whether the planetary alignment could influence the Sun's alpha effect and force an interplanetary low tide at regular intervals. They started with a standard alpha-omega dynamo model and added a small tidal tug to the alpha effect every 11 years to simulate the alignment.

"Our dynamo model is not a completely new one," Stefani explained. "We're really building on the old-fashioned, or conventional, alpha-omega dynamo."

The simulation showed that even a weak tidal tug of 1 meter per second every 11 years forced unstable magnetic twists to pulse with that same period. The simulated dynamo's



An ultraviolet image of the Sun from 2016 is overlaid with a map of its magnetic field lines. Credit: NASA/SDO/AIA/LMSAL

polarity oscillated with a 22-year period, just like the real solar dynamo.

"With a little bit of this periodic alpha," Stefani said, "we can indeed synchronize the dynamo period to 22 years [with] planetary forcing."

Because those magnetic instabilities are connected with solar activity, the researchers argue, this synchronization could also suppress (or generate) sunspots across the Sun at roughly the same time—in other words, the sunspot cycle. The team published these results in *Solar Physics* in late May (see bit.ly/dynamo-model).

This synchronization could suppress (or generate) sunspots across the Sun at roughly the same time.

A Counterintuitive Result?

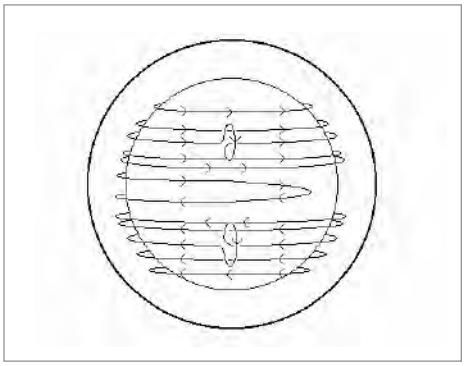
"This is an intriguing paper," said Steve Tobias, a solar dynamo researcher at the University of Leeds in the United Kingdom who was not involved with the research. Tobias argued that the combined planetary tides are too weak to directly set the length of the solar cycle—plasma dynamics deep within the Sun are the more likely cause, he told *Eos.*

Nevertheless, this study "seems to show that even a tiny amount of forcing from tidal processes can resonantly synchronize the cycle," Tobias said. "This counterintuitive result should be explored further by investigating the behavior of proxies for solar activity, such as the production rates of isotopes of beryllium deposited in ice cores."

It's possible that other planetary systems might have tidally dominant planets that resonate with their suns like ours do, Stefani said, but it's not likely that we'll be able to prove it.

For most stars, "we have observations going back about 40 years," he said. "And people are happy if they can identify two or three or four periods. Only for our Sun do we have all the historical observations. We have beryllium data. We can go back for thousands of years."

"Our Sun is quite an ordinary star, but it is quite special in that sense."



A simplified schematic of a single magnetic field line as it wraps around the Sun (the omega effect) and then twists upon itself (the alpha effect). The arrows indicate the direction that solar material moves as it drags the field line with it. Credit: NASA/MSFC

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

Senator Urges Ending Dark Money's Stifling of Climate Action

Sen. Sheldon Whitehouse (D-R.I.) was critical of dark money spending by the fossil fuel industry at a forum in June in Washington, D.C., hosted by ECU and LCV. Credit: Randy Showstack

Anonymous dark money political funding that has poisoned the U.S. political process and throttled action on climate change needs to be unmasked and stopped, Sen. Sheldon Whitehouse (D–R.I.) said at a 19 June forum in Washington, D.C.

"The fossil fuel industry's dark money has polluted our politics as badly as its carbon emissions have polluted our atmosphere and oceans," Whitehouse said at the forum hosted by the Washington, D.C.–based League of Conservation Voters (LCV) and the End Citizens United (ECU) Action Fund, a group advocating to counter the impacts of the Supreme Court's 2010 *Citizens United* decision, which led to unprecedented political spending.

Whitehouse called for continued pressure in Congress and the courts, among other measures, on the fossil fuel industry to curtail and expose the influence of dark money, which is loosely defined as anonymous political spending by organizations such as political action committees (PACs). The For the People Act of 2019 (H.R. 1), which the House of Representatives passed in March, addresses campaign spending. Companion legislation, awaiting action in the Senate, includes the DISCLOSE Act, which Whitehouse introduced to increase transparency surrounding special interest campaign contributions.

> "The fossil fuel industry's dark money has polluted our politics as badly as its carbon emissions have polluted our atmosphere and oceans."

Since the *Citizens United* decision, entities within the energy and natural resources sector have provided more than $668 million in campaign contributions, including more than $185 million in corporate PAC contributions, according to data provided by LCV and ECU that cite information from the Center for Responsive Politics, a group that tracks money in U.S. politics. Three quarters of those contributions have gone to Republican candidates, according to the information.

"Our failure in Congress to address climate change is directly connected to the secret empire of dark money that *Citizens United* launched," Whitehouse said. "Climate denial and dark money are two sides of the same coin."

EPA's Replacement of the Clean Power Plan

Other speakers at the forum also called for an end to dark money. "If we want to protect our air and our water and reduce the impact of climate change, we have to sever the ties between special interest money and candidates for office," said ECU president Tiffany Muller.

Tiernan Sittenfeld, LCV's senior vice president for government affairs, said that the 2020 elections and potential victories by environmental champions "cannot come soon enough."

"I say that on the day when the Trump administration has just pulled back the Clean Power Plan, perhaps the single biggest thing our nation has ever done to combat the climate crisis," she added. The Environmental Protection Agency (EPA) announced on 19 June its final Affordable Clean Energy rule, which replaces the plan put in place by former president Barack Obama.

Whitehouse said that the Trump administration's favoring of the fossil fuel industry goes beyond dark money. "With the Trump administration, there's something that's so kind of shameless about their operation that they really don't need to do a whole lot in terms of dark money. They just pick a fossil fuel stooge right out of the fossil fuel industry and put them in as a decision maker," he said.

EPA director Andrew Wheeler is a former coal lobbyist with the Faegre Baker Daniels consulting firm.

Whitehouse said that although environmental groups may challenge Trump administration rulings and win in court, time is not on the side of the environment. He said that if all the administration is doing is stopping action that needs to be taken to move forward on climate change efforts, "then the advantage is theirs."

"With all the delays and all the fuss on the Clean Power Plan, and the very shabby plan that was announced today, time is not our friend with climate change," Whitehouse said. "So even if they do a complete hash of a job through the administrative procedures act process and then lose in court, we're still in the situation where we've lost another 3 or 4 years where EPA could have done something useful [about climate change] if they tried."

> "Time is not our friend with climate change."

Snuffing Out Bipartisan Climate Efforts

Whitehouse said that when he got to the Senate in 2007 and for a few years afterward, there was bipartisan progress on climate change. The late senator John McCain had a strong climate position when he ran for president in 2008, and there were hopes for bipartisan legislation.

However, that bipartisan effort on climate change "all fell apart" following the Supreme Court ruling that "opened the spigots to the fossil fuel industry to flood unlimited money into our politics," Whitehouse said. "With its

Citizens United weaponry, ruthlessly, through dark money attacks and threats, the fossil fuel industry snuffed out Senate bipartisanship on climate change. Weaponization of that new unlimited dark money power by the fossil fuel industry cost us a decade of climate progress."

Whitehouse told *Eos* that he tells congressional colleagues who publicly supported climate action prior to *Citizens United* that time is running out for meaningful action on climate change.

"You will be on the right side of history" if you support climate action, Whitehouse tells colleagues. "When these fossil fuel pirates blow up, which they will—the whole thing is a big charade; it's phony as a $3 bill—you don't want to go down with them."

> "I think we can disable their dark money power structure, shame corporate America into stepping up in a way that they to this point have not, and keep enormous pressure on the fossil fuel industry."

Whitehouse said he is hopeful that the influence of dark money on climate change efforts can be turned around. He said that corporations are vulnerable to public opinion, and he pointed to polls showing that Americans are concerned about corruption in government and about the impacts of climate change.

"I think we can disable their dark money power structure, shame corporate America into stepping up in a way that they to this point have not, and keep enormous pressure on the fossil fuel industry," he said.

He remains hopeful, too, about the upcoming 2020 elections.

"The dark money problem and the fraudulent climate denial, that whole mess, is something we can attack, and that is a real vulnerability for Republicans," he told *Eos*. "I think that if we had a Democratic president and Democratic majority leader even without a filibuster-proof Senate, and a Democratic speaker, we absolutely could find a way to get a very meaningful bill passed."

By **Randy Showstack** (@RandyShowstack), Staff Writer

Spy Satellite Reveals Accelerated Pace of Himalayan Glacier Melt

Declassified images taken during the Cold War show that the thickness of Himalayan glaciers has been declining twice as fast since 2000.

A study released in June in *Science Advances* compares the thickness of 650 glaciers in the Central Himalayas over a 40-year period (bit .ly/glacier-spies). The results relied on modern methods to digitize declassified film photographs taken by U.S. spy satellites between 1973 and 1976. The analysis revealed that even over large swaths of the Himalayas, which have a range of local climates and pollution levels, scientists found a detectable link between diminishing glacial ice and warming air temperature.

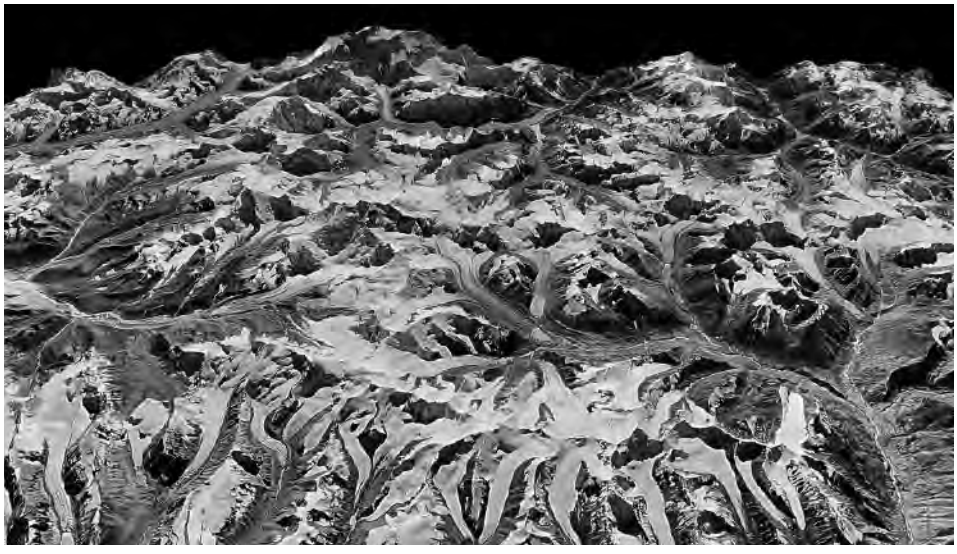
"We see the clearest picture yet of how Himalayan glaciers have responded to climate change," first author and doctoral student at Columbia University Josh Maurer told *Eos*. "As temperatures continue to rise, ice loss will continue to accelerate." He warned of drier days to come for those downstream as water stores melt away.

Tracking glacier melt in the Himalayas can be a tricky business. Unlike some glaciers that recede as they melt, like Exit Glacier in Alaska, Himalayan glaciers often keep their spatial extent but simply become thin. The glacier loses mass, dwindling in height, but the change is difficult to assess from top-down snapshots, like those available in the 20th century when air temperatures began to ramp up due to global warming.

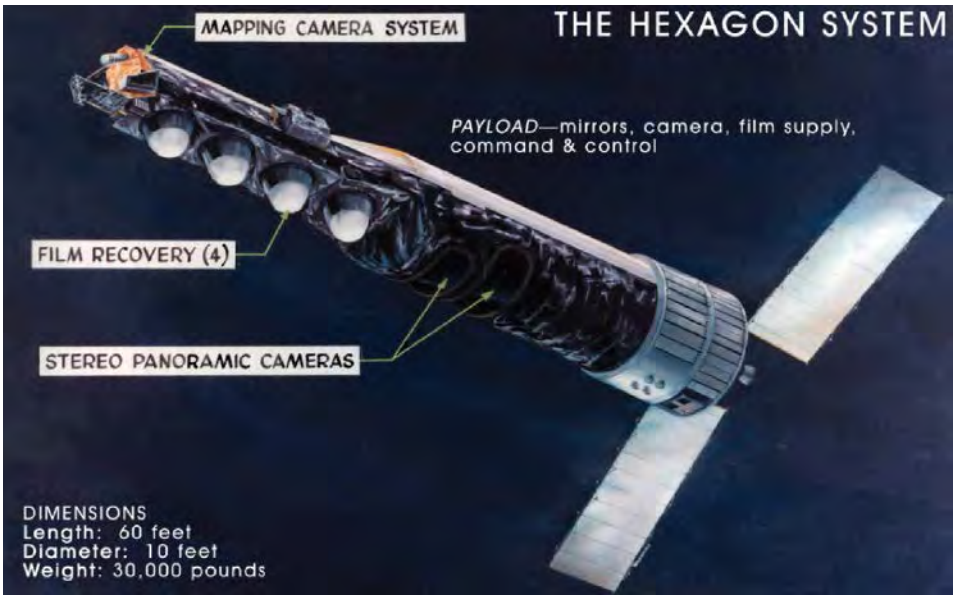
Starting in the 1950s, however, the United States designed sophisticated cameras to spy on the former Soviet Union and allied European and Asian countries. The KH-9 Hexagon spy satellite, first launched in 1971, snapped images from hundreds of kilometers above at such fine resolution that U.S. officials could count the number of launchpads at Soviet missile sites. Images from Hexagon and other spy satellites were declassified in the 2000s, giving scientists a new trove of historical data.

> "We see the clearest picture yet of how Himalayan glaciers have responded to climate change."

The declassified Hexagon images present researchers with a new angle that traditional satellite images couldn't: The spy satellite took photos that overlapped by more than 50% so that U.S. intelligence officials back in Washington could create three-dimensional



A three-dimensional view of the Himalayas was created from declassified KH-9 Hexagon photographs. Credit: Josh Maurer/LDEO



An artist's illustration outlines the KH-9 Hexagon satellite and its camera components. The satellite used nearly 100 kilometers (60 miles) of film per deployment. Credit: National Reconnaissance Office

images. Having the overlapping images allowed Maurer to extract not only the extent of the glaciers but also their volume over time.

"That third dimension is really important," Maurer explained. He created a digital elevation model for the Himalayan region using the old black-and-white film and compared it with three-dimensional images taken today.

The glaciers now have just under three quarters of their 1975 ice mass.

A Landscape Melting Away

The latest study shows the quickening pace of the Himalayan glacial melt. According to the research, the glaciers shrank by an average of a quarter of a meter between 1975 and 2000. Since 2000, however, the glaciers lost twice that amount over the same length of time.

All told, Himalayan glaciers now lose billions of tons of ice per year, Maurer said, enough to fill 3.2 million Olympic-sized swimming pools annually. The glaciers now have just under three quarters of their 1975 ice mass.

The effect wasn't isolated to just one part of the Central Himalayas. "We see a rather homogenous pattern of ice loss across a large and climatically complex region," Maurer explained.

Using measurements from weather stations in the area, the study points to global warming as the underlying cause. "The correlation we observed between rising air temperatures and acceleration of glacier melts over the past 4 decades really highlights how vulnerable these glaciers are to climate change," Maurer noted.

The 650 glaciers considered in the study contain only about half the glacial mass in the Central Himalayas. But Maurer said that the study is representative of the region, because the analysis included the largest glaciers, which have the most to lose, and spans a wide area.

Glaciologist Etienne Berthier, from the French National Centre for Scientific Research, called the paper's doubling pace of ice loss "very convincing" but also said that scientists should wait until further study to attribute ice melt to warming temperatures. "This work paves the way toward more thorough attribution studies," he told *Eos.*

Maurer plans to apply this method to other parts of High Mountain Asia, such as the Hindu Kush mountain range at the Afghan and Pakistani border. He said that the Hexagon program didn't cover just U.S. adversaries but has images worldwide.

"They were taking images wherever they could, all over the globe," Maurer said. "There are lots of images that are just sitting there in an archive waiting to be used."

By **Jenessa Duncombe** (@jrdscience), News Writing and Production Fellow

Many Water Cycle Diagrams Promote Misconceptions

Quick—name a scientific diagram you studied as a grade-schooler.

A depiction of the water cycle probably tops that list. But researchers now have shown that the majority of familiar water cycle diagrams are flawed in fundamental ways. That's bad news, because students, educators, and policy makers alike often accept water cycle diagrams as accurately representing the movement of our planet's most basic resource.

Human activity, including the introduction of nonnative vegetation like this grassy golf course outside Las Vegas, Nev., influences the water cycle in ways not depicted in most water cycle diagrams, new research suggests. Credit: Pete McBride/National Geographic Image Collection/Getty Images

Where Are the People?

This investigation of water cycle diagrams started as an academic question over lunch one day, said Benjamin Abbott, an ecosystem ecologist at Brigham Young University in Provo, Utah. How are people thinking about the Earth's big cycles like the water cycle, he and other researchers wondered? When Abbott and his colleagues started looking at a few water cycle diagrams, they realized something.

"It kind of dawned on us," said Abbott. "People are missing from almost all of these."

Abbott and his collaborators began systematically collecting water cycle diagrams. They did Internet image searches for terms such as "water cycle" and "hydro cycle," among others, and pulled up 350 diagrams from 12 countries. The researchers also mined textbooks, scientific literature, and government-published documents and recovered 114 English language diagrams of the water cycle.

In total, they amassed over 450 unique diagrams published as early as the 1940s.

The researchers then analyzed these depictions of water cycling through, on, and above the terrestrial Earth. They found that the vast majority of the diagrams—85%—failed to show any effect of humans on the water cycle.

That's unfortunate and inaccurate, said Abbott, because people have had a pronounced impact on the water cycle. Humans have changed the distribution of vegetation, for example, he said. "That's actually affecting the land-to-atmosphere flux of water and also what happens to precipitation after it falls."

> The vast majority of the diagrams failed to show any effect of humans on the water cycle.

Visual Bias

Researchers found that many of the diagrams were biased because of how they visually presented water resources, said Abbott. For instance, groundwater was often shown as extending down to the bottom of the page.

"That's kind of implying there's unlimited groundwater," Abbott said.

Over 95% of the water cycle diagrams showed temperate, forested regions despite the fact that most of the world's population lives in drier areas.

Finally, climate change and water pollution, both major contributors to water crises, were noted in only 2% of the diagrams.

"You're missing all of these realities," said Abbott. These results were published in *Nature Geoscience* (see bit.ly/water-cycle-diagrams).

A Few Suggestions

The scientists suggest that water cycle diagrams can be improved in three ways: by portraying different types of biomes, by conveying temporal changes in water cycling in different seasons, and by showing humans interacting with water.

"There's no reason why we can't integrate that into our water cycle diagrams, especially when we're using animated or interactive diagrams," said Abbott.

This is a unique study that melds human and physical aspects, said Paul Durack, an oceanographer at Lawrence Livermore National Laboratory in Livermore, Calif., not involved in the research. "How we communicate human influence and interference into the water cycle is something we could do a far better job of."

Abbott and his colleagues are currently applying for funding to put together an open-source suite of static and interactive water cycle diagrams. They plan to work with teachers and hydrologists to produce diagrams that are accurate, visually appealing, and useful to audiences ranging from students to policy makers.

"We want to effectively communicate what's going on with water and what we could be doing better to solve the global water crisis," said Abbott.

By **Katherine Kornei** (@katherinekornei), Freelance Science Journalist

North Carolina Bald Cypress Tree Is at Least 2,674 Years Old

Wired to survive in dry, wet, or even swampy soil conditions, bald cypresses are hardy, tough, and adaptable. Yet even the hardiest of these rugged, magnificent conifers can't guard against tree-killing humans.

Less than 1% of bald cypress forests have survived periods of heavy logging, according to David Stahle, a geoscientist at the University of Arkansas who uses dendrochronology, radiocarbon dating of tree samples, and other information (such as rainfall data) to reconstruct ancient climate conditions.

Like rhino populations decimated out of desire for their horns, humans have ruthlessly "hunted" almost all of the otherwise resilient bald cypress trees for their timber.

However, many bald cypresses 1,000 or more years old along southeastern North Carolina's Black River (a tributary of the Cape Fear River) have managed to escape this fate. Stahle and his collaborators now report their discovery of the oldest-known tree among those at Black River in a study published in *Environmental Research Communications* in May (bit.ly/oldest-tree). The tree is at least 2,624 years old, according to their analysis, which included tree ring chronology and radiocarbon dating of nondestructive core samples.

The bald cypress is also the oldest-known living tree species in eastern North America and the oldest-known wetland species of tree in the world, the researchers wrote.

Bald cypress trees in North Carolina's Black River have been dated to more than 2,000 years old. Credit: Danita Delimont/Gallo Images/Getty Images Plus

An Ancient Tree Could Lead to More Discoveries

"We were surprised and gratified" to discover the minimum age of this ancient tree, said Stahle, who has studied Black River bald cypresses since 1985.

When he first arrived at the Black River, Stahle was stunned by the sheer number of ancient trees found there. To find that many trees that appear to be at least 1,000 years old in one place is "pretty rare," he said.

"Dave is a pioneer in our field, particularly in the eastern U.S. and with bald cypress. His discovery of a truly ancient bald cypress is a natural trajectory of his career and his lab's efforts over the decades," Neil Pederson, a senior forest ecologist at Harvard University's Harvard Forest in Petersham, Mass., wrote in an email to *Eos*. Pederson wasn't involved with this study.

"I was pretty sure Dave and his lab would find a 2,000-year-old bald cypress. With this discovery, I [now] kind of expect that they [will] find one that is over or very close to 3,000 years old. (No pressure, Dave)," wrote Pederson.

The study also revealed that the area of old-growth Black River bald cypress is about 10 times larger than Stahle previously thought. Pederson actually considers that the most surprising finding of this study.

"It gives hope that there is more forest out there that has mostly escaped the heavy logging of the last four centuries," he wrote.

Preserving Ancient Wonders

In a 1988 study published in *Science*, Stahle shared his discovery of a Black River bald cypress that was at least 1,700 years old (bit.ly/tree-rings). This work inspired The Nature Conservancy to act.

"We began protecting land on the Black River because of Dr. Stahle's original research, which found trees dating from Roman times," Katherine Skinner, executive director of the organization's North Carolina chapter, wrote in an email to *Eos*. (The Nature Conservancy provided funding for Stahle's recent research.)

"There really is no other place like it in the world," Skinner added.

The Nature Conservancy has protected 19,000 acres (77 square kilometers) in the Black River basin. "The ancient forest is totally protected at this time, which was our top priority," Skinner wrote.

A bald cypress in the Black River, above, is the oldest-known living tree in eastern North America. Credit: Dan Griffin

A River Region Bursting with Natural Treasures

In the 1980s, Stahle primarily studied the Black River bald cypresses to learn more about the area's climate record. He continues to focus on this aspect of his research, and his team's paper extends the paleoclimate

record in the southeastern United States by 900 years.

However, Stahle's work with these trees has evolved over time to include dating individual Black River trees, especially older ones, and the conservation of the river and its floodplain.

That ecosystem is home to black bears, bobcats, river otters, rare fish species (including the Santee chub and broadtail madtom), the Cape Fear spike and other rare mussels, and neotropical songbirds, including the prothonotary warbler and the yellow-throated vireo.

Protected from Harvesting

Before The Nature Conservancy protected the ancient Black River bald cypresses, these trees were probably spared because they were too worn and weathered to attract loggers, Stahle said.

Before The Nature Conservancy protected Black River bald cypresses, the trees were probably spared because they were too worn and weathered to attract loggers.

However, it is now common to harvest trees for their biomass. "With nations labeling biomass as carbon neutral, there has been renewed logging that has been pretty destructive of the productive and rich ecosystems in the southeastern U.S.," Pederson wrote. "Ironically, one part of the green economy movement is a real threat to forests. Do not misunderstand. We need to change our economy to battle human induced climatic change [but] one early approach has become a threat to forests," he added.

Another unexpected threat? The garden mulch industry. "Recently, other cypress forests in North Carolina were logged for cypress mulch. What a tragedy it would have been to lose these trees to mulch in someone's yard," Skinner wrote.

By **Rachel Crowell** (@writesRCrowell), Science Writer

Damselfish in Distress?

Some types of damselfish, like these cinnamon clownfish, are sensitive to noise pollution caused by motorboats, according to new research. Credit Nick Hobgood, CC BY SA 3.0 (bit.ly/ccbysa3-0)

Humans are changing the face of the planet. We've had sufficient impact on the surface that scientists have proposed a new geologic age, the Anthropocene, and we're also changing the hydrosphere. In addition to toxins and plastics, the oceans are increasingly filled with human-generated noise pollution. Scientists first realized that this noise pollution affects marine mammals 3 decades ago, but new research is now highlighting its effects on species lower down on the food chain.

A study in *Marine Pollution Bulletin* looking at the effects of boat noise on the early life development of two types of damselfish found that heightened noise was associated with increased heart rates and physical changes to the fishes' bodies (bit.ly/fish-bodies). The results suggest that growing up in a noisy reef could affect the fishes' long-term survival rates.

Noise pollution in the ocean has increased fourfold since the 1950s, largely because of commercial shipping, and the effects are noticeable. Previous work has shown that noise pollution changes the behavior, communication, and movements of marine wildlife and also induces stress in fish, but there is little research to date on noise's impact on early development.

The new research looked at the development of two species of damselfish, cinnamon clownfish and spiny chromis, as they grew from embryos to hatchlings in tanks. Half of the embryos were exposed to normal levels of marine sounds, and the other half were exposed to the additional noise of motorboats. The researchers noted that the boat noise increased the fishes' heart rates by 10% in both species, which indicates that they were stressed by the noise.

After hatching, the spiny chromis exposed to boat noise were slightly larger and had bigger eyes and smaller egg yolk sacs. The fish are sustained by yolk until they're able to find their own food, so noise pollution may affect the way fish develop into adults.

In the lab, both noise groups had similar survival rates at birth, but in natural environments it is possible that increased stress makes the fish more vulnerable to predation. The differences between the two species further suggest that some fish might be more resilient to noise pollution.

"With the fish, [scientists] are just starting to touch the surface of who might be vulnerable and who are the more resilient species," said Lauren McWhinnie, a researcher at the University of Victoria in Canada who was not involved with the new study. "We've looked before with climate and acidification, seeing that there are certain species that will be more resilient to those things, but noise is quite a new factor."

By **Mara Johnson-Groh,** Freelance Science Writer and Photographer

Banned CFC Emissions Tracked to Eastern China

Atmospheric data from the Gosan monitoring station in South Korea have been used in a new study to infer a rise in emissions of CFC-11 from eastern China. Credit: Korean Meteorological Administration

In 2010, a chlorofluorocarbon known as CFC-11 was phased out of production because of its detrimental impact on Earth's protective ozone layer. But since 2013, a slowdown has been observed in the rate at which the banned substance has been declining in the atmosphere, suggesting that the foaming agent is once again being manufactured somewhere on Earth. A new study is helping to narrow down the source of the easily dispersed gas to two industrial areas in eastern China, an important step in curbing its production.

In 1987, the Montreal Protocol on Substances That Deplete the Ozone Layer was enacted in an effort to halt the production of chemicals that break down the ozone layer, which protects the planet from harmful ultraviolet rays. To date, it is the only United Nations treaty to be ratified by every country on Earth.

Last year, a study published in *Nature* (bit.ly/2018-CFC-11) showed an unexpected and persistent increase in CFC-11 emissions, starting in 2013. The paper's "findings suggested that somebody, somewhere, has started to emit CFC-11 in quite substantial quantities, on the order of 10,000 tons per year," said Matthew Rigby, an atmospheric chemist at the University of Bristol in the United Kingdom and lead author of the new study, also published in *Nature* (see bit.ly/CFC-11).

But narrowing down a point source of an easily dispersed gas is not easy, Rigby said. "The atmosphere is very diffusive. The further you get from the source, the more diffuse the signal becomes."

To help pinpoint the source of the emissions, Rigby and his colleagues turned to two atmospheric monitoring stations in South Korea and Japan run by the Advanced Global Atmospheric Gases Experiment and the Japanese National Institute for Environmental Studies.

By combining the monitoring data with models that work backward to trace how CFC-11 is dispersed through the atmosphere, the team was able to gauge that starting around 2013, an extra 7,000 tons of CFC-11 annually was coming from eastern China, particularly from in or around the provinces of Shandong and Hebei.

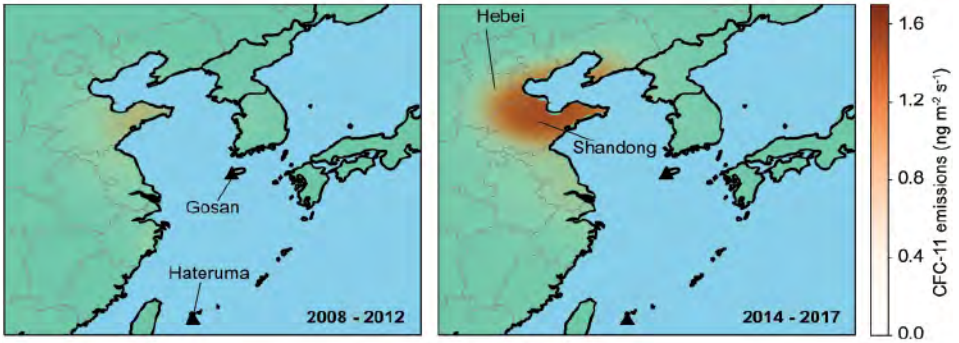
"We can't yet say if it's being emitted from one place or several in those areas," Rigby said. But the sheer magnitude of the emissions strongly suggests that the source must be new production, not the breakdown of existing materials such as through demolition of old buildings containing CFC-11 materials, he said.

Stopping the production will likely fall to Chinese authorities, said Neil Harris, an atmospheric chemist at Cranfield University in the United Kingdom who was not involved in the new study. "I think that the attention these studies is getting in the scientific community and in the media will be enough to motivate the Chinese government to regulate their factories."

The sheer magnitude of the emissions strongly suggests that the source must be new production, not the breakdown of existing materials.

Detecting the other fraction of the rogue global CFC-11 emissions will take a more comprehensive monitoring network, Rigby said. Currently, the United States, parts of Europe, and Japan have reasonably good coverage with existing networks, but "there's a huge swath of the planet we don't monitor at all," including South Asia, South America, and Africa.

"If there's one thing these two studies have shown, [it] is how absolutely crucial atmospheric monitoring measures are for the continued success of the Montreal Protocol," Rigby said. "If it [weren't] for these records, we would have no idea that new production was occurring."



Atmospheric observations show an increase in CFC-11 emissions from eastern China between 2008–2012 and 2014–2017. The emissions rise is primarily from Shandong, Hebei, and surrounding provinces. Credit: Matt Rigby and Luke Western, University of Bristol

By **Mary Caperton Morton** (@theblondecoyote), Science Writer

National Academy Can Now Expel Scientists in Cases of Misconduct

The National Academy of Sciences, established during Abraham Lincoln's presidency, has long been an exclusive circle of distinguished scientists. But membership in the institution, previously conferred for life, can now be rescinded.

Scientists who violate the organization's Code of Conduct can be stripped of their membership, the National Academy of Sciences (NAS) announced on 3 June. The change to the organization's bylaws was approved after its thousands of members were polled, and the result was overwhelmingly in support of the amendment.

Membership as a "Major Award"

Scientists are elected to the National Academy of Sciences by invitation; fewer than 100 researchers are inducted annually. Members are quick to note the advantages of being part of the select group.

"It's absolutely a benefit for people who get in," said Donald Turcotte, a geophysicist at the University of California, Davis who was elected as a member in 1986. "Short of [a Nobel Prize], it's the major award that somebody can get." In Turcotte's case, he says that the honor helped him secure a faculty position.

Recently, there's been increased scrutiny over how scientific prizes and honors—like membership in the National Academy of Sciences—are awarded. That's because of growing concerns over misconduct in the sciences.

Scientific prize–granting organizations are being faced with important questions: Should a scientist's ethical conduct be considered in addition to his or her scientific prowess? Who decides the severity of the misconduct? Is there a statute of limitations?

The answers to these questions and others aren't clear. What is clear is that the effects of misconduct, including various forms of harassment, can have far-reaching, long-lasting consequences: Scientists who have been harassed have switched research fields to avoid their harassers and even left academia altogether.

> Should ethical conduct be considered in addition to scientific prowess? Who decides the severity of the misconduct? Is there a statute of limitations?

"In the Past, There Was No Way of Doing This"

Some scientific organizations have already taken a stance on this complicated issue.

In September 2017, AGU updated its ethics policy to take a much stronger position against harassment. The organization also requires that candidates for an AGU award, honor, or governance position complete a Professional Conduct Disclosure Form in which individuals must disclose whether they have been the "subject of a filed allegation, complaint, investigation, sanction or other legal, civil or institutional proceeding." Last year, AGU rescinded an award after receiving a formal ethics complaint about the prize winner.

The National Academy of Sciences, however, hasn't had any policies in place to strip scientists of their membership. "In the past, there was no way of doing this," said Turcotte.

The National Academy of Sciences has its headquarters in Washington, D.C. Credit: FYI/William Thomas

But in late April, scientists attending the 156th Annual Meeting of the National Academy of Sciences in Washington, D.C., began setting changes in motion.

At a business session on 30 April, NAS members voted to amend the organization's bylaws. The vote allowed the 17-member NAS Council to revoke the membership privileges of scientists who violated the Code of Conduct.

Citing the "substantive" nature of this amendment, however, the National Academy of Sciences decided that the vote would need to be ratified by its full membership. An email was sent to all of the organization's roughly 2,300 members asking them to cast their ballot through the NAS website.

Cathy Whitlock, an Earth scientist at Montana State University in Bozeman, voted in favor of amending the bylaws. "I'm completely supportive of the effort," said Whitlock, who was elected to the National Academy of Sciences in 2018 and is also a member of AGU. "It's bringing the NAS up to the issues that are being faced today."

The outcome of the voting, which closed on 31 May, was a resounding 84% in favor of the amendment.

"The amendment passed by a large margin," Susan Wessler, home secretary of the National Academy of Sciences, announced to members on 3 June.

Adhering to the Highest Standards of Professional Conduct

This change will potentially affect only a "very, very small number" of NAS members, but it sends a strong message, said Turcotte.

Marcia McNutt, president of the National Academy of Sciences, echoed this sentiment. "This vote is less about cleaning house and more about sending the message that the members of the National Academy of Sciences adhere to the highest standards of professional conduct and are serious about expecting that their colleagues abide by our code," McNutt told *Science*. McNutt, a marine geophysicist, was president of AGU from 2000 to 2002.

The National Academy of Sciences' decision is an important one, said Chris McEntee, AGU's chief executive officer and executive director. "We are pleased to see organizations like the National Academy of Sciences…look at updating their own codes of ethics to address serious issues of harassment, bullying, and discrimination in science."

By **Katherine Kornei** (@katherinekornei), Freelance Science Journalist

World's Oldest Meteorite Collection Found in World's Oldest Desert

One of the larger chondrites found in the Atacama Desert sits among smaller, lighter rocks and a rock hammer for scale. Credit: Jérôme Gattacceca, CEREGE

Each year, millions of meteors intersect with Earth. Most of these burn up on entering our atmosphere, but some larger space rocks survive the journey and land on Earth's surface.

A study looking at a sampling of more than 300 meteorites collected in Chile's Atacama Desert is shedding some light on the rate and variety of meteor strikes over the past 2 million years.

Meteorites can land anywhere on Earth, but those that fall in deserts and on ice sheets are more likely to be preserved and recovered, said Alexis Drouard, an astrophysicist at Aix-Marseille University in France and lead author of the study, published in *Geology* in May (bit.ly/oldest-desert).

But both locations have drawbacks: Most deserts on Earth are only a few thousand years old, and meteorites that land on ice sheets are often transported and concentrated by glacial processes, making it difficult to determine how many meteors might have fallen in a given time period, a statistic known as the meteorite flux.

"We wanted to see how the meteorite flux to Earth changed over longer timescales, over millions of years," said Drouard.

To find evidence of older meteorites in a stable environment, Drouard and his colleagues turned to a collection of over 300 meteorites found in Chile's Atacama Desert. "The Atacama is the oldest desert on Earth," Drouard said. "The Sahara was green 5,000 years ago, but the Atacama has been arid for at least 7 million years and maybe for as long as 20 million years."

The team subjected a sample of 54 rocky meteorites to cosmogenic age dating using the chlorine-36 isotope and found that the oldest samples fell to Earth between 1 million and 2 million years ago, with a mean age of 710,000 years, making this the oldest meteorite collection found to date on Earth's surface.

A systematic search of Chile's Atacama Desert turned up hundreds of meteorites, many of which date back to over 1 million years. Credit: Katherine Joy, University of Manchester

"This confirms the long-term, multimillion-year stability of the Atacama Desert surfaces and offers a unique opportunity to study the meteorite flux to Earth and meteorite weathering over the million-year timescale," the team wrote in *Geology*.

Being able to study the meteorite flux sheds some light on cosmic processes and events, such as collisions, that may produce more meteorites or change the type of debris. The team found that the flux of meteorites remained constant over a 2-million-year time span, with 222 meteorites more massive than 10 grams falling per square kilometer every million years.

"It's extremely rare to find a record like this that spans such a long, continuous chunk of time," said Philipp Heck, a meteorist at the Field Museum in Chicago who was not involved in the new study.

The team also found that the type of meteorite that fell on the Atacama changed over the time period studied. All 54 meteorites studied were ordinary chondrites, the most common type of rocky meteorite, but the collection falls into three groups: high iron (H type; 25 meteorites), low iron (L type; 26 meteorites), and low iron, low metal (LL type; 3 meteorites). The team detected a sharp increase in the proportion of H chondrites over L chondrites between 1 million and 0.5 million years ago.

"This confirms the long-term, multimillion-year stability of the Atacama Desert surfaces and offers a unique opportunity to study the meteorite flux to Earth."

"It's an interesting and important result that they found an overabundance of H chondrites between 1 million and 0.5 million years ago," Heck said. "When one type of meteorite dominates, it's most likely related to an event such as a collision that released those objects from the parent body."

For a follow-up study, Drouard's team could use cosmic ray exposure dating to determine how long the meteors traveled through space before entering Earth's atmosphere, Heck said. "This can tell us something about where they came from and the trajectory they were traveling before they intersected with the Earth."

By **Mary Caperton Morton** (@theblondecoyote), Science Writer

Stress Testing for Climate Impacts with "Synthetic Storms"

Passengers disembark from a crowded ferryboat in Khulna, Bangladesh. A recent study modeled the effects of a tropical cyclone on this industrial city by mathematically "moving" three past cyclones from other locations to Khulna. Credit: iStock.com/suc

Increased levels of greenhouse gases and the resulting warming on a global scale are expected to alter local climate- and weather-related risks [*Field et al.,* 2012]. We are seeing evidence of this already: Drought-related wildfires, slow moving hurricanes, and nuisance flooding are increasingly common events. To deal with these coming threats and challenges, scientists have investigated not only how severe these events might be but also how commonly they are likely to occur.

We propose a new strategy for providing this information: simulated stress testing for buildings and infrastructure to see how they stand up to extreme weather events. To do this, we need high-resolution climate information describing various aspects of local weather during extreme events.

This information can come from observing real-world phenomena or from simulations. Here we describe an approach that draws on both of these informational sources.

Mining Weather Forecast Archives

Archived global operational weather forecasts can complement regional climate modeling and add a new source of information to impact studies. We suggest using such archives to generate a catalog of extreme events for stress testing.

We already know from reports and real observations when and where extreme events have taken place and what consequences they have had for various locations. Archived global forecasts of recent events have even higher spatial resolution than for typical regional climate simulations. For example, archives from the European Centre for Medium-Range Weather Forecasts (ECMWF) provide forecasts with about 16-kilometer resolution, compared with 50-kilometer resolution from the Coordinated Regional Downscaling Experiment (CORDEX) [*Gutowski et al.,* 2016]. Recent global operational forecasts also have a higher spatial resolution than the latest model reanalysis, but earlier events may have lower spatial resolution.

Climate Models and Their Limitations

Climate models simulate trends and events at a variety of scales, from global to local, but applying a chain of models to simulate events at local scale is not a trivial task. Regional climate models can provide a bridge between large and small scales; they are often used to downscale transient simulations from coarse global climate models to provide a more detailed description of the local climate change. However, global climate models may not necessarily reproduce the regional boundary conditions for extreme events, especially when their output is limited to a small set of simulations.

Climate modelers often construct simulations using multiple models, drawing on the strong points of each one. This approach is called ensemble simulation. Previous analyses of ensemble simulations show that on regional scales, because of internal climate variability, models can produce different outcomes for the same forcing, and these differences can be larger than differences in the models and in climate trends [*Benestad et al.,* 2016; *Deser et al.,* 2012]. Therefore, a small set of climate simulations provides an incomplete sampling with an inadequate description of the natural variability, which implies that this approach may not represent rare and extreme events well.

Even with perfect models and downscaling, generalizing from a small number of simulations is expected to provide misleading results (see "the law of small numbers" of *Kahneman* [2012]). On the other hand, archives of downscaled results for large ensembles would require large volumes of data, and even then, there would be no guarantee that extreme events embedded in the results would be represented with sufficient realism. For example, climate models may neglect subtle but important aspects of air-sea coupling, which may affect the simulations of storms [*Karnauskas and Zhou,* 2018]. It is also a demanding job to sift through all the climate model simulations and find interesting events because the simulated weather is not synchronized with the real world.

To address these issues, the European Union project EU-CIRCLE, an initiative that works to strengthen infrastructure resilience to climate change, came up with a series of case studies that illustrated potential effects of a changing climate on various regions around the world.

Hurricane Matthew Visits Bangladesh

One of the EU-CIRCLE case studies looked into the potential effects of tropical cyclones

on the city of Khulna in Bangladesh. This industrial city is located in an interior coastal area between the megacities of Dhaka and Kolkata. Climate change is expected to drive people away from inundated coastlines, and many of them could make their homes in Khulna. However, the city faces its own hazards from climate change: increased risk of cyclones and storm surges and the associated damage to roads, electrical utilities, water supplies, and other municipal systems.

Existing regional climate model results were insufficient to illustrate these hazards because it was difficult to find good specimens of tropical cyclones over the Bay of Bengal in the South Asia CORDEX regional climate model simulations. At present, there are few tropical cyclones in this region, and the driving global climate models may not sufficiently simulate conditions needed for cyclones to spawn. These simulations also have a spatial resolution of about 50 kilometers, which was inadequate for this case study.

As an alternative to the regional simulations, we asked, "What if a storm like X were to hit Khulna?" We chose forecasts for known tropical cyclones from different parts of the world and "displaced" them to Khulna, creating scenarios that EU-CIRCLE refers to as synthetic storms.

In this case, we selected Cyclones Nargis and Mora in the Indian Ocean (April–May 2008 and May 2017) and Hurricane Matthew in the North Atlantic/Caribbean (September–October 2016) and "moved" them to Khulna by changing the coordinates of the mean sea level pressure, 10-meter zonal and meridional wind components, and precipitation (Figure 1).

The EU-CIRCLE team met with critical infrastructure operators in Khulna in September 2017 to get input data for simulating storm impacts and then invited key stakeholders to a demonstration event in April 2018. The results showed that we could take city infrastructure information, incorporate it into our synthetic storm analysis, and visualize the effects of high winds and extreme precipitation on power distribution, roads, water supply, and the city's health and education sectors.

Scaling Past Storms to Present Conditions

Such case studies can be used as a basis to extend the concept of synthetic storms through the use of statistical techniques. These techniques analyze the ways in which a storm's intensity, size, duration, and other factors depend on the global environment.

Historical storms can also be cataloged together with information about the ambient conditions, as well as a description of the storms' consequences and damages. This makes it possible to exploit all relevant information for stress testing under new climate conditions. For example, what would be different if Hurricane Andrew had occurred in 2018 rather than 1992?

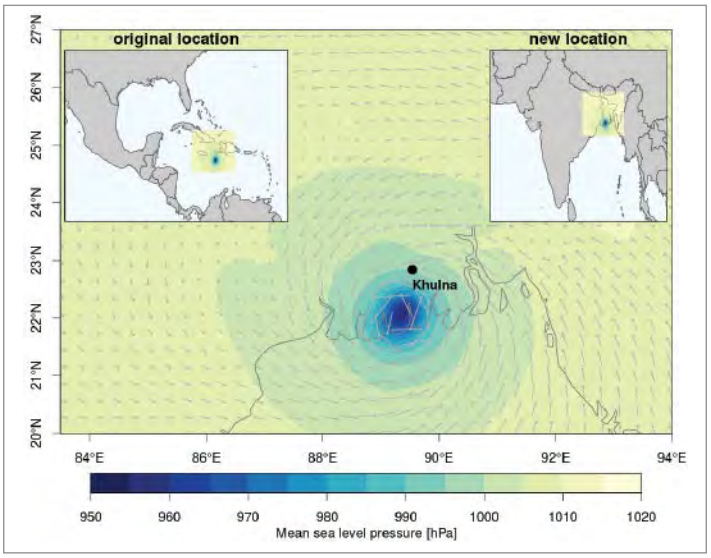


Fig. 1. Variables were taken from ECMWF operational forecasts and used for stress testing simulations for critical infrastructure in the city of Khulna in Bangladesh. In this example, Hurricane Matthew (29 September 2016, 18:00 central European summer time) has been displaced from the Gulf of Mexico 163.5° eastward and 5° northward to just offshore of Bangladesh. Conditions for sea level pressure (colors), 10-meter zonal and meridional wind components (arrows), and precipitation (not shown) were replicated in a simulation of this new location to gauge the damage that such a storm might inflict on this region.

Using the Method Effectively

The synthetic storm approach provides a wealth of information, but users must be made aware of the strengths and limitations of the technique. This method cannot be used for all types of climate change adaptation. Therefore, it is essential for users to interpret the information correctly and understand these limitations.

Synthetic storms involve a preselection of specific events. This approach differs from picking random samples, which is needed for proper statistical analysis such as return value analysis. Return value analysis indicates the typical time between events. Because extreme events occur relatively infrequently, a selection of the most extreme events represents a high, albeit unknown, return value. Because the selection is made from many locations and thus would involve multiple return values, one limitation is that it is not possible to say much about probability or return values.

There may also be a physical consistency that depends on local factors, such as topography, and it is unrealistic to move storms everywhere. However, the synthetic storm strategy may be particularly suitable for coastal cities and island states surrounded by oceans.

Despite its limitations, this "shortcut" approach can be valuable to decision makers who do not need estimates of probabilities and return values but merely a plausible estimate for storm magnitude or intensity. For instance, planning for disaster risk reduction and security often relies on perceived perils, and in this context, such stress testing may provide a valuable contribution.

Acknowledgments

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References

Benestad, R. E., et al. (2016), Climate change and projections for the Barents region: What is expected to change and what will stay the same?, *Environ. Res. Lett., 11*(5), 054017, https://doi.org/10.1088/1748-9326/11/5/054017.

Deser, C., et al. (2012), Communication of the role of natural variability in future North American climate, *Nat. Clim. Change, 2*(11), 775–779, https://doi.org/10.1038/nclimate1562.

Field, C. B., et al. (Eds.) (2012), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change,* Cambridge Univ. Press, New York, https://doi.org/10.1017/CBO9781139177245.002.

Gutowski, W. J., Jr., et al. (2016), WCRP Coordinated Regional Downscaling Experiment (CORDEX): A diagnostic MIP for CMIP6, *Geosci. Model Dev., 9*(11), 4,087–4,095, https://doi.org/10.5194/gmd-9-4087-2016.

Kahneman, D. (2012), *Thinking, Fast and Slow,* 504 pp., Penguin, London.

Karnauskas, K. B., and L. Zhou (2018), Hurricanes and the sea: It takes two to tango, *Eos, 99,* https://doi.org/10.1029/2018EO097895.

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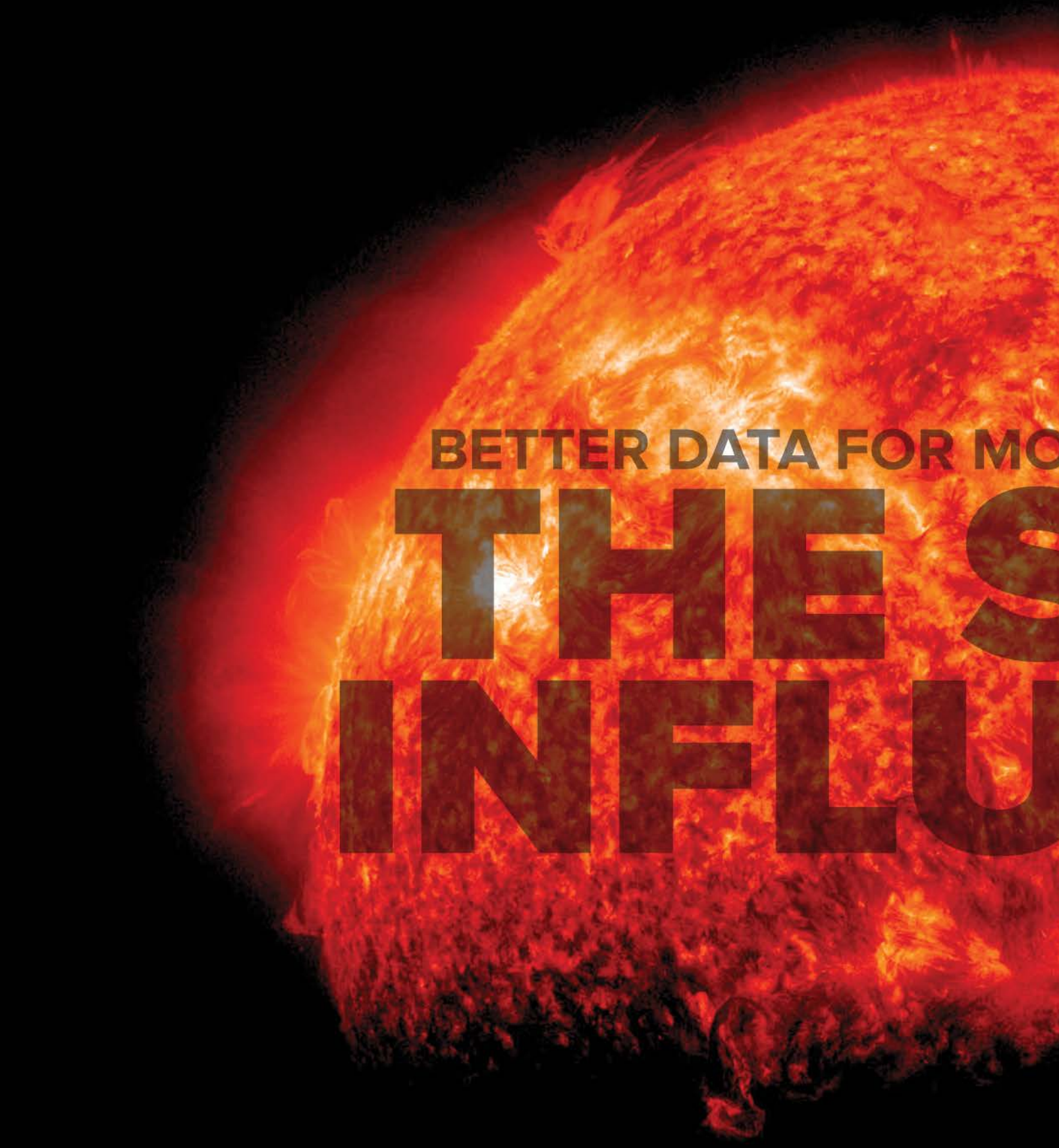

BETTER DATA FOR MO
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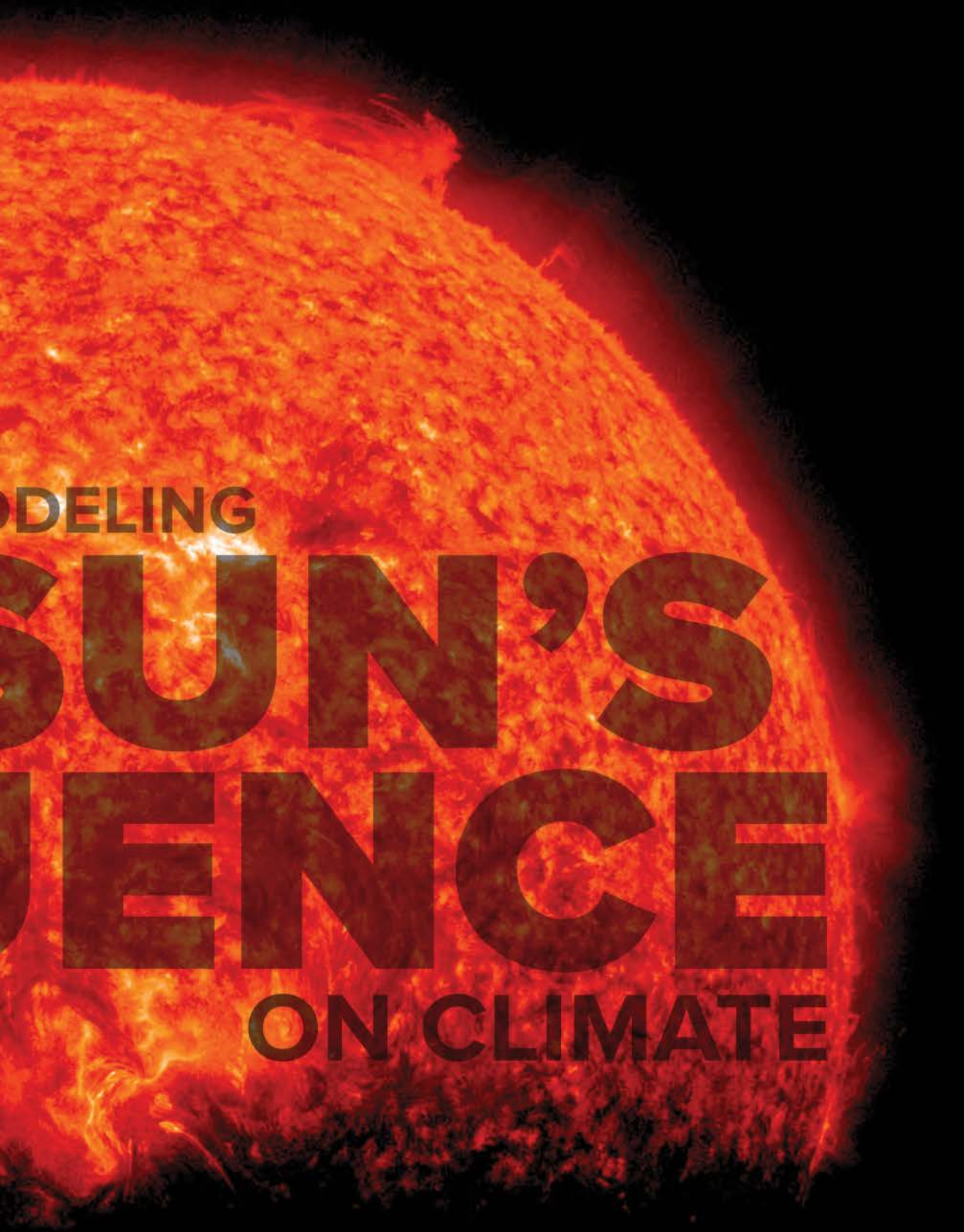
INFLU

Several international initiatives are working to stitch together data describing solar forcing of Earth's climate. Their objective is to improve understanding of climate response to solar variability.

By T. Dudok de Wit, B. Funke, M. Haberreiter, and K. Matthes



DELING SUN'S UENCE ON CLIMATE

Compared with other stars, our Sun is a remarkably steady source of light and heat, but its output does vary. Solar light, heat, and particle streams drive weather and atmospheric chemistry, but how (and by how much) does the Sun's variability affect the climate here on Earth? The role of solar variability in recent global warming is not just a bone of contention; it is also a question of overriding importance for scientific understanding of our Sun and of climate change.

Scientists simulate historical and future climates by setting up a suite of initial conditions and seeing

Earth passes in front the sun, blocking the light at the bottom of the image, in this view from NASA's Solar Dynamics Observatory. Credit: Stocktrek Images/Getty Images

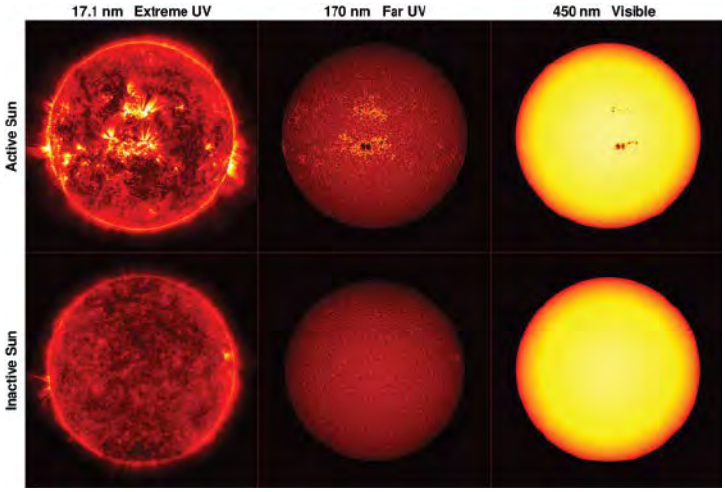
how these conditions change when various factors, called forcings, are applied. For example, how does Earth's surface temperature change if it receives more or less heat from the Sun? How do the streams of ionized particles that make up the solar wind affect certain weather patterns on Earth? Data sets compiled from historical records provide the necessary information for model forcing, so ensuring that these data sets provide accurate, relevant information is key to producing realistic climate model scenarios.

A series of initiatives brought together scientists working on different aspects of this highly multidisciplinary issue. These efforts shared several common objectives, including better estimates of solar forcing and identifying and quantifying the uncertainties in these estimates.

Here we report on the outcome of three of these initiatives:

- "Towards a more complete assessment of the impact of solar variability on the Earth's climate" (TOSCA), a project that uses a network of European scientists from 20 countries who met from 2011 to 2015 to assess contributions of solar variability to Earth's climate
- Solar Irradiance Data Exploitation (SOLID), a European-funded project dedicated to merging all exploitable spectrally resolved solar irradiance records into one single composite data set
- An international team of scientists that met at the International Space Science Institute (ISSI) to produce a comprehensive data set that includes solar radiative forcing and contributions from energetic particles

These initiatives have culminated in the production of two public data sets to assist with the scientific analysis of solar forcing: a composite data set of all irradiance observations and a comprehensive data set containing different solar forcings (radiative and by particles) since 1850.



NASA's Solar Dynamics Observatory satellite took these images of the Sun at three different wavelengths. The top row shows the Sun on 2 February 2014 during an active phase with several sunspots. The bottom row shows the Sun on 3 March 2018 during a period of low solar activity with no sunspots. The left-hand images were taken in the extreme UV wavelength region (17.1 nanometers), the center images were taken in the far UV region (170 nanometers), and the right-hand images were taken in the visible region (450 nanometers). Dark sunspots cause a small decrease in irradiance in the visible band, but they increase irradiance in the ultraviolet bands. Scientists wonder how solar activity across wavelengths influences climate. Credit: NASA

> **Careful statistical analysis is required to extract the effect of solar variability on climate from a noisy background.**

How Does Solar Variability Affect Climate?

Solar variability affects Earth's climate in many intricate and nonlinear ways. Most effects are ultimately driven and modulated by the solar magnetic field and its conspicuous solar cycle, which repeats approximately every 11 years.

The effect of solar variability on climate is mostly hidden in the natural variability of the climate system; thus, careful statistical analysis is required to extract it from a noisy background. Such analyses require records that extend over a long period of time, but the paucity of observations in existing records poses a serious challenge. For example, scientists have been making direct measurements from space of the total solar radiative input into Earth's atmosphere only since 1978, although there had been earlier attempts to measure it from the ground.

Although solar radiation represents more than 99.9% of the energy entering Earth's system, radiation is not the only means by which solar variability affects climate. Another source of variability comes from energetic particles, some of which originate from the Sun.

The most energetic particles, known as galactic cosmic rays, have an extragalactic origin; their role in cloud formation has attracted strong media attention. However, recent experiments at the European Organization for Nuclear Research (CERN) suggest that these cosmic rays have a limited impact on the microphysics of clouds. Energetic protons produced during solar flares and energetic electrons that originate from the Earth's magnetosphere have received much less attention, yet they may play a role by contributing to catalytic ozone loss in the polar atmosphere [*Andersson et al.*, 2014]. Such ozone depletion primarily affects the upper layers of the atmosphere (60–80 kilometers), but eventually it affects the lower layers and climate as well.

For many years, a single quantity, total solar irradiance (TSI), which describes the total solar radiated power incident on Earth's upper atmosphere, was used to summarize the solar contribution to climate models, neglecting other contributions. The assumption was that solar radiation would mainly act on Earth's environment by directly heating the oceans, continents, and lower atmosphere.

The discovery of the effects of radiation in the ultraviolet (UV) wavelength band shattered this simple picture. Researchers have shown that UV radiation affects climate through direct heating and the production and destruction of ozone in the stratosphere, which then leads to regional

An aurora observed from the International Space Station in September 2014. Such aurorae are produced by energetic electrons that penetrate Earth's atmosphere after a perturbation of the solar wind has occurred. They are brightest between altitudes of 90 and 150 kilometers, which is where most of the electrons are absorbed. In comparison, most of the UV radiation is absorbed at lower altitudes, in the stratosphere. That layer approximately corresponds to the thin blue layer observed at the horizon. Solar variability drives aurorae as well as variations of UV radiation. These affect Earth's environment in different ways, through a complex chain of mechanisms. Understanding these mechanisms is crucial to quantifying their long-term impact on climate. Credit: ESA, CC BY-SA 3.0 IGO (bit.ly/ccbysa3-0)

effects at Earth's surface through a complex chain of mechanisms. All these effects, however, are found to have a minor impact on climate in comparison with recent anthropogenic global warming.

Splitting Up the Spectrum

Although the TSI is a key ingredient in Earth's global energy budget, the spectrally resolved solar irradiance (SSI) provides much deeper insight into the impact of solar variability on the atmosphere. Unlike TSI, which integrates the contribution from all spectral bands (UV, visible, infrared) into one single quantity, SSI reveals variations at specific wavelengths, each of which affects Earth's environment in a different way.

Unfortunately, the record of SSI observations is fragmented in time and in wavelength, even more so than TSI observations.

Making accurate SSI observations is a real challenge: SSI measurements must be carried out from space to capture radiation that would otherwise be partly absorbed by Earth's atmosphere. However, instruments degrade in the harsh environment of space, leaving researchers with large uncertainties in the data.

On the few occasions when several instruments measured the SSI simultaneously, their observations often disagreed, which highlights the importance of calibrating the instruments and having several of them that operate simultaneously. For example, NASA's Solar Radiation and Climate Experiment (SORCE) mission, which started operating in 2003, reported an unusually large solar cycle variability in the UV. This variation remains hotly debated because most wavelengths are monitored only by SORCE, with no alternative observations.

Difficulties like these have been a major impediment to a more systematic scientific exploitation of SSI observations, and they remain the prime reason for the large uncertainties in the long-term evolution of solar radiative forcing.

The TOSCA Handbook

To help overcome these difficulties, TOSCA produced a handbook that summarizes our present understanding of these different processes by which solar variability may affect climate [*Lilensten et al.,* 2016]. This handbook was the main outcome of TOSCA, a pan-European COST Action (Cooperation in Science and Technology) network of scientists devoted to that question. It addresses the assumptions, the data, the models, and the unknowns behind the numerous mechanisms by which solar variability may impact climate variability.

Solar Data Sets

Coinciding with the publication of the TOSCA handbook, scientists produced a data set describing solar forcing through SOLID, a European-funded project with worldwide contributions, which aimed at merging all exploitable SSI records into one single composite data set.

This merged data set, which has recently been made public, covers the period from 1978 to the present [*Haberreiter et al.,* 2017]; it includes data for the UV, visible, and

near-infrared bands. To guarantee transparency and traceability, a statistical procedure was developed to merge the original measurements from 20 instruments and also to produce data-driven estimates of their uncertainties.

SOLID's observational composite is a major first step toward improved versions, and we are now awaiting community feedback to determine whether corrections should be applied and what they should be. One of the lessons we learned from this exercise is the importance of separating the methodological problem (What is the best way of constructing the composite?) from the scientific one (What prior information goes into the correction of the original data sets?).

In addition, a new community-driven reference composite for TSI only is also expected soon. This new TSI composite should replace three existing ones whose differing trends have fueled fierce debates.

Elusive Long-Term Irradiance Variations

Because SSI observations really took off only in the late 1990s, we still lack the necessary hindsight to properly assess the impact of solar variability on climate: Longer records are needed. Today we must rely on SSI records produced by models that rely on solar proxies such as the sunspot number and cosmogenic isotopes such as carbon-14.

Several empirical and semiempirical models have been developed for that purpose, and most match the observations well. That is, they reproduce recent observations well over the short period on which they have been trained, typically one or a few decades.

How accurately these models reproduce SSI before direct observations started remains a major open question. All these models assume that the present relationship between SSI and solar proxies holds for past variations. The recent and unusually long period of low solar activity that took place in 2008–2009, however, challenges our ability to reconstruct solar activity from proxies.

A Comprehensive Data Set on Solar Forcing

To overcome challenges with solar irradiance models, scientists need to piece together a record longer than the past few decades. An international team of scientists, challenged by the fragmentation of historical solar forcing data, met at ISSI to produce another comprehensive data set for direct use by climate modelers, who require long-term reconstructions.

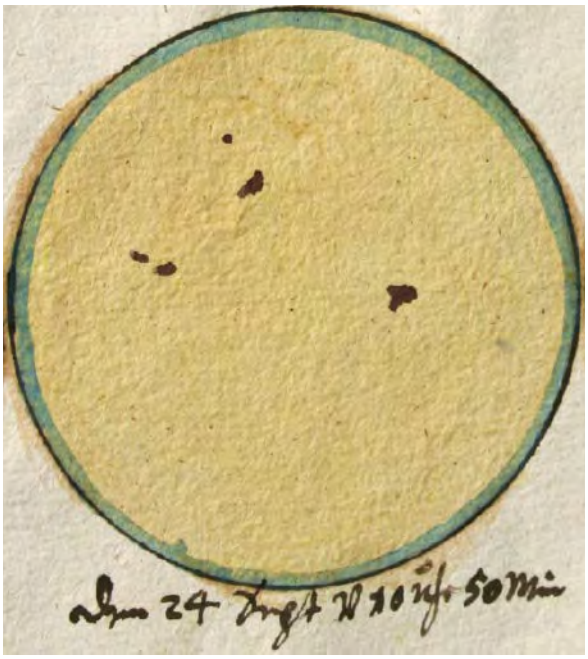
This data set, which runs from 1850 to 2015, includes solar radiative forcing using TSI and SSI reconstructions. It is the first to incorporate contributions from energetic particles such as magnetospheric electrons, solar protons, and galactic cosmic rays. Here, too, we welcome community feedback for improving future versions. The data set comes with recommendations on solar-induced ozone variations that are consistent with these solar forcing data, and it has been recommended for the current Coupled Model Intercomparison Project Phase 6 (CMIP6) initiative [*Matthes et al.*, 2017].

Moving Ahead

What is now the way forward? Clearly, improving our understanding of the physical mechanisms on the Sun that drive irradiance variations, particularly those that may lead to long-term climate variations, should be a priority. Several teams are actively working on this issue.

We are still missing an international framework that enables a critical comparison of irradiance models with the aim of improving them. The highest priority, however, is to continue simultaneous total and spectral irradiance observations by different instruments. Our ultimate aim is to quantify more precisely the role of the Sun in the natural forcing of climate variability and climate change.

In short, the Sun still has a lot to tell us.



Sunspot drawing made by J. C. Staudach on 24 September 1762. Such historical archives are precious evidence of past solar activity, which helps us better constrain how solar activity and output vary over the long term. However, quantifying the level of activity from such drawings is a major challenge. Other proxies of past solar activity, such as carbon-14, provide more accurate reconstructions on decadal to millennial timescales. Credit: R. Arlt, Leibniz Institute for Astrophysics, Potsdam, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

References

Andersson, M. E., et al. (2014), Missing driver in the Sun–Earth connection from energetic electron precipitation impacts mesospheric ozone, *Nat. Commun., 5,* 5197, https://doi.org/10.1038/ncomms6197.

Haberreiter, M., et al. (2017), A new observational solar irradiance composite, *J. Geophys. Res., Space Phys., 122,* 5,910–5,930, https://doi.org/10.1002/2016JA023492.

Lilensten, J., T. Dudok de Wit, and K. Matthes (Eds.) (2016), *Earth's Climate Response to a Changing Sun,* EDP Sci., Paris, http://www.cost.eu/media/publications/Earth-s-climate-response-to-a-changing-Sun.

Matthes, K., et al. (2017), Solar forcing for CMIP6 (v3.2), *Geosci. Model Dev., 10,* 2,247–2,302, https://doi.org/10.5194/gmd-10-2247-2017.

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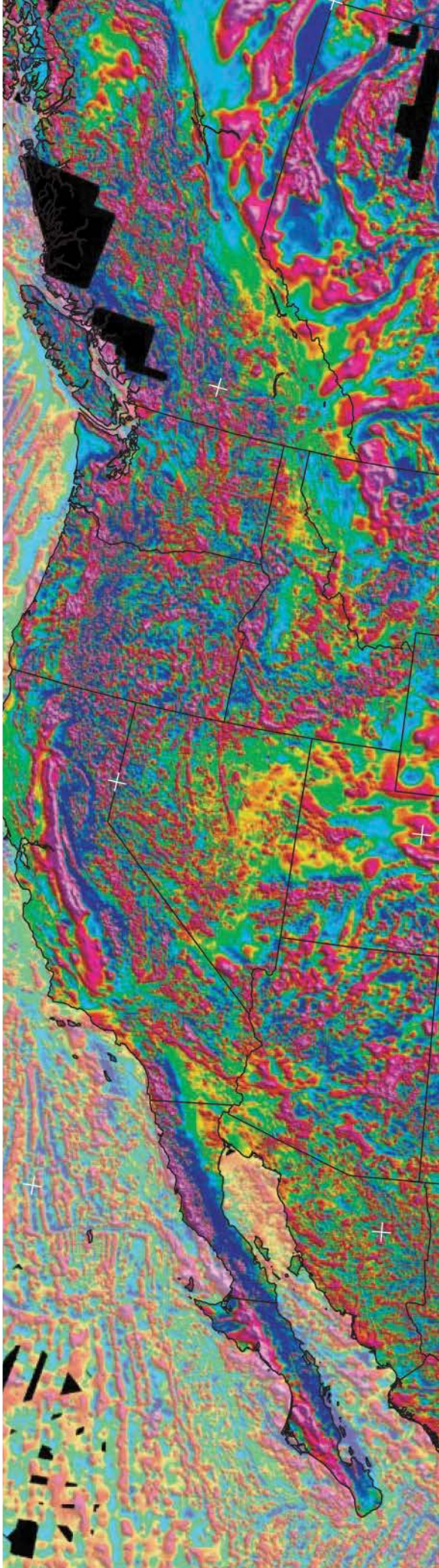
FINDING THE GAPS IN AMERICA'S MAGNETIC MAPS

By Benjamin J. Drenth and V. J. S. Grauch

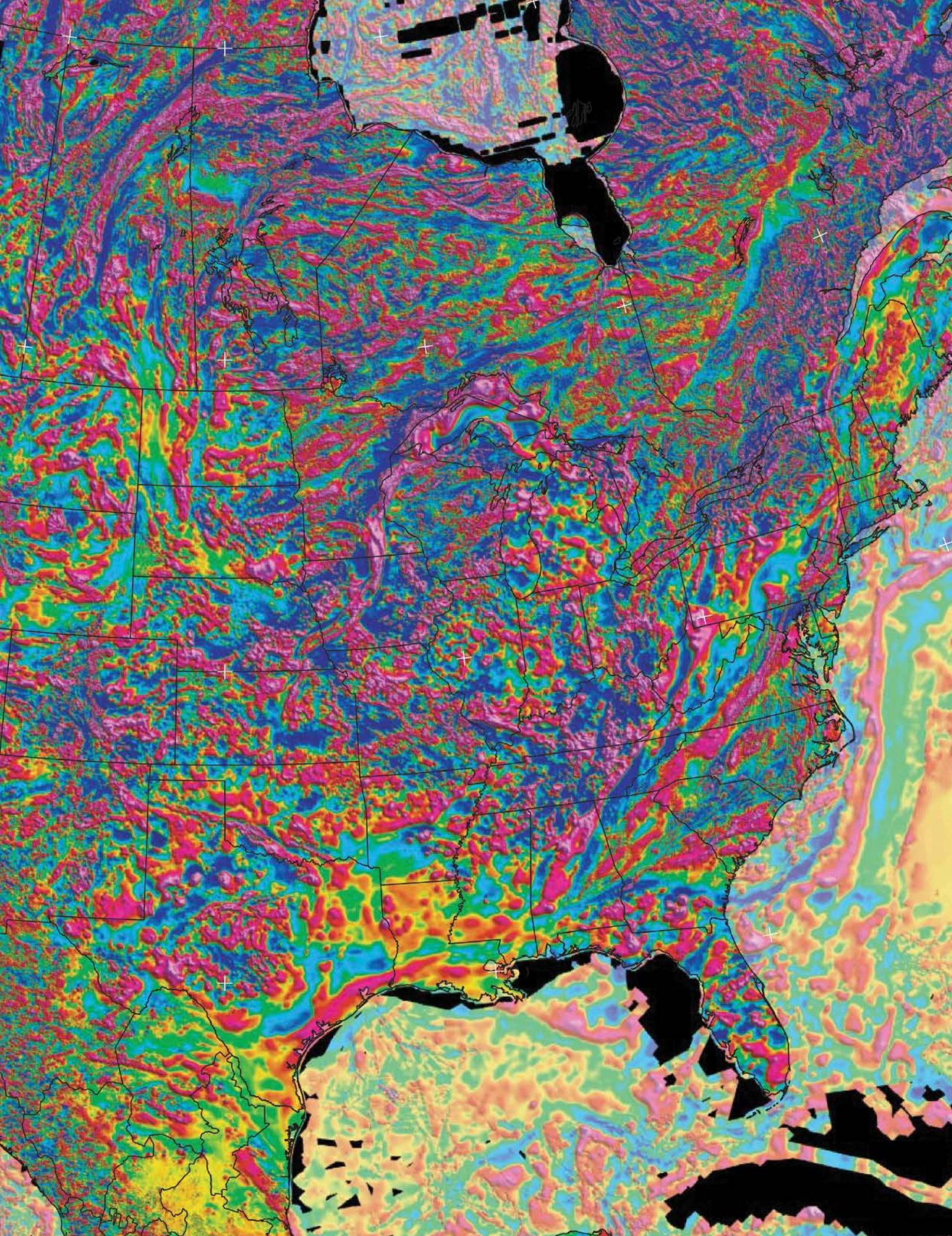
A 2017 executive order mandated a plan to evaluate U.S. access to critical mineral resources, but the airborne magnetic survey maps that support this effort are sadly out of date.

A helicopter flies back and forth over the high desert, tracing small fluctuations in Earth's magnetic field with a magnetometer at the end of its wandlike "stinger" attachment and marking the locations with GPS coordinates. Later, scientists scour the magnetic field data for clues to mineral and petroleum deposits, faults, buried lava flows, water resources, and even pipelines and landfills buried beneath the surface of the ground. When the area was first surveyed 40 years ago, data processors recorded approximate locations and drew contour lines on a paper map. This time, using modern best practices, the details can come into focus.

Aeromagnetic surveys measure the intensity of Earth's natural magnetic field. From these surveys, we construct maps representing variations of magnetic rock properties and two- and three-dimensional models of the geology of Earth's crust. High-quality aeromagnetic data are profoundly useful—they



A map published in 2002 of the magnetic anomalies measured over the United States and offshore areas. Credit: USGS



Coauthor Tien Grauch (middle) with the flight crew as they prepare to survey the magnetic field near Great Sand Dunes National Park and Preserve in Colorado. Credit: Benjamin J. Drenth

help geologists characterize features on the surface and below, providing information directly relevant to geologic mapping and structure, mineral resources, groundwater, earthquake hazards, volcanic hazards, and petroleum resources. Moreover, aeromagnetic data are inexpensive to acquire compared with other types of geoscientific data.

Simply put, aeromagnetic data are foundational for constructing 3-D geologic models that can be used to address society's geoscientific needs. However, some areas are covered more thoroughly than others. Also, private industries like petroleum and mineral companies often do their own surveys but prefer to keep their most recent and accurate data to themselves.

It is thus no surprise that many countries in both the developed and the developing world have completed or are working to complete national-scale coverage of publicly available ("precompetitive"), high-quality aeromagnetic data. Cost-benefit economic analyses of such national programs produce compelling estimates of the long-term return on investment [e.g., *Indecon International Economic Consultants*, 2017].

The U.S. Geological Survey (USGS) has recently completed an assessment of existing, publicly available aeromagnetic data for the United States to identify and prioritize areas that need better coverage. We developed a system for ranking the available data using current best practices, and we created a map that summarizes the current coverage in the United States.

What We Have Now

The U.S. public aeromagnetic data program is managed by the USGS, the agency that acquires, stores, and serves most of these data. The USGS was an early pioneer in aeromagnetic surveys and has been acquiring aeromagnetic data since the 1940s. However, the USGS has been unable to replace older, inadequate data with modern surveys.

Instead, legacy analog data have been digitized, surveys that have inadequate sampling have not been replaced, modern surveys have been acquired only over postage stamp–sized areas (generally <2,000 square kilometers), and these disparate data sets have been merged without

Table 1. Criteria Used for Ranking Aeromagnetic Surveys[a]

CATEGORY	RANK 1	RANK 2	RANK 3	RANK 4	RANK 5
Data type	data acquired digitally with GPS navigation	data acquired digitally without GPS navigation	rank not given	digitized points	rank not given
Survey specifications	TC[b] < 152 meters and ratio[c] ≤ 2	TC < 152 meters and 2 < ratio ≤ 3 152 meters ≤ TC ≤ 305 meters and ratio ≤ 2	TC < 152 meters and 3 < ratio ≤ 6 152 meters ≤ TC ≤ 305 meters and 2 < ratio ≤ 6	TC < 305 meters and 6 < ratio ≤ 12 TC > 305 meters and ratio ≤ 12	ratio > 12
Data issues	no significant data issues	minor issues that can be resolved or that affect only small parts of the survey area	significant data issues, data gaps, and/or poorly known survey parameters	unresolvable data issues, large data gaps, and/or unknown survey parameters	data unreadable, data format unknown, or data publicly unavailable

[a]Overall rank for an aeromagnetic survey is determined by the worst rank (largest number) assigned to any of the three categories.

[b]Terrain clearance.

[c]Ratio of flight line spacing to typical distance above shallowest magnetic sources in the survey area. Thresholds of 152 meters and 305 meters are derived from typical legacy survey parameters for the United States.

the ability to standardize the data to common parameters. As a result, high-quality public aeromagnetic data do not exist for most of the United States, placing the country behind much of the rest of the world.

Ranking the Data

Just how inadequate is the U.S. aeromagnetic coverage? We recently developed an assessment, or ranking, methodology that considers modern best practices for acquisition of aeromagnetic data, common practices in the past, and the suitability of the data to support geologic mapping and other research activities. We ranked the quality of existing aeromagnetic surveys and the corresponding data with respect to three categories: data type, survey specifications, and data issues (Table 1). The three categories were ranked separately for each survey; then an overall rank was assigned on the basis of the poorest category rank, with 1 being the best and 5 being the worst.

Data type. The issue of data type focuses on two considerations (Table 1). The first is real-time GPS navigation, a revolutionary development for aeromagnetic surveys that emerged in the mid-1990s. Surveys flown with GPS have more accurate positioning and thus superior data quality. GPS navigation is required for a rank 1 survey.

The second consideration is the presence or absence of digital flight line data, that is, the data that represent the sampling of the magnetic field acquired during the survey. Digital flight line data allow for rigorous quantitative interpretation and are required for rank 1. Unfortunately, many public aeromagnetic surveys flown in the 1940s–1960s are available only as digitized representations of paper contour maps, not digital data points.

Survey specifications. The proper specifications for an aeromagnetic survey consider two related principles. The first principle is that the lower the terrain clearance of the aircraft (i.e., the closer the magnetometer is to the ground surface), the greater the resolution of the data in the direction of flight, meaning that subtle anomalies related to finer details of the geology are more likely to be captured (Figure 1). Surveys with rank 1 specifications are flown with terrain clearances of 500 feet (~152 meters) or less (Table 1), as permitted by safety and legal airspace restrictions. Many surveys in the database were flown much higher (especially before the 1970s), with an average terrain clearance of 1,000 feet (305 meters).

The second principle is related to the spatial sampling required to produce adequate maps of the magnetic field—how closely spaced are the data points? Maps representing magnetic sources that are near the ground surface require more closely spaced sampling points than those for sources deep underground. Because sampling points are always tightly spaced along flight lines, the critical consideration is how far apart to space the lines to get an accurate representation of sources at different depths. In a classic paper, *Reid* [1980] showed that the ratio of flight line spacing to the shallowest source depth (Figure 1) is ideally 1:1 for modern analysis, and this ratio should not exceed 2:1. In survey areas where most of the magnetic sources are elongated perpendicular to the direction that survey flight lines are flown, a 2:1 ratio can provide sufficient resolution, because signals coming from the elongated sources can be extrapolated between flight lines. Otherwise, a 1:1 ratio is essential to achieving optimum resolution. Rank 1 survey specifications have a ratio that does not exceed 2:1. It is not possible to determine the true magnetic field between flight lines if the line spacing exceeds that threshold.

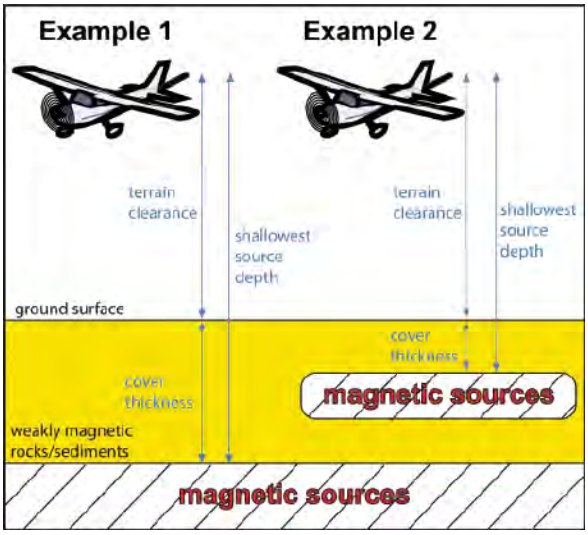


Fig. 1. Illustration of terms used in aeromagnetic surveying. The shallowest source depth is defined as the distance from the magnetometer (aboard the aircraft) to the shallowest magnetic sources in the survey area, or the sum of the terrain clearance and the thickness of weakly magnetic cover. Because the source of the magnetic signal in example 1 is buried more deeply than the one in example 2, the appropriate flight line spacing can be greater for example 1 than for example 2. For a survey with a terrain clearance of 100 meters, where 50 meters of weakly magnetic cover overlies the shallowest magnetic sources, the shallowest source depth is 150 meters, and a 2:1 ratio dictates a flight line spacing of no greater than 300 meters.

Data issues. The final criterion considered for the ranking scheme evaluates the presence and severity of problems that commonly plague legacy public data. These problems include data gaps, instrumentation errors, processing errors, and data accessibility problems. Surveys with no significant data issues receive a rank of 1 for this criterion. Ranks 2–5 have increasing severity or an increasing number of issues. Determining the severity of data issues can be subjective, depending on an expert's past experiences in overcoming specific data issues. Thus, some inconsistency in how different experts rank surveys in this category is to be expected.

What the Rankings Mean

The overall survey rank (Table 1) communicates the quality of aeromagnetic data relative to the standard of supporting both qualitative and quantitative studies of the shallowest

Cost-benefit economic analyses of national aeromagnetic data programs produce compelling estimates of the long-term return on investment.

Table 2. Suitability of Aeromagnetic Data for Supporting Geologic Studies by Overall Rank

	RANK 1	RANK 2	RANK 3	RANK 4	RANK 5
General quality statement	meets modern standards and best practices for qualitative and quantitative interpretation	good for most qualitative interpretation, quantitative interpretation handicapped	useful for qualitative interpretation of large features, generally not appropriate for quantitative interpretation	limited use for very broad qualitative interpretation, not appropriate for quantitative interpretation	useful only for interpretation of very broad features
Appropriate scale(s) of study	from detailed scale (1:24,000; e.g., geologic mapping) to national or continental scales (e.g., studies of midcrust and deeper)	from intermediate scale (1:50,000 to 1:100,000; e.g., watershed studies) to national or continental scales (e.g., studies of midcrust and deeper)	from regional scale (1:250,000; e.g., regional tectonic studies) to national or continental scales (e.g., studies of midcrust and deeper)	from statewide or multistate compilations (1:500,000; e.g., studies of upper crust) to national or continental scales (e.g., studies of midcrust and deeper)	national to continental scales (e.g., studies of midcrust and deeper)

magnetic sources that produce short-wavelength anomalies. This standard is important even for geologic studies focused on deeper magnetic sources, because the shallowest magnetic sources will produce anomalies in the data. Failure to adequately sample these anomalies will cause problems (often unknown and unnoticed) with interpretation of deeper magnetic sources.

Rank 1 aeromagnetic data can meet these needs in all cases. That is, they were acquired using modern best practices for survey design, meet all modern standards for data type and quality, and support the widest variety of geologic studies. Rank 2 data can meet some of these needs, but quantitative interpretation is handicapped. Rank 3, rank 4, and rank 5 present increasingly difficult, even impossible, challenges to geologic interpretation (Table 2).

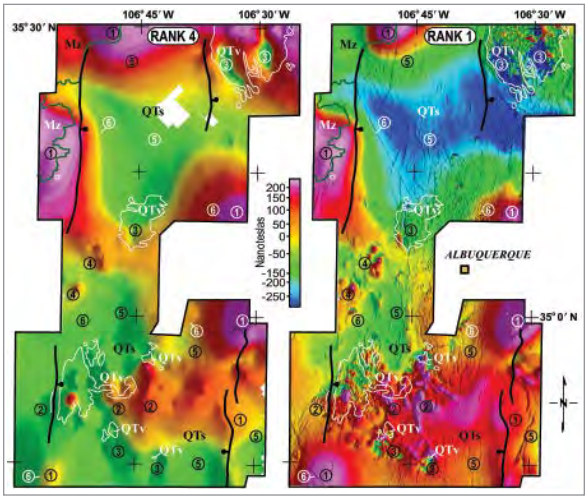


Fig. 2. Aeromagnetic surveys of the Albuquerque Basin near Albuquerque, N.M. The rank 4 survey is from a 1974 digitized contour map with line spacing of 1,609 meters and average terrain clearance of 621 meters (ratio of 2.6). The rank 1 survey is from 1996–1997 data, taken with real-time GPS navigation. Color scale is magnetic field strength in nanoteslas. QT is Quaternary–Tertiary; s is alluvium and basin-fill sediments; v is intrabasin volcanic rocks; Mz is Mesozoic sedimentary rocks on the basin flanks; bold black lines represent major basin faults. Circled numbers: 1 is uplifted crystalline basement, 2 is shallowly buried lava flows, 3 is volcanic rocks that likely formed during a reversal of Earth's magnetic field, 4 is buried small intrusions, 5 is intra-sedimentary faults, 6 is commercial buildings, landfills, and a pipeline (southwest corner of map). See Grauch and Hudson *[2007] for more details.*

Figure 2 is an illustration of the large improvement in resolution of rank 1 over rank 4 data.

A group of USGS experts applied the ranking scheme to every public aeromagnetic data set in the United States to assess the quality of existing aeromagnetic data coverage. This analysis is a national-scale, first-approximation evaluation to be reexamined in detail as future research priorities dictate. The resulting map (Figure 3) reveals that most of the United States requires updated, high-resolution aeromagnetic data.

For example, only about 1% of the lower 48 states is covered by rank 1 data that meet modern standards, and no rank 1 surveys have been flown in Alaska or Hawaii. More than 95% of the country is covered by ranks 3, 4, and 5 data; geoscience studies in these areas are hampered by a lack of supporting information from aeromagnetic data.

An Emerging Urgency

The need to improve the nation's aeromagnetic data has recently taken on greater urgency. Executive Order 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," implemented by Department of the Interior Secretarial Order 3359, "Critical Mineral Independence and Security," directs the USGS to develop a plan to improve the nation's understanding of domestic critical mineral resources. Key parts of the plan include assessing and improving the quality of the nation's geologic mapping, topographic data, and airborne geophysical data, particularly aeromagnetic data.

So what now? Although efforts to create better databases of existing public data have been largely successful [*Finn et al.*, 2001], past attempts to promote a nationwide, systematic collection of modern aeromagnetic surveys have

New executive and secretarial orders may spur an effort to acquire rank 1 aeromagnetic surveys across the United States.

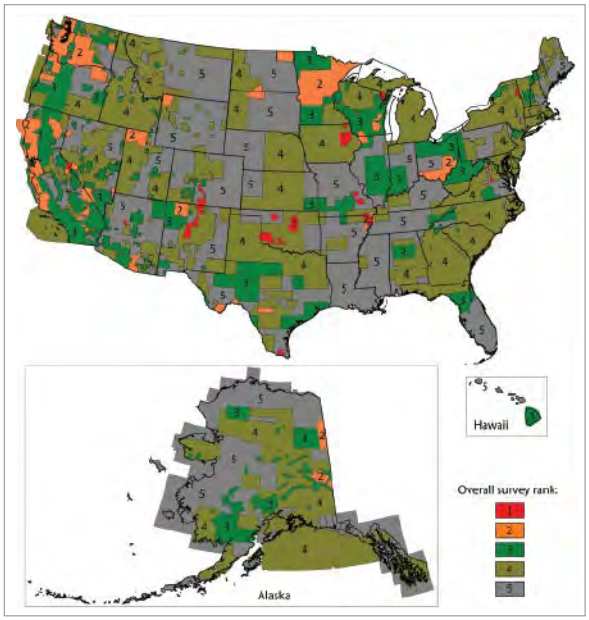


Fig. 3. Assessment of the quality of existing aeromagnetic surveys for the United States, with rank 1 indicating the best quality and rank 5 indicating the worst. The map results from the ranking scheme applied to each public aeromagnetic survey by Eric Anderson, Ben Drenth, V. J. S. Grauch, Anne McCafferty, Anji Shah, and Dan Scheirer of the USGS.

not gained traction [*Hildenbrand and Raines,* 1990; *U.S. Magnetic-Anomaly Task Group,* 1995]. The new executive and secretarial orders may spur an effort to acquire rank 1 aeromagnetic surveys across the United States, now in the planning stages at the USGS.

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References

Finn, C. A., et al. (2001), New digital data base helps to map North America, *Eos Trans. AGU, 82*(30), 325–330, https://doi.org/10.1029/01EO00190.

Grauch, V. J. S., and M. R. Hudson (2007), Guides to understanding the aeromagnetic expression of faults in sedimentary basins: Lessons learned from the central Rio Grande rift, New Mexico, *Geosphere, 3*(6), 596–623, https://doi.org/10.1130/GES00128.1.

Hildenbrand, T. G., and G. L. Raines (1990), Need for aeromagnetic data and a national airborne geophysics program, in *Geologic Applications of Modern Aeromagnetic Surveys,* edited by W. F. Hanna, *U.S. Geol. Surv. Bull., 1924,* 1–5, https://doi.org/10.3133/b1924.

Indecon International Economic Consultants (2017), An economic review of the Irish geoscience sector, 91 pp., Geol. Surv. Ireland, Dublin, https://www.gsi.ie/en-ie/publications/Pages/An-Economic-Review-of-the-Irish-Geoscience-Sector.aspx.

Reid, A. B. (1980), Aeromagnetic survey design, *Geophysics, 45*(5), 973–976, https://doi.org/10.1190/1.1441102.

U.S. Magnetic-Anomaly Task Group (1995), Task group plans upgrade of the U.S. magnetic-anomaly database, *Eos Trans. AGU, 76*(14), 137–140, https://doi.org/10.1029/95EO00072.

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GAUGING IN THE RAIN

By Bas den Hond

HOW MUCH RAIN DID WE GET TODAY?

It seems like a simple question to answer after a rainy day or a rainstorm.

Putting a bucket or other container out to measure the amount of rainfall is a gauging method that may be as old as agriculture itself and, at least in India, was known at least 2 millennia ago: "The quantity of rain that falls in the country of Jángala is 16 dronas; half as much more in moist countries," it says in the *Arthashastra*, a Sanskrit treatise on politics, economics, and military strategy. The text goes on to instruct, "According as the rainfall is more or less, the superintendent shall sow the seeds which require either more or less water."

In today's measurements, a drona represents about 50 millimeters of precipitation, according to a history of rain gauges by Ian Strangeways found in the journal *Weather*. But did those ancient instruments, to be positioned "in front of the storehouse" according to the *Artha-*

Xhin Mania/EyeEm/Getty Images

Workers install the prototype gamma ray gauge spectroscopy station in an agricultural field near Budrio in Italy. Credit: Laboratory for Nuclear Technologies Applied to the Environment

shastra, always record the right amount of dronas? Great care has to be taken lest gauges of that type are fooled by water splashing in or out or by wind preventing rain from falling nicely and vertically into a round opening.

At the annual General Assembly of the European Geosciences Union in Vienna, Austria, in April, three methods were discussed to improve or extend the measurement of rainfall. They nicely complemented one another: One would work best in an urban environment, one would work in an agricultural setting, and one would work out at sea.

Gauging Umbrellas

In urban areas, measuring rainfall is a pain, said Marie-Claire ten Veldhuis, a hydrometeorologist at Delft University of Technology (TU Delft) in the Netherlands. "All the rain gauges we use now are way outside towns, because they have to be far from buildings. There are no good places for rain gauges in cities."

That doesn't mean there are no rain gauges there. Lots of people like to install their own weather stations in their yard or on their roof. And these could be useful.

"But you need a great many of them to establish the pattern of rainfall in the city," ten Veldhuis said.

Information from rain gauges would be very valuable for city authorities, for instance, to anticipate or possibly prevent flooding.

To help gather this information, ten Veldhuis's group in the Water Management Department at TU Delft is developing portable rain gauges of a kind most people presumably wouldn't mind carrying around for science: umbrella-mounted ones. A prototype shown in Vienna sports a piezoelectric sensor on its top. The umbrella would report its data and GPS-calculated position to a central server, so that city authorities would know how much rain is really falling at any given moment at many locations.

> "THERE ARE NO GOOD PLACES FOR RAIN GAUGES IN CITIES"

For the first feasibility study, the umbrella was installed in an open area, with a traditional rain gauge nearby, to see whether counting rain droplets falling on the sensor would lead to a correct estimate of the amount of precipitation. As an alternative to drop counting, the circuitry also detected the general sound level generated by the rain.

In the first trial, both techniques worked, although both had issues. During counting, small drops would go undetected. With the sound measurement, wind noise could be a problem.

All in all, the measurements were most reliable when drops were counted in heavier rain. That makes the method already suitable for cities with a tropical climate, ten Veldhuis noted. "In many of those countries, alternatives like high-resolution radar aren't available yet." Her group is working with a number of cities in Africa, such as Dar es Salaam in Tanzania, Kumasi and Accra in Ghana, and Narok in Kenya, to develop "sensor-based weather services," she said. "These umbrellas could be very useful there."

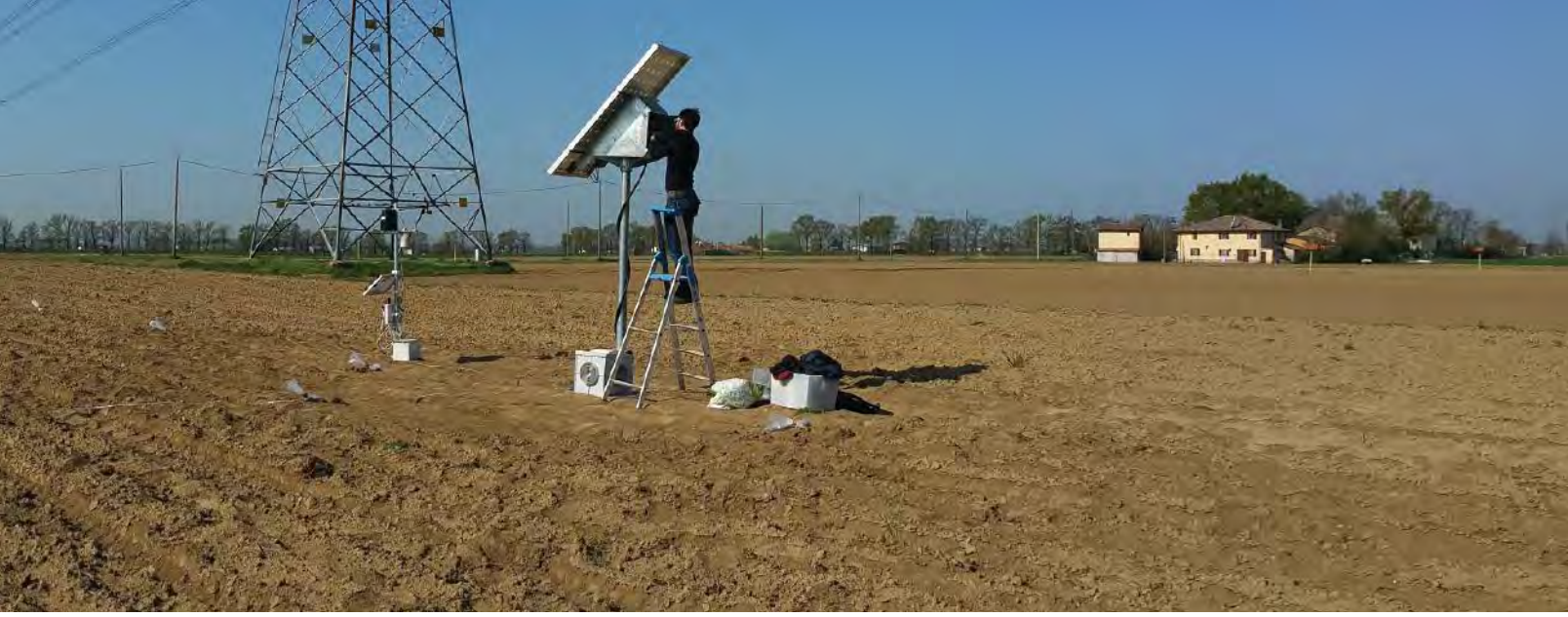
The Delft group is working with NASA to turn the rain-gauging umbrellas into a citizen science project.

Radioactive Rain

Even those who would gladly carry an umbrella for science might recoil at being asked to help measure radioactivity after a rainstorm. The experiment isn't as dangerous as it might sound.

Every bout of precipitation brings a tiny uptick in gamma radiation from the ground, and that fact can be exploited for gauging purposes, said Marica Baldoncini, a physicist at the University of Ferrara and the National Institute of Nuclear Physics in Italy.

The gamma radiation boost results from the transport of a series of radioactive elements first up and then down. The process starts with uranium and thorium deep in the earth. In a sequence of radioactive decay steps, a number of other unstable elements are produced, among which is radium, which produces radon, which as a gas escapes into the atmosphere. There it decays into unstable isotopes of lead and bismuth. It's these isotopes that enter into the hydrologic cycle.



"Radon is chemically inert," Baldoncini explained, "but when it decays, the daughter products are typically produced in a positively charged state and for that reason have high chemical reactivity. They attach to aerosols."

Within clouds, these aerosols are "scavenged" by water drops circulating in them and are eventually brought to the ground when the drops fall as rain. There, the decay of the lead and bismuth produces the gamma radiation that Baldoncini has been measuring.

"You see a sharp increase in the count rate, and the height of that peak is essentially proportional to the amount of water that is going to the ground," she said.

Baldoncini's goal is to turn this phenomenon into an alternative way to gauge rainfall, one that would work particularly well in rural areas, in combination with satellite measurements. From satellites, falling rain itself is not detected, but the water content of soil is. Indirectly, these data can deliver an accurate estimate of rainfall, except when other sources of moisture are active, such as irrigation. A ground-based rain gauge that records spikes of gamma radiation above the natural background could fill that gap and would also need less human intervention than a conventional gauge.

At the Vienna meeting, Baldoncini reported measurements of a dozen rainfall events with both conventional rain gauges and sodium iodide scintillators, which detect gamma radiation. This comparison allowed her to develop an algorithm to connect both measurements.

In Baldoncini's experiments, the hydrology of the location, an agricultural field near Budrio in the north of Italy, was exactly known. "There were people taking care of all that information, such as the amount of water added, the frequency, when the plants were sown. Typically, you don't know this, because people don't maintain a database about the irrigation frequency," she said.

Once the algorithm is fully developed, the gamma ray gauge could both improve local precipitation information and make satellite data more useful. "We plan to merge all the information from this proximal remote sensing that works at the scale of half a hectare with satellite measurements," Baldoncini said. "And then [we] can tell in the satellite data: This is irrigation, and this is precipitation."

Drops and Bubbles

If, eventually, cities are covered by umbrellas and the countryside is covered by gamma ray detectors, that leaves the world's oceans as an underserved area for rain gauges.

Conventional gauges are used on islands, of course, and it is possible to mount them on buoys. But in the latter case, they are easily damaged by waves and are even sometimes stolen by the crews of passing ships, said Dimitrios Galanis, an undergraduate student at the School of Civil Engineering of the National Technical University of Athens in Greece.

Instead, meteorologists would like to develop rain gauges for use underwater. These instruments would be essentially hydrophones, anchored to the seafloor. They would record both the noise that raindrops make as they strike the water surface and also the noise that emanates from the air bubbles that the raindrops create. These bubbles resonate at specific frequencies depending on their size.

Although the idea is straightforward, making the connection between noise and rainfall rate turns out to be difficult, Galanis said. And the work he presented at the Vienna meeting hasn't cracked the problem just yet.

Galanis analyzed published data from measurements in the Gulf of Mexico from both sound and conventional rain gauges, extracting two statistical characteristics from them, the power spectrum and the climacogram, to see which one would correlate best with the actual rainfall rate.

The power spectrum is a widely used measure and can be visualized as a plot of the relative strength of different frequencies in the sound. The climacogram is less common and plots whether sound is more constant or variable as it is averaged over shorter or longer timescales.

So far, the climacogram seems to work best. "But it is still very preliminary," Galanis cautioned. Rain gauging may have progressed a great deal since precipitation was measured in dronas, but so far it hasn't quite gotten its sea legs.

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▶Read the full story at bit.ly/Eos_gauging-rain

EL REVENTADOR CONTINUALLY REMAKES ITSELF

By Marco Almeida, H. Elizabeth Gaunt, and Patricio Ramón

A research team from Ecuador's Geophysical Institute keeps a close eye on an unusually active and unstable volcano in the nation's remote jungles.

EL REVENTADOR IS CURRENTLY THE MOST ACTIVE volcano in Ecuador. When this volcano (whose name translates as "the Exploder") erupts, it sends incandescent rock projectiles into the air, along with ash columns approximately 3 kilometers high. The volcano also releases significant amounts of lava flows, volcanic bombs, and ash from flow and fall deposits onto the surrounding ground. This relatively small stratovolcano has destroyed and rebuilt its edifice on a large scale throughout its evolution. Its eruptive behavior changes rapidly, and its

El Reventador volcano in Ecuador erupts in November 2015. Credit: Morley Read/Photolibrary/Getty Images

complex behavior is significantly different from that of all other volcanoes in the Ecuadorian Andes.

During the past 3 years, El Reventador has repeatedly destroyed and rebuilt itself on a smaller scale as well, and inherent instabilities in its edifice pose an ongoing hazard. This hazard is particularly severe on the active cone, where complex effusive and explosive events occur on a daily basis. Our research group, which monitors this remote jungle volcano, has found evidence of multiple small collapses in the border flanks of the crater, complex multivent behavior, and the opening and closing of new vents on a relatively short timescale of weeks to months. Our studies are providing new insights into the inner workings of this volcanic system.

Fig. 2. El Reventador volcano, showing the ridges of Basal Reventador, Paleo Reventador, and the new stratocone. Credit: M. Almeida, IG/EPN

Monitoring El Reventador

El Reventador (Figure 1a) is part of the back-arc volcanism on the eastern side of the Cordillera Real of Ecuador, located approximately 90 kilometers east of the capital city of Quito. The Instituto Geofísico (IG) of the Escuela Politécnica Nacional (EPN) in Quito monitors the activity of this remote volcano. A very large explosive eruption in 2002 initiated the current period of activity, prompting the IG to install a permanent, telemetered seismic monitoring station in 2003.

Over the past 16 years, the IG's monitoring capabilities at El Reventador have expanded into a comprehensive network of seismometers, infrasound stations, thermal and visual cameras, a digital optical absorption spectroscopy (DOAS) gas monitoring station, and acoustic flowmeter lahar monitoring stations within the caldera itself (Figure 1b). Since 2016, 10 ash meters installed on the volcano have collected high-quality volcanic ash samples for ongoing petrological monitoring of the eruption [*Bernard,* 2013].

We conduct monthly field campaigns on foot and by air to complement data recorded by the permanent monitoring network. During these field campaigns, we collect targeted thermal image sequences, gas measurements (e.g., multiGAS, mobile DOAS), and visible-light photography. In conjunction with the U.S. Geological Survey's Volcano Disaster Assistance Program, the IG conducts photogrammetric surveys to create 3-D models of the lava flows and edifice. Samples of ash, ballistics, and lava flows are also regularly collected and used for petrological analyses, which provide insights into eruption dynamics, magma storage, and the geometry of the plumbing system.

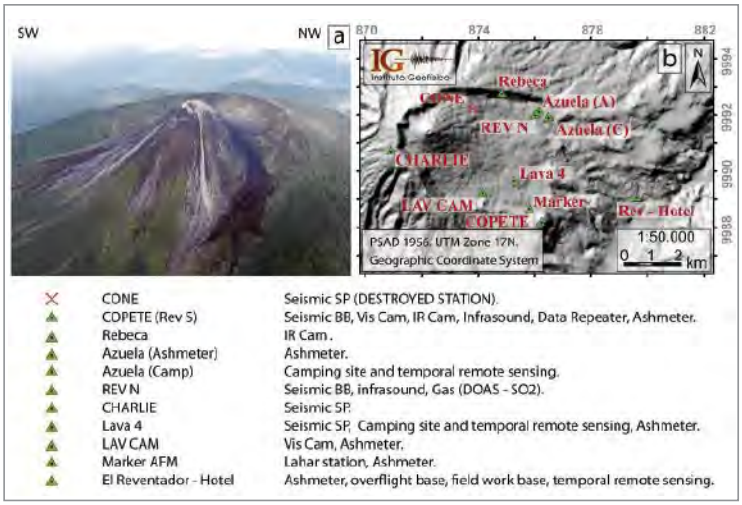

Fig. 1. (a) El Reventador volcano. Note the small stratovolcano inside the Paleo Reventador amphitheater. (b) El Reventador monitoring network stations. BB, broadband; DOAS, differential optical absorption spectroscopy; IR, infrared; SO2, sulfur dioxide; SP, short period; PSAD, Provisional South American Datum 1956; UTM, universal transverse Mercator. Credit: M. Almeida, IG/EPN

Past and Present Activity

During El Reventador's history, at least two catastrophic events almost completely destroyed the edifice, although the timing of these events is not known [*Instituto Ecuatoriano de Electrificación,* 1988]. The current active cone of El Reventador sits within the collapse caldera of Paleo Reventador on the western side (Figure 2). Since 1541, the volcano has experienced about 20 different eruptive periods [*Naranjo et al.,* 2016].

El Reventador's 3 November 2002 eruption, after 26 years of quiescence, is considered to be the largest Ecuadorian eruption in the past century. It was categorized as a subplinian eruption, and it spewed out 0.37 cubic kilometer of material [*Hall et al.,* 2004]. During the eruption, a large part of the summit was destroyed, reducing its height by almost 100 meters and creating a large crater approximately 480 meters in diameter.

One of the most interesting aspects of recent activity at El Reventador is the configuration of the active eruptive vents. During a field campaign in January 2016, we observed two different active summit vents for the first time. Subsequent overflights confirmed the presence of these two separate vents, now called the north vent and the south vent (Figure 3). Subsequent overflights and continued visual monitoring of the activity through the permanent cameras revealed that the mode of activity in the south

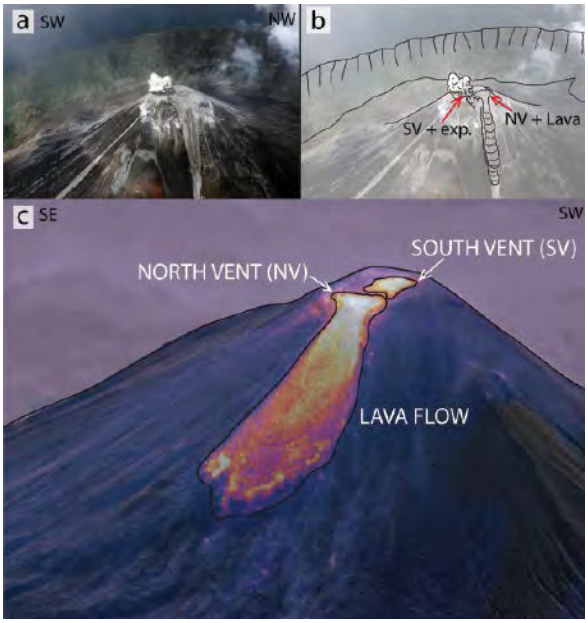

Fig. 3. (a) Explosion in the south vent on 7 June 2017 and a small lava flow associated with the north vent. (b) A trace of the activity of the north and south vents highlighting the explosion (exp.) and lava flow. (c) Superposition of visible and thermal images showing the separate north and south vents and the lava flow being extruded from the north vent on 28 January 2016. Credit: (a), (b) P. Ramón; (c) M. Almeida, IG/EPN

vent was predominantly explosive, whereas in the north vent it was mostly effusive.

Activity in the two vents often appears to be independent, where explosions occur out of either one vent or the other. Occasionally, however, the explosions originate from both vents simultaneously. These observations suggest that the feeding system to the two vents is connected at some level in the conduit but that the vents are also able to behave independently.

We observed intermittent, but less frequent, explosions from the north vent. During November 2016, activity in the north vent seemed to shift to a more explosive regime, and this shift in activity persisted until January

El Reventador's 3 November 2002 eruption, after 26 years of quiescence, is considered to be the largest Ecuadorian eruption in the past century.

2017. Moreover, during May 2017, while the two summit vents continued their hourly explosive activity, a new third vent producing lava flows was identified on the northeastern flank about 70 meters below the summit (Figure 4a).

This multivent behavior, coupled with continued high levels of activity, has filled the crater left by the 2002 eruption, reconstructing the active cone to its pre-2002

Aerial view of El Reventador volcano, showing the emission column after an explosion on 27 August 2017. Credit: P. Ramon, IG/EPN

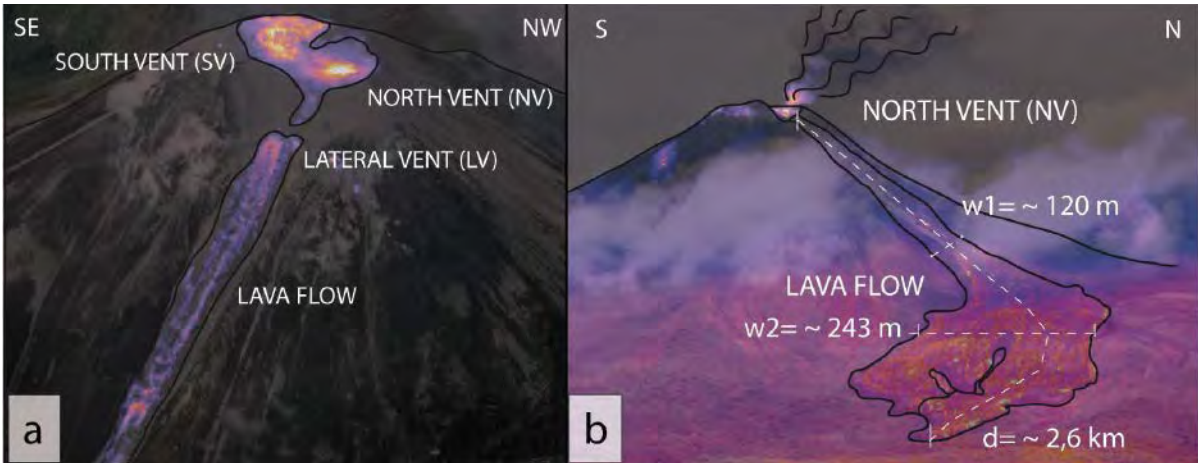

Fig. 4. (a) Superposition of visible and thermal images showing the two summit vents, the lateral vent, and the lava flow on 2 June 2017. (b) Superposition of visible and thermal images of the large lava flow extruded between 22 June and 1 July 2017. This was the largest lava flow emitted since 2008. Credit: M. Almeida, IG/EPN

height. Frequent moderate-scale collapses of the edifice and high levels of ongoing eruptive activity result in regular, significant changes to the shape of the summit area of the active cone.

El Reventador Starts Another Makeover

In June 2017, El Reventador experienced its highest level of activity in more than 10 years, beginning with the explosive opening of a new vent on the northeastern flank. This vent released large, fast moving currents of hot gases and volcanic matter called pyroclastic density currents (PDCs) that reached more than 5 kilometers from the summit. This PDC activity was followed by the rapid effusion of the largest lava flow since 2008, which reached nearly 3 kilometers from the summit (Figure 4b).

The edifice collapsed again in April 2018, destroying a large section of the summit and forming a new large crater, open to the north-northwest (Figure 5). We identified three new vents within the collapse scar, highlighting how quickly the morphology of this volcano can change. These rapid changes and frequent collapse and rebuilding events have resulted in an inherently unstable cone. Collapse events, big and small, are commonplace, with small collapses occurring on a weekly basis. Moderate to large collapses also occur yearly, such as before the June 2017 lava flow and in April 2018.

Particularly unstable areas include the edge of the current crater, where loose material builds up during explosive and effusive events and intermittently collapses, leaving easily identifiable collapse scars around the summit area. Explosions and sector collapses of the edges of the crater regularly produce primary and secondary PDCs. These sector collapses are not always necessarily associated with explosive behavior, so they are inherently unpredictable.

Preparing for Future Hazards

Eruptive activity at volcanoes can change rapidly from relatively benign to potentially life threatening with very little warning. The history of El Reventador demonstrates that it is capable of not only its hourly explosive behavior but also catastrophic activity.

Recent events have demonstrated that rapid changes can occur and that inherent instabilities exist within the volcanic edifice. New eruptive vents can open up anywhere on the active cone, and the daily high levels of eruptive activity create the potential for new edifice collapses and the generation of large PDCs, which could affect local infrastructure.

At present, El Reventador's activity levels remain high, and the volcano shows no signs of slowing down. Continuous monitoring by the IG and constant work to improve the monitoring network will enable us to provide better early warnings of impending volcanic activity in the future.

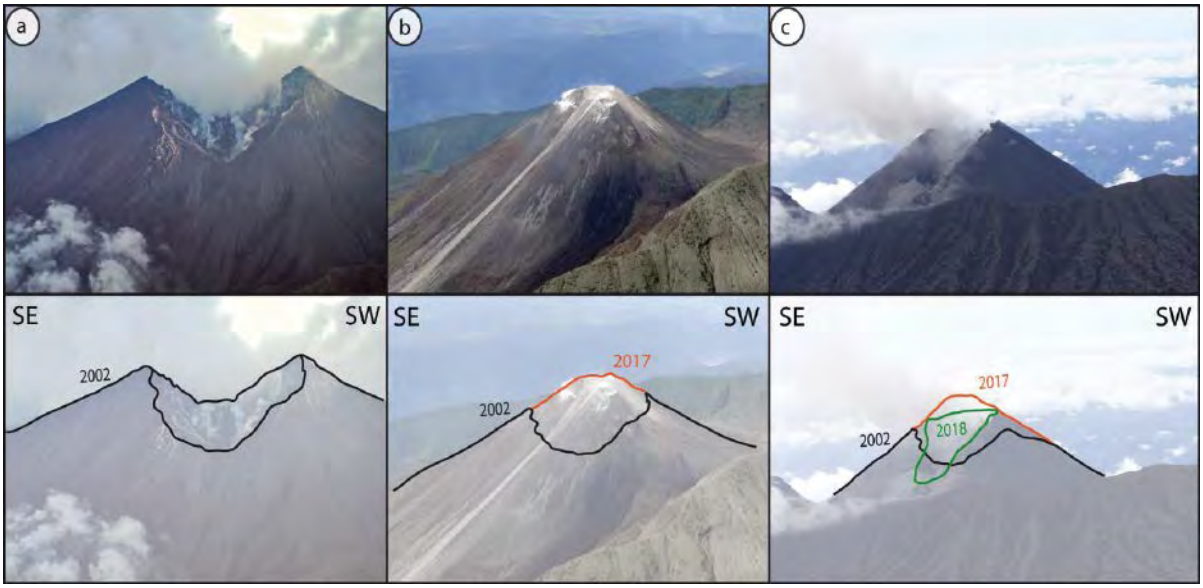

Fig. 5. (a) After an explosive event in 2002, part of the summit of El Reventador volcano was destroyed, as shown in this aerial photo. (b) Since then, the crater has been almost completely filled in, as shown in this photo of the active cone in June 2017. (c) This aerial photo shows the most recent collapse event, which occurred in April 2018. Credit: (a) P. Ramón, IG/EPN; (b) M. Almeida; (c) S. Vallejo, IG/EPN

Acknowledgments

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References

Bernard, B. (2013), Homemade ashmeter: A low-cost, high-efficiency solution to improve tephra field-data collection for contemporary explosive eruptions, *J. Appl. Volcanol., 2*(1), 1, https://doi.org/10.1186/2191-5040-2-1.

Hall, M., et al. (2004), Volcanic eruptions with little warning: The case of Volcán Reventador's surprise November 3, 2002 eruption, Ecuador, *Rev. Geol. Chile, 31*(2), 349–358, https://doi.org/10.4067/S0716-02082004000200010.

Instituto Ecuatoriano de Electrificación (1988), Estudio vulcanológico de "El Reventador," Quito.

Naranjo, M. F., et al. (2016), Mapping and measuring lava volumes from 2002 to 2009 at El Reventador volcano, Ecuador, from field measurements and satellite remote sensing, *J. Appl. Volcanol., 5*(1), 8, https://doi.org/10.1186/s13617-016-0048-z.

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Until 3 September, we will continue to accept direct manuscript submissions through GEMS; after that date the portal will close.

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By **Heather Goss** (@heathermg), Editor in Chief

Data Mining Reveals the Dynamics of Auroral Substorms

EOS CENTENNIAL COLLECTION
AGU100

Aurorae shimmer over Lofoten, Norway, during a substorm, a disturbance in Earth's magnetic field that can cause aurorae to wash over the globe. Credit: Johannes Groll on Unsplash

Space physicists have long known that coronal mass ejections hurl into space vast amounts of charged particles, which can cause magnetic storms on Earth. These days-long periods of enhanced activity in the planet's magnetic field can create spectacular aurorae and take down power grids on continental scales.

But the dynamics of how the Sun interacts with Earth's magnetic field during such storms remains mysterious, especially the brief periods of peak intensity, which last just a few hours.

In the mid-1900s, scientists realized that there are distinct phases to these events, now called auroral substorms. First, the solar wind buffets and stretches out Earth's magnetic field, which stores energy like a rubber band. Next, the field's tail rebounds, jetting charged particles back toward the planet's nightside and causing a surge of aurora that sweeps west across the planet. Finally, the magnetic field recovers to a quieter state.

This picture emerged in the 1970s, but it's hard to piece together a comprehensive picture of Earth's magnetic field during any given substorm because of the limited number of satellites making observations.

Stephens et al. have taken a new approach: creating a unified data set spanning 5 decades by mining and merging the archives of 15 satellites from NASA, the National Oceanic and Atmospheric Administration, the European Space Agency, and the Japan Aerospace Exploration Agency. The resulting models behave as if 11,000–50,000 virtual satellites were observing a single representative substorm, making the simulation the most comprehensive view yet of substorms and their distinct phases.

As every substorm is unique and unfolds at its own pace, the researchers needed to synchronize all of them. To do this, they turned to magnetic field readings from ground monitoring stations and satellite observations of the solar wind. These observations track the phases of the storm in the form of calculated indices, which act as a sort of time code that allows the spacecraft data to be matched to the correct phase of the substorm.

This unified data set is powerful and flexible. It can be used to construct a model of a representative, "average" substorm. But it can also be used to reconstruct any individual substorm in greater detail by starting with data for that event and filling in the rest of Earth's magnetic field with closely matched data from the general data set.

This process allowed the team to track the system of currents that pulse around the planet as a substorm grows, expands, and recovers, including the wedge of current in the magnetic field's nightside tail, the ring current above the planet's equator (which is enhanced during a substorm), and the jets of particles that arc toward the poles to generate the aurora.

This global picture could help scientists better understand substorms on Earth, including their risk to infrastructure. It could also help scientists understand similar processes that have been observed in the magnetic fields of other planets and stars. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1029/2018JA025843, 2019) **—Mark Zastrow, Freelance Writer**

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The Thermosphere Responds to a Weaker Than Normal Solar Cycle

Space shuttle Endeavour *orbits in the thermosphere in 2010 while en route to the International Space Station. The orange layer is the troposphere, the lowest part of the atmosphere; the whitish layer is the stratosphere; and the blue layer is the mesosphere. Credit: NASA*

The Sun undergoes a magnetic metamorphosis approximately every 11 years, when the celestial body flips its magnetic poles: North becomes south, and south becomes north. The Sun is currently in solar cycle 24, which began in June 2009. No cycle is the same. The length can vary from 9 to nearly 14 years, and the degree of solar activity fluctuates as well. Within each solar cycle, the frequency of sunspots and flares ebbs and flows in response to the changing magnetic field around the star.

The thermosphere, one of the outer layers of Earth's atmosphere, is particularly sensitive to variations in solar activity. The thermosphere forms about 100 kilometers (62 miles) above our heads and extends for several hundred kilometers above that. It absorbs much of the X-ray and ultraviolet radiation from the Sun. During periods of high solar activity, X-ray and ultraviolet radiation from the Sun increases, and the thermosphere swells as it sops up this increase in energy from the Sun. As the Sun approaches solar minimum, the thermosphere cools and shrinks as the intensity of the X-ray and ultraviolet radiation decreases. Because the International Space Station and many satellites orbit through this layer, changes in thermospheric boundaries and densities can affect their operation and the maintenance of their orbits.

The cooling near solar minimum is natural and specific to the thermosphere. The cooling thermosphere does not affect the troposphere, the layer of the atmosphere closest to Earth's surface. The temperatures we experience on the ground do not get colder because of this solar cycle. Climate researchers at NASA and elsewhere continue to see a warming trend in the troposphere. These two effects are ongoing but unrelated.

Nitric oxide and carbon dioxide play important roles in cooling the thermosphere. These molecules are able to radiate energy at infrared wavelengths and thus moderate the effects of energy inputs to the thermosphere. In particular, nitric oxide acts as a thermostat and, in concert with carbon dioxide, can significantly influence the temperature of the atmosphere, especially during periods when the thermosphere is disturbed during geomagnetic storms. The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on NASA's Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) satellite was launched in 2002 and has been observing the infrared radiation from these molecules ever since.

Here *Mlynczak et al.* looked at the past 16 years of SABER data to quantify how much energy nitric oxide and carbon dioxide discharged from the thermosphere over the past two solar cycles. The period covers most of solar cycle 23 and all of solar cycle 24 to date.

The authors found that the infrared power emitted by the two molecules during solar cycle 24 is substantially lower than the emissions during solar cycle 23. In fact, the radiated energy from nitric oxide and carbon dioxide are only 50% and 73%, respectively, of the average emission of the five prior cycles dating back to 1954. The low rates of radiation are likely tied to the relative weakness of solar cycle 24. To equal the average infrared radiation released from within the thermosphere over the past five cycles, the current solar cycle would need to span an additional 1,690 days. At that projected length, it would make the current cycle a full year longer than its predecessor and one of the longest in the historical record.

The study offers insightful information on the thermal state of Earth's atmosphere above 100 kilometers. The Sun's influence on the thermosphere is a growing topic of research, and this study provides crucial quantitative context for future work. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL080389, 2018) **—Aaron Sidder, Freelance Writer**

Understanding the Turbulent Nature of the Solar Wind

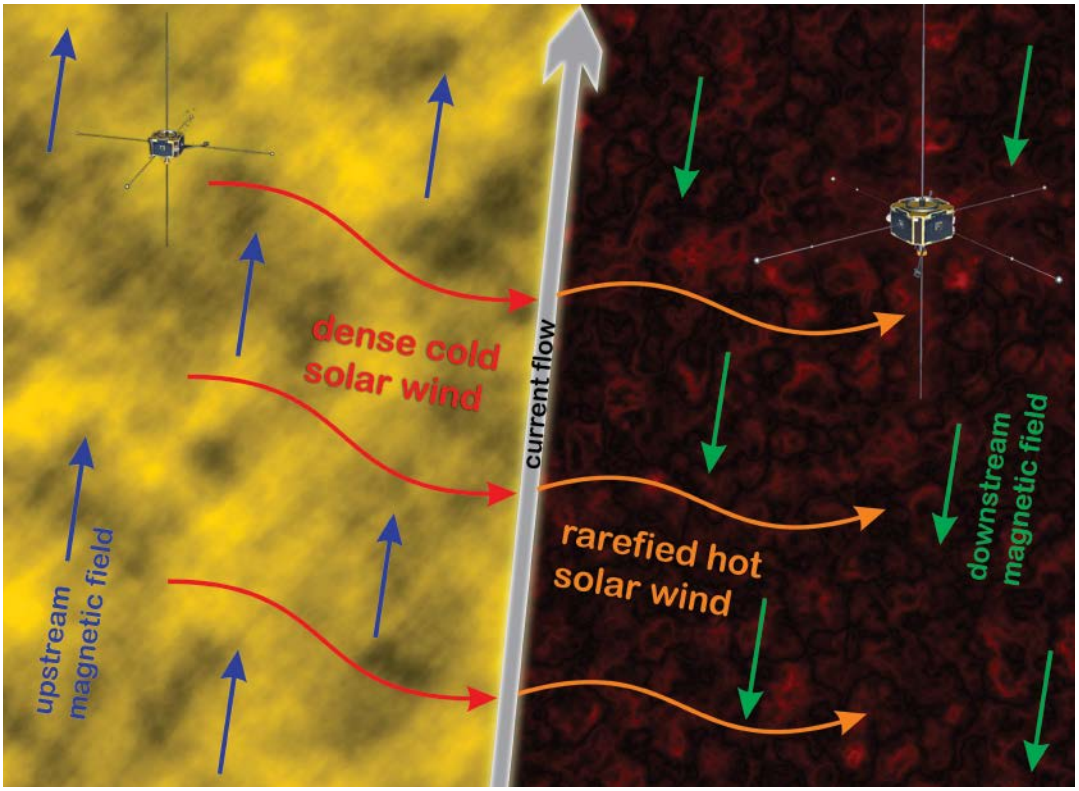
EOS CENTENNIAL COLLECTION
AGU100

The phrase "solar wind" may conjure up images of streams of protons wafting off the Sun and floating into space like a gentle breeze. But these particles, traveling at upward of 400 kilometers per second, more often resemble a raging, turbulent current, with swirls and eddies.

Some of the most dramatic features of the solar wind are discontinuities, where the magnetic field inside the stream abruptly changes direction.

Discontinuities are analogous to wind shear that aircraft encounter in Earth's atmosphere, and, similarly, their presence usually means that there's more turbulence nearby. Strong electric currents flow near a discontinuity, and these are an important generator of turbulence throughout the solar wind.

Investigating these dynamics in detail is not easy and requires data from multiple spacecraft that straddle such a boundary.



This is an artist's depiction of a typical solar wind discontinuity, as observed by the twin ARTEMIS probes. Discrete plasmas on either side of the discontinuity exhibit different magnetic fields, densities, and temperatures, with a thin, intense layer of current flow at the boundary. Credit: A. V. Artemyev, E. Masongsong, UCLA EPSS

Now *Artemyev et al.* have used data from NASA's Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS) mission, a pair of satellites that orbit the Moon and have a unique vantage point in the pristine solar wind. By mining data from its suite of instruments on the solar wind, its plasma, and its magnetic field, the authors identified roughly 300 discontinuities and analyzed their structure.

They found that the currents that accompany solar wind discontinuities are actually two currents in one: They have a dual-layer structure with an intense, but thin, layer of current flowing within a thicker one. The thin, embedded layer is typically on the order of a few thousand kilometers thick, whereas the weaker, outer layer can span hundreds of thousands of kilometers.

The team also found that the behavior of solar wind discontinuities doesn't fit neatly into theoretical categories.

In fluid dynamics theory, discontinuities like those in the solar wind come in two forms. In some, plasma flows in the same direction but at different speeds, so that no plasma flows across the boundary—a so-called tangential discontinuity. In others, the discontinuity is a kind of shock wave, so that plasma can cross the boundary but is sent off in another direction as it does—a rotational discontinuity.

The discontinuities the team observed look like a combination of both categories. The density and temperature of the solar wind's plasma change dramatically from one side of the discontinuity to another, suggesting a stark, tangential discontinuity where no particles could cross. Yet the team also observed that some electrons—those with energies of hundreds of electron volts or higher—could freely cross over the boundary, as in a rotational discontinuity.

The key to resolving this contradiction may lie in the motion of individual plasma particles as they gyrate through space under the influence of electric and magnetic fields, the authors write. A drop in electric potential could make for conditions that appear to create separate groups of plasma—like one layer embedded in another—yet still allow some particles to cross over the discontinuity. Investigating this possibility will require theorists to branch out from treating the solar wind as a pure fluid and to use models that consider the motions of individual particles, the authors write. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1029/2019JA026597, 2019) **—Mark Zastrow, Freelance Writer**

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Atmospheric Sciences

Physical Science Administrator (Program Director)

The National Science Foundation is seeking qualified candidate for a Physical Science Administrator (Program Director) position for the Lower Atmosphere Observing Facilities program in the Division of Atmospheric and Geospace Sciences (AGS) within the Directorate for Geosciences (GEO), Alexandria, VA.

AGS supports fundamental research into the physical, chemical, and biological processes that impact the composition and physical phenomena and behavior of matter between the sun and the surface of the Earth. This includes a wide variety of important processes that impact humans and society, such as weather, climate, air quality and space weather. Specific programs include studies of the physics, chemistry, and dynamics of earth's upper and lower atmosphere and its space environment, and research on climate processes and variations.

AGS supports the atmospheric and related sciences community with a portfolio of observing facilities and through the National Center for Atmospheric Research (NCAR), an NSF-sponsored Federally Funded Research and Development Center based in Boulder, Colorado. The scientific oversight of NCAR is the responsibility of the entire AGS division, with leadership, oversight and program management provided by the AGS NCAR and Facilities Section (NFS). NFS also manages the AGS programs in lower atmosphere observing facilities and in education and cross-cutting research. The NSF lower atmosphere observing facilities include the NSF C-130 and G-V aircraft operated by NCAR, the University of Wyoming King Air, and airborne and ground-based instrumentation such as radars and sounding systems that are operated by NCAR and other institutions

Working closely with colleagues in the NCAR and Facilities Section, AGS, and throughout NSF, the incumbent will have primary responsibility for the programmatic oversight, award management and lifecycle planning of the AGS-funded lower atmosphere observing facilities. The incumbent will also support the Section's oversight of NCAR and cross-cutting programs. Specific duties will include:

- Manage solicitations, programs and budgets for operating and deploying AGS national lower atmospheric observing facilities.
- Oversee and serve as the primary point of contact for the lower atmosphere observing facilities operated by the NCAR.
- Work with NSF science program officers to ensure that the deployment of the AGS lower atmosphere observing facilities is well-coordinated, technically feasible and equitable.
- Working with colleagues, the scientific community and facility managers, lead the development of long-range plans for the AGS national lower atmospheric observing facilities.
- Serve as a Divisional point of contact and program officer for NSF-wide research infrastructure initiatives.
- Serve on intra-agency, inter-agency and international committees involving lower atmosphere observing facilities

Apply by emailing Alindsle@nsf.gov.

Biogeosciences

Postdoctoral Position in Soil Structure and Climate Change

A postdoctoral scholar position is available in the Pedology Laboratory in the Department of Environmental Sciences at the University of California, Riverside. We are looking for a highly-motivated independent researcher to join a collaborative, NSF-funded project to work on understanding the mechanisms behind recent observations of rapid, climate-induced soil structural changes and their consequences on soil hydraulic properties. A major goal of the project is to apply advanced multivariate techniques on recently-compiled, large, soil morphological, chemical, physical, and environmental datasets to answer questions about soil structural development. Hence, experience with statistical/ geostatistical analysis of big data is highly desirable as is formal training and experience with structural equation modeling.

Qualifications:

The successful candidate should hold a PhD degree in soil science, critical zone science, ecosystem ecology, or a related field with an emphasis on statistical analysis or pedometrics. The candidate should have experience with analyzing complex datasets using scripting languages such as R, Python, or MATLAB and ideally have published in peer reviewed scientific journals. Candidates must have received a PhD within the past five years from an accredited college or university.

Application contents:

–One-page cover letter describing the applicant's research experiences and interests

–Curriculum vitae

–Names, addresses, emails, and phone numbers for 3 references

Applications or informal inquiries can be sent to Dr. Daniel Hirmas at daniel.hirmas@ucr.edu with SOIL POSTDOC as the subject line.

UCR is an EEO/AA/ADA/Vets Employer.

Interdisciplinary

Assistant Professor (tenure track) in Paleoclimate Sedimentology

The Faculty of Geosciences and the Environment (FGSE) of the University of Lausanne invites applications for a professorship in Paleoclimate Sedimentology, to be based in the Institute of Earth Sciences (ISTE).

We are looking for an excellent sedimentologist who focuses on the reconstruction of past climate changes (including sedimentary, paleoclimate, biological and paleoceanography changes) at geological timescales using the stratigraphic and sedimentary record. We seek a candidate who can provide an innovative interpretation of sedimentary archives, using laboratory, and field techniques and reconstructing Earth system history. The ideal candidate should have a strong background in geology, a strong commitment to field-based research and a willingness to contribute to field-based teaching.

The successful candidate will actively participate in the research activities of the Institute of Earth Sciences, will teach in the Bachelor of Geosciences and Environment and in relevant Masters taught by the FGSE, and will supervise masters and doctoral students.

Appointment will be at the Assistant Professor level (tenure track). However, exceptionally, we will consider outstanding candidates for direct appointment to the Associate or Ordinary Professor level, notably if this corresponds with our equal opportunity objectives.

Application deadline: August 24th, 2019 (23:59 Swiss time GMT+2)

Details how to apply on:

https://bit.ly/2PPF6Da

Or www.unil.ch/central/en/home.html -> Jobs -> search sedimentology

Associate Professor in Tectonophysics of Orogenic Processes

The Faculty of Geosciences and the Environment (FGSE) of the University of Lausanne invites applicationsfor a professorship in Tectonophysics of Orogenic Processes, to be based in the Institute of Earth Sciences (ISTE).

We are looking for an excellent candidate interested in the tectonophysics of mountain building processes to strengthen and complement the research foci of the FGSE on orogenic processes and geocomputing. The ideal candidate will use various geophysical methods such as seismology, gravimetry, and/or remote sensing to investigate mountain belts, preferentially focusing on the Alps and the Himalayas. We are particularly interested in candidates who integrate field observations and computational models. Areas of interests will cover the role of tectonic activity on lithospheric deformation processes, including the interactions between sub-surface and surface processes, such as those that affect human environments.

The successful candidate will actively participate in the research activities of the Institute of Earth Sciences, will teach in the Bachelor of Geosciences and Environment and in relevant Masters taught bythe FGSE, and will supervise masters and doctoral students.

Appointment will be at the Associate Professor level. However, exceptionally, we will consider outstanding candidates for direct appointment to the Full Professor level, notably if this corresponds withour equal opportunity objectives.

Application deadline: August 22nd, 2019 (23:59 Swiss time GMT+1)

The application will be considered only if sent through this website where you find a full description ofthe position: https://bit.ly/2N6Hs2K or www.unil.ch/central/en/home.html -> Jobs -> search Tectonophysics

Faculty Position in Paleontology

The Museum of Paleontology and the Department of Earth and Environmental Sciences at the University of Michigan are searching for a full-time tenure-track faculty candidate in the field of Paleontology at the assistant professor/assistant curator level. This is a university year appointment with an expected start date of September 1, 2020. The Museum of Paleontology has recently relocated its internationally significant collections of plant, invertebrate and vertebrate fossils to the new Research Museums Center. Paleontology faculty labs and offices are in

the newly completed Biological Sciences Building, which houses other academic units and the Museum of Natural History which attracts over 165,000 visitors a year.

We seek applicants who have broad research and teaching interests within developing areas of evolutionary or environmental paleontology. We are especially interested in applicants investigating the invertebrate fossil record, although exceptional candidates with other areas of taxonomic expertise will be considered. The Museum and Department invite applicants in fields including, but not restricted to: macroevolution, interactions of developmental biology and evolution, extinction dynamics, paleoecology, organismal paleobiology, and biotic responses to global change.

The successful candidate is expected to establish an externally funded research program and contribute to excellence in undergraduate and graduate teaching. Applicants must have a Ph.D. at the time of appointment and should submit the following: 1) cover letter; 2) CV; 3) statement of current and future research plans; 4) statement of teaching philosophy and experience; 5) evidence of teaching excellence, if available; 6) statement of activities contributing to diversity, equity, and inclusion in academia; 7) up to four publications; and 8) the names and contact information for at least four references.

Information about the Museum and Department can be found at www.lsa.umich.edu/paleontology and www.lsa.umich.edu/earth. To apply please go to https://ummp-earth.lsa.umich.edu/search19/, complete the online form, and upload the required application documents as a single PDF file. If you have any questions or comments, please send an email message to ummp-earth-search@umich.edu.

The application deadline is August 31, 2019 for full consideration, but applications will continue to be reviewed until the position is filled. We expect to begin on-campus interviews in late Fall 2019.

The University of Michigan is supportive of the needs of dual career couples and is an Affirmative Action/Equal Opportunity Employer. Women and members of minority groups are encouraged to apply.

Tenure-Track & Postdoc Positions in Dept. of Atmospheric and Oceanic Sciences, Peking University

The Department of Atmospheric and Oceanic Sciences of Peking University invites applications for multiple tenure-track faculty positions in atmospheric and oceanic sciences. Four positions are available in physical oceanography, particularly in the areas of ocean general circulation and dynamics, air-sea interaction and climate, ocean biogeochemical cycle, ocean model development, and satellite oceanography. Five positions are available in atmospheric sciences, particularly in the areas of climate dynamics and modeling, synoptic and meso-scale meteorology, radiation and remote sensing, atmospheric chemistry, cloud physics, atmospheric boundary layer, land-air interaction, and planetary atmospheres. All positions are at the tenure-track assistant professor level under the "Young Qianren" or "Bairen" programs. For exceptional cases, a more senior starting position may be considered. Recruiting is conducted three times each year, until all positions are filled. On-site interview is conducted in January, April, or October, and the application deadline is normally one month before the on-site interview. The deadline of the next round of application is September 15, 2019. For application qualifications, benefits, required materials, and contact information, visit http://www.atmos.pku.edu.cn/rczp/99282.htm.

Meanwhile, all disciplines of our department are hiring postdocs with different application deadlines and compensation packages; see http://www.atmos.pku.edu.cn/rczp/99283.htm.

Postdoctoral Researcher in Aqueous Geochemistry/Hydrothermal Systems

The Department of Earth Sciences at the University of Minnesota-Twin Cities seeks applicants for a post-doctoral position involving experimental and theoretical studies of mineral-fluid reactions in hydrological and hydrothermal systems. The position requires a Ph.D. in geochemistry or related fields. Familiarity with laboratory research, computer modeling, and experience with mineral surface analysis is beneficial. This is a one-year appointment with the likely possibility of renewal based upon performance and ongoing operational needs. Please visit the research group website:

https://www.esci.umn.edu/groups/Bill-Seyfried/Aqueous-Geochemistry

For questions regarding the position please contact Dr. Seyfried (wes@umn.edu).

Candidates must apply online at http://humanresources.umn.edu/jobs; Job Posting ID Number: 324489*; and must submit CV/Resume and a Cover Letter. Recommended but not required are Statement of Research Interests and Names of Three References.

The University of Minnesota is committed to the policy that all persons shall have equal access to its programs, facilities, and employment without regard to race, color, religion, national origin, sex, age, marital status, disability, public assistance status, veteran status or sexual orientation.

Professor of Geophysics

The Board of Electors to the Professorship of Geophysics invite applications from persons whose work is connected with relevant aspects of the Earth Sciences, to take up an appointment in the academic year 2019/20 or as soon as possible thereafter.

Candidates will have an outstanding research record of international stature in quantitative physical Earth Sciences, especially in the broad areas of geophysics, geodynamics or tectonics. The person appointed will have the vision, experience and enthusiasm to provide leadership to the Department's multidisciplinary research strategy, which seeks to place fundamental Earth science research at the heart of addressing current and future societal challenges. They will hold a PhD or equivalent postgraduate qualification.

Standard professorial duties include teaching and research, examining, supervision and administration. The Professor will be based at the Bullard Labs and develop intellectual links between the two geographically separate sites occupied by the Department (at the Bullard Labs and in central Cambridge). A competitive salary will be offered.

Further information is available at: http://www.hr.admin.cam.ac.uk/professorships or contact the Human Resources, University Offices, The Old Schools, Cambridge, CB2 1TT, (email: professorships@admin.cam.ac.uk).

Applications, consisting of a letter of application, a statement of current and future research plans, a curriculum vitae and a publications list, along with details of three referees should be made online (http://www.jobs.cam.ac.uk/job/21829) no later than 30 July 2019.

Informal enquiries may be made to Professor Harrison, Convenor of the Board of Electors, Cambridge, telephone +44 (0)1223 333380 or email rjh40@cam.ac.uk

The Department is committed to equality and diversity and inclusion, we would particularly welcome applications from women and minority candidates. Details of some of the family-friendly policies operated by the University are at: http://www.hr.admin.cam.ac.uk/pay-benefits/cambens-employee-benefits/family-friendly. We are committed to fostering a collaborative and inclusive working environment and the University holds an institutional Athena-SWAN silver award and the Department holds an Athena-SWAN bronze award.

See also our website http://www.esc.cam.ac.uk

Department of Earth Sciences, Downing Street, Cambridge CB2 3EQ, UK.

Professor of Mineralogy and Petrology

The Board of Electors to the Professorship of Mineralogy and Petrology invite applications from persons whose work is connected with relevant aspects of the Earth Sciences, to take up appointment in the academic year 2019/20 or as soon as possible thereafter.

Candidates will have an outstanding research record of international stature in the broad areas of mineralogy, petrology or geochemistry. The person appointed will have the vision, experience and enthusiasm to provide leadership to the Department's multidisciplinary research strategy, which seeks to place fundamental Earth science research at the heart of addressing current and future societal challenges. They will hold a PhD or equivalent postgraduate qualification.

Standard professorial duties include teaching and research, examining, supervision and administration. The Professor will be based in the Department of Earth Sciences in Cambridge and develop intellectual links between the two geographically separate sites occupied by the Department (in central Cambridge and at the Bullard Labs). A competitive salary will be offered.

Further information is available at: http://www.hr.admin.cam.ac.uk/professorships or contact the Human Resources, University Offices, The Old Schools, Cambridge, CB2 1TT, (email: professorships@admin.cam.ac.uk).

Applications, consisting of a letter of application, a statement of current and future research plans, a curriculum vitae and a publications list, along with details of three referees should be made online (http://www.jobs.cam.ac.uk/job/21830/) no later than 30 July 2019.

Informal enquiries may be made to Professor Harrison, Convenor of the Board of Electors, Cambridge, telephone +44 (0)1223 333380 or email rjh40@cam.ac.uk

The Department is committed to equality and diversity and inclusion, we would particularly welcome applications from women and minority candidates. Details of some of the family-friendly policies operated by the University are at: http://www.hr.admin.cam.ac.uk/pay-benefits/cambens-employee-benefits/family-friendly. We are committed to fostering a collaborative and inclusive working environment and the University holds an institutional Athena-SWAN silver award and the Department holds an Athena-SWAN bronze award.

See also our website http://www.esc.cam.ac.uk

Department of Earth Sciences, Downing Street, Cambridge CB2 3EQ, UK.

Near Surface Geophysics

Berkeley Lab's Energy Geosciences Division has an immediate opening for a Staff or Senior Scientist in Applied Geophysics.

About Energy Geosciences at Berkeley Lab:

The Energy Geoscience Division (EG., https://eesa.lbl.gov/our-divisions/energy-geosciences/D) of Berkeley Lab is advancing and integrating multi-disciplinary expertise to accelerate scientific discoveries and their translation into scalable solutions for the sustainable utilization and management of the Earth's subsurface. We strive to promote the intelligent use of the subsurface as a substantial resource for energy and water, as well as its wise use for waste disposal. We work at the cutting edge of observation, measurement, and simulation of rock-fluid processes through the development and use of methodologies that span from the molecular to field scales. Together with our sister division in the Earth and Environmental Sciences Area (EESA, https://eesa.lbl.gov/), we address the most pressing energy and environmental challenges of our time, striving for scientific excellence that makes a difference in a changing world. We deeply care for an inclusive and diverse work environment and we are fully invested in the well-being and advancement of our staff.

About the position:

The Earth Scientist in this position is an outstanding Applied Geophysicist with a record of scientific vision and innovative research in characterizing and imaging subsurface structures and processes. A successful candidate is expected to lead and expand a vibrant, extramurally supported frontier research program in applied geophysics with a broad range of exciting research projects involving novel field methods and experiments. Particular focus is on geophysical methods such as active source seismic techniques, borehole seismic acquisition and source development, distributed fiber optic sensing methods, permanent reservoir monitoring, and time-lapse seismic imaging approaches. Aligned with EGD's 'Sustainable Earth' (https://eesa.lbl.gov/about/strategic-vision-2025/sustainable-earth/) Strategic Direction, these methods will be utilized in a variety of contexts relevant to DOE's mission of finding scientific solutions for the sustainable utilization of the subsurface, including characterization and monitoring of geological carbon storage, geothermal systems, oil and gas reservoirs, nuclear waste disposal, and groundwater management. The successful candidate will take advantage of world-class experimental and computational facilities at Berkeley Lab, including LBNL's unique Geosciences Measurement Facility which has extensive resources for novel field seismic acquisition including high-temperature wirelines, downhole tools, recording systems, instrument fabrication facilities, and fiber optic sensing resources as well as more traditional geophysical instrumentation. Active collaboration with other scientific divisions across

ASSISTANT/ASSOCIATE/FULL PROFESSORS-GEOPHYSICS, STRUCTURE GEOLOGY, GEODESY, SPACE PHYSICS

The Department of Earth and Space Sciences(ESS) at Southern University of Science and Technology of China (SUSTech) invites applications for tenure-track (or tenured) faculty positions at the ranks of **Assistant, Associate, and Full Professors.** Applicants must have earned a doctoral degree in Geophysics Structure Geology Geodesy Space Physics Planetary Science or closely related fields. Successful applicants will be expected to establish a robust, externally funded research program and demonstrate strong commitment to undergraduate and graduate teaching, student mentoring, and professional services. These positions will remain open until filled.

For more other information about ESS, please go to the website **http://ess.sustech.edu.cn/.**

SUSTech is a public university founded in Shenzhen, China. It is intended to be a top-tier international university that excels in interdisciplinary research, nurturing innovative talents and delivering new knowledge to the world. SUSTech was born in 2011 with a mission to reform higher education in China. Since then, it has been widely regarded as a pioneer and innovator in collectively moving China's higher education forward to match China's ever-growing role in the international arena. Research, Innovation and Entrepreneurship are the three pillars for SUSTech to stand out with distinctive Characteristics.

To apply, please submit an e-mail application that includes a cover letter, a CV with a full list of publications, a research statement, a teaching statement and contact information for three references to Prof. Xiaofei Chen at **chenxf@sustech.edu.cn.**

The Department of Geosciences at The Pennsylvania State University, University Park, PA invites applications for multiple faculty positions:

TWO TENURE-TRACK POSITIONS IN EARTH HISTORY

The Department of Geosciences at The Pennsylvania State University, University Park, PA invites applications for two tenure-track faculty positions in fields broadly related to understanding the history and evolution of Earth's surface, atmosphere, and oceans over a range of timescales. We seek creative colleagues working to understand the coupling and feedbacks between Earth-surface processes, deep-Earth processes, ocean dynamics, and/or climate. We are especially interested in applicants who integrate modeling, laboratory, and/or field techniques and whose research and teaching would complement existing departmental strengths in geobiology, geochemistry, and geophysics. The Department of Geosciences is part of the College of Earth and Mineral Sciences (EMS) and, along with the Earth and Environmental Systems Institute (EESI), houses research programs spanning a broad range of Earth Systems Science. Successful applicants will be expected to engage with our research and teaching community by developing vigorous, externally funded research programs, contributing to the Department's undergraduate and graduate teaching mission, and working to advance equity and inclusion in geosciences. Applicants must have a Ph.D. in geosciences or related field at the time of appointment. We anticipate filling the positions at the Assistant Professor level, but applications at higher rank may be considered in exceptional circumstances. Appointments could begin as early as July 1, 2020. Review of applications will begin on August 15, 2019 and continue until the positions are filled. Applications should be submitted online and include: (i) cover letter; (ii) curriculum vitae; (iii) statement of research plans and vision; (iv) statement of teaching philosophy and interests; (v) statement describing ideas for fostering diversity, inclusion and equity within the department and the applicant's research community; and (vi) names and contact information for three references. Questions about the position should be directed to Liz Hajek, Search Committee Chair, at mailto:hajek@psu.edu.
To apply, visit **https://apptrkr.com/1506653**

TENURE-TRACK FACULTY, HYDROGEOLOGY

The Department of Geosciences at The Pennsylvania State University, in University Park, PA invites applications for a tenure-track faculty position in the field of Hydrogeology, to be filled at the rank of Assistant or Associate Professor, depending upon the successful candidate's qualifications and experience. We seek a creative colleague who will develop a vigorous externally-funded research program, teach undergraduate and graduate courses, and demonstrate commitment to advancing equity and inclusion. The Department of Geosciences is part of the College of Earth and Mineral Sciences, and houses top-ranked research programs in environmental and climate sciences, geology, geophysics, and geochemistry. Water is an important component of the University Strategic Plan, and Penn State hosts several campus-wide initiatives in water resources through, for example, the Penn State Institutes of Energy and the Environment (http://www.iee.psu.edu) and the Earth and Environmental Systems Institute (http://www.eesi.psu.edu). Applications should be submitted online and include: cover letter, curriculum vitae, statement of research vision, statement of teaching interests, and evidence, either woven through their application materials or as a separate diversity statement, of a commitment to fostering diversity, equity, and an inclusive environment in their department/workplace. Additionally, we request names and contact information for four references. Applicants must have a Ph.D. in Geosciences or related field at the time of appointment. Appointment could begin as early as July 1, 2020. Review of applications will begin on October 10, 2019 and continue until the position is filled. For additional information, please contact Don Fisher, Chair of the Search Committee, at mailto:dmf6@psu.edu.
To apply, visit **https://apptrkr.com/1508765**

DIRECTOR OF DIVERSITY PROGRAMS IN GEOSCIENCES

The Department of Geosciences at The Pennsylvania State University, on the University Park Campus, invites applications for a fixed-term multiyear faculty position as Director of Diversity Programs. The initial appointment will be for a 3-year term, from the date of hire, with excellent possibility for renewal. We seek a colleague who will build on existing departmental programs, mentor students, and lead, develop and innovate a suite of sustainable research and teaching initiatives that promote and support a diverse body of students, staff, and faculty members committed to inclusivity and equity. Existing programs within the Department of Geosciences and the College of Earth and Mineral Sciences (EMS) include AfricaArray, TRiO programs, a joint degree program with Fort Valley State University, Millennium Scholars, WISER (Women in Science and Engineering) and oSTEM (Out in STEM). The successful candidate will work to develop and implement programs broadening diversity, inclusion, and educational equity in the Department of Geosciences at Penn State and within the broader academic community. This work will include: fostering existing and developing new diversity initiatives in Geosciences; acquiring outside funding for projects; an expectation to teach and/or conduct research that is published in peer reviewed journals, reports, and conference abstracts; engaging in professional development leading to national or international stature in the candidate's areas of interest. Ideal candidates will have experience in multicultural excellence and Geosciences pedagogy, including demonstrated experience working with a diverse population of students and a demonstrated ability to work collaboratively towards common goals with a variety of stakeholders. The successful candidate will work closely with the EMS Office of the Associate Dean for Educational Equity. At the time of appointment, applicants must have either a Ph.D. in Geology or a related field and demonstrated experience managing diversity, inclusion and/or educational equity programs, or a Ph.D. or equivalent degree in Education, Multicultural Affairs, Sociology or a related field and demonstrated experience managing Earth Science projects. We anticipate filling the position at the assistant research or assistant teaching professor rank but applications at higher rank may be considered under exceptional circumstances. Appointment could begin as early as January 1, 2020. Review of applications will begin on September 1, 2019 and continue until the position is filled. Applications should be submitted online and include: a cover letter; curriculum vitae; a statement demonstrating evidence of fostering diversity, equity, and an inclusive environment in the department/workplace; a statement of research and teaching vision; and names and contact information for four references. For additional information, please contact Tanya Furman, Chair of the Search Committee, at mailto:furman@psu.edu.
To apply, visit **https://apptrkr.com/1508766**

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/, which will also provide you with detail on how to request a hard copy of the Annual Security Report.

The Pennsylvania State University`s College of Earth and Mineral Sciences takes an active role in building talented, inclusive and culturally competent workforce. We understand that our shared future is guided by basic principles of fairness, mutual respect, and commitment to each other. Applicants should share this commitment to fostering diversity, equity, inclusive excellence, and belonging and of engagement that creates an inclusive environment in their department/workplace.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

Berkeley Lab as well as with UC Berkeley is expected.

How To Apply

Apply directly online at http://50.73.55.13/counter.php?id=162838 and follow the on-line instructions to complete the application process.

Berkeley Lab's Energy Geosciences Division has an immediate opening for a Staff or Senior Scientist in Applied Geophysics.

About Energy Geosciences at Berkeley Lab:

The Energy Geoscience Division (EG., https://eesa.lbl.gov/our-divisions/energy-geosciences/D) of Berkeley Lab is advancing and integrating multi-disciplinary expertise to accelerate scientific discoveries and their translation into scalable solutions for the sustainable utilization and management of the Earth's subsurface. We strive to promote the intelligent use of the subsurface as a substantial resource for energy and water, as well as its wise use for waste disposal. We work at the cutting edge of observation, measurement, and simulation of rock-fluid processes through the development and use of methodologies that span from the molecular to field scales. Together with our sister division in the Earth and Environmental Sciences Area (EESA, https://eesa.lbl.gov/), we address the most pressing energy and environmental challenges of our time, striving for scientific excellence that makes a difference in a changing world. We deeply care for an inclusive and diverse work environment and we are fully invested in the well-being and advancement of our staff.

About the position:

The Earth Scientist in this position is an outstanding Applied Geophysicist with a record of scientific vision and innovative research in characterizing and imaging subsurface structures and processes. A successful candidate is expected to lead and expand a vibrant, extramurally supported frontier research program in applied geophysics with a broad range of exciting research projects involving novel field methods and experiments. Particular focus is on geophysical methods such as active source seismic techniques, borehole seismic acquisition and source development, distributed fiber optic sensing methods, permanent reservoir monitoring, and time-lapse seismic imaging approaches. Aligned with EGD's 'Sustainable Earth' (https://eesa.lbl.gov/about/strategic-vision-2025/sustainable-earth/) Strategic Direction, these methods will be utilized in a variety of contexts relevant to DOE's mission of finding scientific solutions for the sustainable utilization of the subsurface, including characterization and monitoring of geological carbon storage, geothermal systems, oil and gas reservoirs, nuclear waste disposal, and groundwater management. The successful candidate will take advantage of world-class experimental and computational facilities at Berkeley Lab, including LBNL's unique Geosciences Measurement Facility which has extensive resources for novel field seismic acquisition including high-temperature wirelines, downhole tools, recording systems, instrument fabrication facilities, and fiber optic sensing resources as well as more traditional geophysical instrumentation. Active collaboration with other scientific divisions across Berkeley Lab as well as with UC Berkeley is expected.

How To Apply

Apply directly online at http://50.73.55.13/counter.php?id=162830 and follow the on-line instructions to complete the application process.

Ocean Sciences

Oceanography Tenure-Track Faculty

Data Science in Oceanography spans disciplines from climate science to molecular biology. Its integration into Oceanography has the potential to change conventional research approaches by combining emerging data analytics technology with high-resolution and multidisciplinary ocean-related datasets. We seek an interdisciplinary early career scholar with a record of active research and publication in the area of Ocean Data Science to join the Department of Oceanography at Texas A&M University at the rank of tenure-track Assistant Professor. We expect this individual to play an active role in strengthening our existing interdisciplinary research programs by nucleating new research initiatives that utilize data analytics, information processing, and/or high performance computing to address problems in Oceanographic research. In addition to collaborations within the Department of Oceanography, the newly established Texas A&M Institute of Data Science (TAMIDS) (https://tamids.tamu.edu) provides an excellent platform to launch new Data Science related research collaborations. We welcome applicants with any disciplinary specialty in Ocean Data Science application and technology, including biological oceanography, ocean remote sensing, ocean and climate modeling, and others.

Applicants should have a Ph.D. (or equivalent) and at least 5 years of research experience in Ocean Data Science application and technology. Candidates for this position should submit a letter of application, curriculum vitae, and the names of three confidential references to http://apply.interfolio.com/62774. Review of applications will begin on September 1, 2019 and continue until the position is filled.

The Department of Oceanography at Texas A&M University, located in College Station, Texas is part of an alliance of Ocean Sciences that includes the Marine Biology and Marine Sciences Departments at TAMU Galveston, the Geochemical and Environmental Research Group, the International Ocean Discovery Program, and Texas Sea Grant. This alliance of Ocean Sciences represents a unique concentration of educational and research resources. The capacity is greatly enhanced by close ties to the College of Geosciences Departments of Atmospheric Sciences, Geography, and Geology & Geophysics, as well as the Berg Hughes Center, the Texas Center for Climate Studies and the International Laboratory for High-Resolution Earth System Prediction. The Department web site http://ocean.tamu.edu contains a full description of our program.

Texas A&M University is committed to enriching the learning and working environment for all visitors, students, faculty, and staff by promoting a culture that embraces inclusion, diversity, equity, and accountability. Diverse perspectives, talents, and identities are vital to accomplishing our mission and living our core values.

The Texas A&M System is an Equal Opportunity/Affirmative Action/Veterans/Disability Employer committed to diversity.

Questions regarding this position should be directed to the committee chair: Dr. Ping Chang at: ping@geos.tamu.edu.

Planetary Sciences

Europa Geophysical Modeling

Overview

New ideas are all around us, but only a few will change the world. That's our focus at JPL. We ask the biggest questions, then search the universe for answers—literally. We build upon ideas that have guided generations, then share our discoveries to inspire generations to come. Your mission—your opportunity—is to seek out the answers that bring us one step closer. If you're driven to discover, create, and inspire something that lasts a lifetime and beyond, you're ready for JPL.

Located in Pasadena, California, JPL has a campus-like environment situated on 177 acres in the foothills of the San Gabriel Mountains and offers a work environment unlike any other: we inspire passion, foster innovation, build collaboration, and reward excellence.

Responsibilities

The research may geological and/or structural mapping of Europa using GIS tools and quantitative analyses of mapped data, including modeling of associated stresses. Geophysical analyses may involve modeling of impact, melt, and/or tectonic processes relevant to Europa, with possible application to other outer planet satellites. Dr. Robert Pappalardo will serve as the postdoctoral advisor. The appointee will carry out research in collaboration with the JPL advisor and others, resulting in publications in the open literature.

Qualifications

Candidate should have a recent Ph.D. in geology, physics, or a related field with a strong background in geophysical research. Experience in modeling and/or research relevant to the outer planet satellites is highly desirable. The appointment is contingent upon evidence of completion of a Ph.D.

Candidates who have received their PhD within the past five years since the date of their application are eligible. Postdoctoral Scholar positions are awarded for a minimum of one-year period and may be renewed up to a maximum duration of three years.

Candidates should submit the following to pappalardo@jpl.nasa.gov: CV, representative publications, contact information for three references, and a cover letter stating their research accomplishments and interests.

Hej, AGU!

Greetings from the North Pole! As part of the U.S.–Swedish expedition Arctic Ocean 2018, we are here to study Arctic aerosols and clouds. In particular, we are investigating the importance of local particle sources (e.g., from marine microbiology) in relation to long-range transported aerosol to the formation of low-level Arctic clouds. I'm sending this photo from our 5-week ice camp, where we have installed tethered balloons and a floating aerosol chamber to sample aerosol particles and cloud water. Most of my time is spent on the fourth deck of the icebreaker *Oden*, which you can see in the background, where we continuously collect particles and cloud droplets or ice crystals, which are then analyzed with instruments housed in laboratory containers.

We hope to present some exciting results at AGU's Fall Meeting 2019 in San Francisco! Until then, hej då from Sweden.

—Paul Zieger, Stockholm University, Stockholm, Sweden

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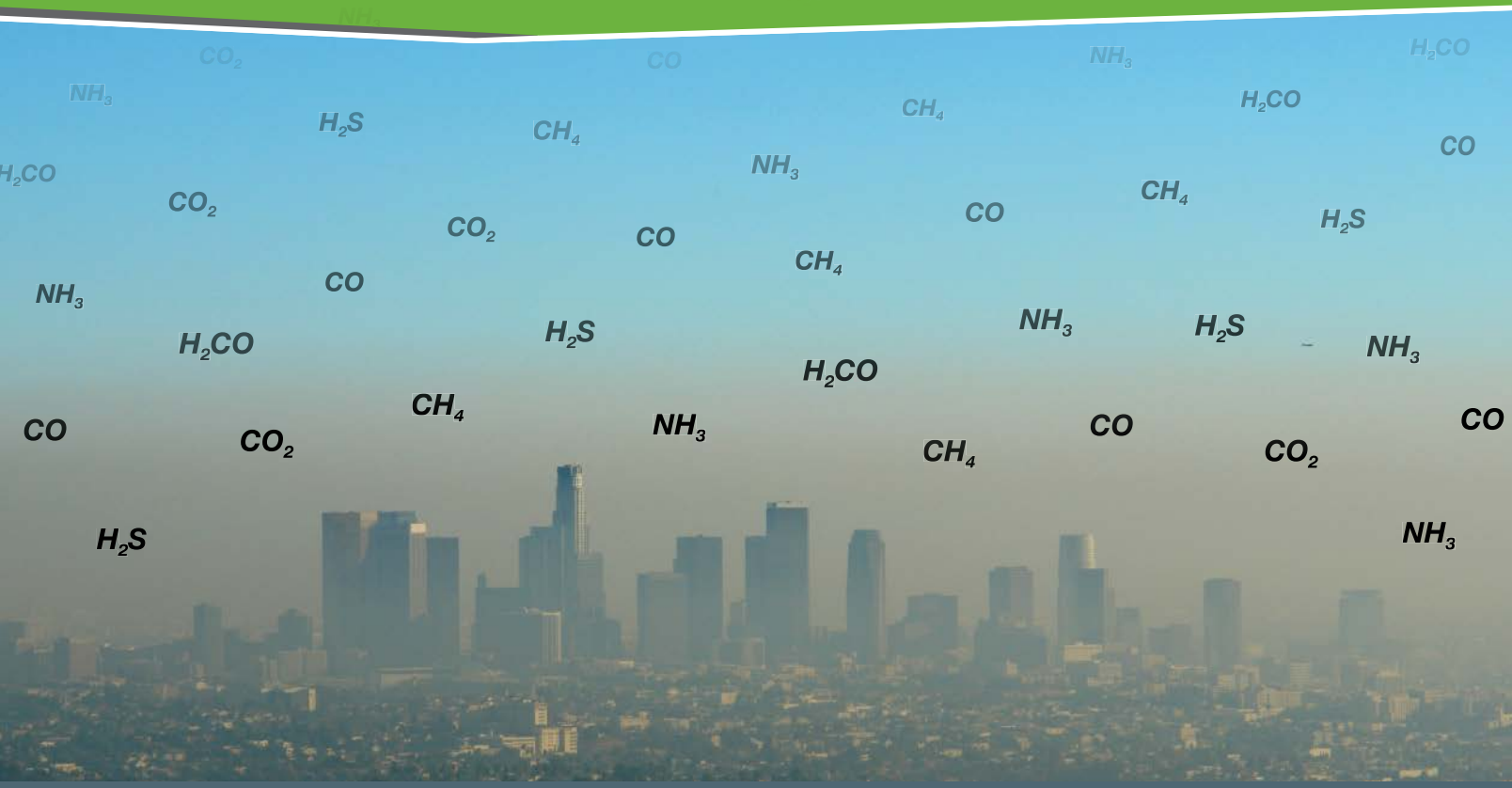

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G2301	CO_2 - CH_4 - H_2O
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