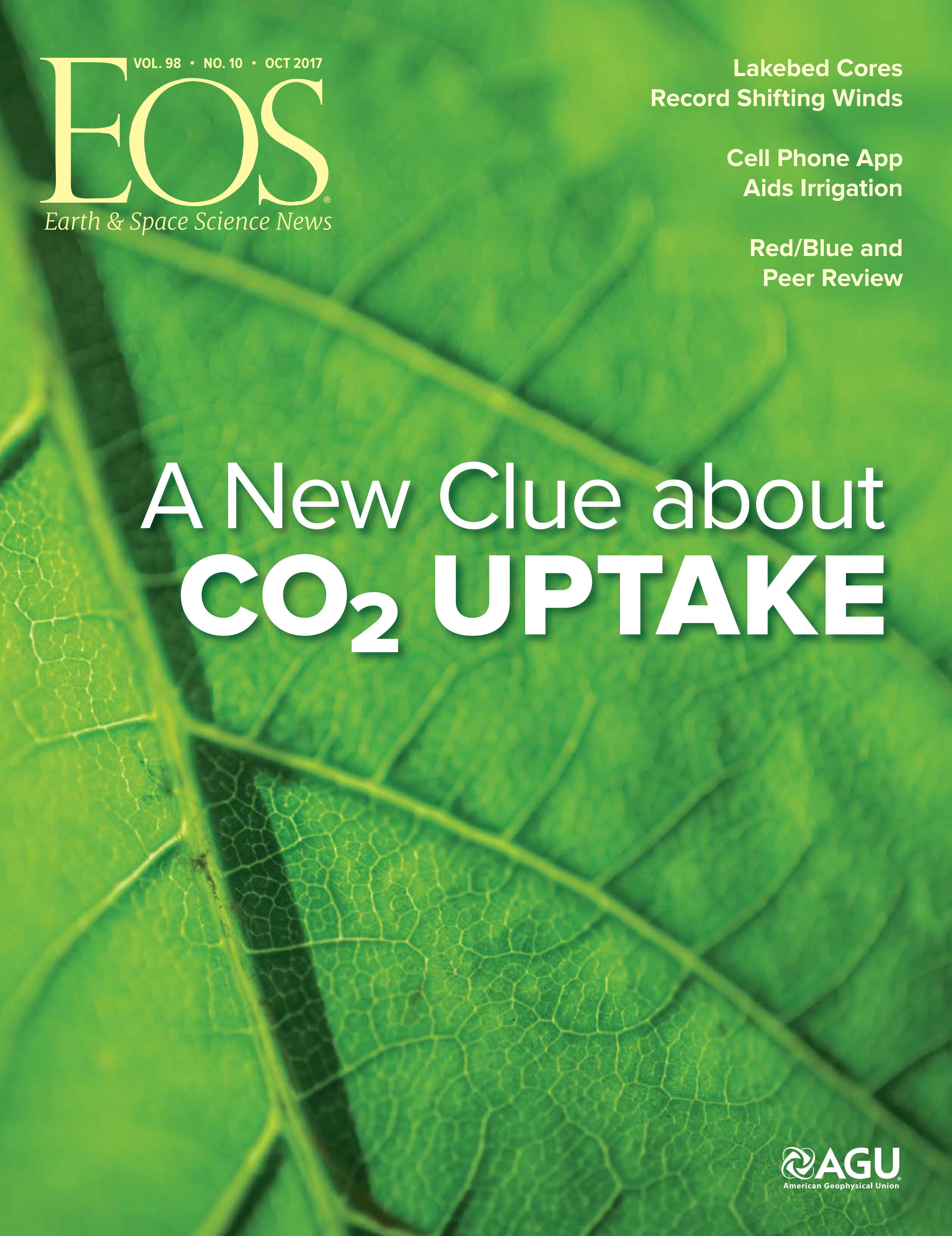

VOL. 98 • NO. 10 • OCT 2017

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Earth & Space Science News

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OCTOBER 2017
VOLUME 98, ISSUE 10

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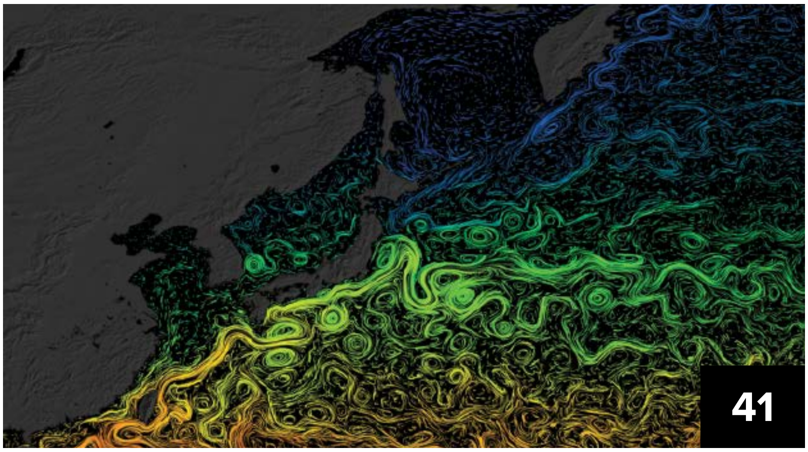

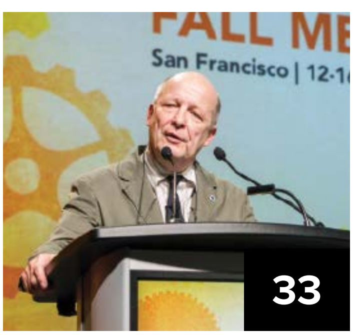

On the Cover

Credit: Bahadir Tanriover/iStock/Getty Images Plus.

EOS®

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

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

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Christine W. McEntee, Executive Director/CEO

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Indonesian Cave Reveals Nearly 5,000 Years of Tsunamis

The cave didn't look that promising from the outside, Charlie Rubin remembers. But when the earthquake geologist and his colleagues walked in and started digging, "our jaws dropped," he said. The researchers noticed that a depression in the floor of the cave—near Banda Aceh, Indonesia—contained distinct stratigraphy: dark layers of organic material separated by clearly defined layers of lighter-colored sand.

"We looked at each other and wondered if the sand was tsunami sand," Rubin said. After closer examination, the team members realized they had found a natural record of tsunamis sweeping sand repeatedly into the cave over thousands of years. By radiocarbon dating the sandy layers, the researchers were able to achieve what's often thought of as a holy grail in tsunami science: a reconstruction of when previous tsunamis occurred thousands of years in the past.

Rubin and his colleagues showed that at least 11 tsunamis had swept over the region over a span of about 5,000 years. But the massive waves were not regular in time; periods of calm ranged from millennia to merely decades. This finding—that tsunami recurrence intervals are highly variable—is proof that regional hazard mitigation plans should be based on the high likelihood of future destructive tsunamis rather than on estimates of recurrence intervals, the team suggests. That's particularly important in the Indian Ocean, a region that's prone to megathrust earthquakes and, accordingly, large tsunamis. Those massive waves include the deadliest tsunami in history, which was unleashed in 2004 not far offshore from where the cave is located and which killed more than 200,000 people.

> The massive waves were not regular in time; periods of calm ranged from millennia to merely decades.

The geological record contained within the Banda Aceh cave is "extraordinary," said Brian McAdoo, a tsunami scientist at Yale-NUS College in Singapore. This study also represents the first time that cave data have been used to measure tsunami recurrence intervals, McAdoo said.

A Layer Cake

In 2011 and 2012, Rubin and his colleagues excavated six trenches at the rear of the 120-meter-long coastal cave. Beneath a crust of sand topped with bat guano, they dug into alternating layers of sand and organic material that reached depths of 2 meters in some places. The scientists carefully collected tiny pieces of charcoal and shells from the layers and radiocarbon dated the material in the laboratory. Using these radiocarbon measurements, the team calculated the most likely age of each of the 11 buried layers of sand and therefore the approximate date of each tsunami.

The researchers found that the 11 sand layers spanned roughly 4,500 years, from about 7,400 to 2,900 years ago. However, the guano-encrusted twelfth and uppermost sand layer—which contained shreds of clothing, suggesting it was deposited very recently—differed from the stack of alternating deposits beneath it: Its bottom face was jagged and irregular, unlike the smooth boundaries between the deeper layers.

The scientists suspect that this irregularity resulted from powerful waves from the 2004 tsunami triggered by the Sumatra-Andaman earthquake sweeping into the cave, scraping away previously deposited material, and literally erasing the geological record laid down after 900 B.C.E. The older layers of sand were probably never dis-

Kerry Sieh (left) and Charlie Rubin use fluorescent lights to look for charcoal and shells in sediment layers in a cave in Indonesia to use to radiocarbon date tsunami deposits. Credit: Earth Observatory of Singapore rupted in a similar way because they're located in a natural depression in the cave, Rubin said. "They're packed down and they're protected."

The research team reported its findings in July in *Nature Communications* (http://bit.ly/nat-comms-paper).

Far from Constant

Rubin and his team showed that the time span between successive tsunamis is far from constant. Although 10 intervals within 4,500 years breaks down to an average of 450 years between the events, the researchers found evidence of one 2,000-year period free of tsunamis and also a single century that saw four tsunamis. "This study provides new evidence that tsunami recurrence can be highly variable," said Katrin Monecke, a geoscientist at Wellesley College in Wellesley, Mass.

The researchers, who included earthquake scientists, hypothesized that the thickness of each sand layer reflects the magnitude of the tsunami-causing earthquake because a larger earthquake would produce a larger tsunami and therefore plausibly transport more sand into the cave. According to this theory, the thickest sand layer, measuring roughly 25 centimeters, should correspond to the strongest earthquake that occurred within the nearly 5,000 years of history recorded in the cave.

The scientists inferred that no tsunamis occurred for more than 2,100 years after this thickest layer of sand was laid down. This extremely long interseismic gap is consistent with a period of reduced stress along faults—and therefore of a lower probability of another quake—after a massive temblor released a large amount of energy, the team suggests. Conversely, the researchers found that the four sand layers corresponding to the four tsunamis that occurred within 100 years of each other were all thin (fewer than 10 centimeters), which makes sense, they argued in their paper, because short interseismic periods are consistent with weaker earthquakes.

Rubin said he and his colleagues hope to find additional caves containing evidence of past subduction zone earthquakes. Although other complementary techniques exist for determining that tsunamis occurred in the past, for example, oral histories and chemical analysis, Rubin and his team are excited to literally dig into the past. "The only way to get at tsunami[s] older than historical records is with geology," Rubin said.

By **Katherine Kornei** (email: hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist

Satellite Observations Could Help Forecast an Eruption's End

Lava flowing from Kīlauea volcano destroyed a road on the island of Hawai'i in 2010. A new study uses satellite observations to help predict how long such outpours of lava will last. Credit: U.S. Geological Survey Hawaiian Volcano Observatory

A method for predicting when a volcano will erupt has long remained out of reach. Less studied, but also important for public safety, is forecasting when eruptions will end, a feat that has proven equally elusive.

Now researchers are using satellite data to test a 1981 theory that lava flow–forming eruptions follow a predictable pattern, and they have confirmed the pattern in many cases. What's more, they find that by using the theoretical model and observations from space as their guides, they can predict with considerable accuracy when those pattern-fitting eruptions will stop.

"I actually didn't think it would work at all," said Estelle Bonny, a Ph.D. candidate at the University of Hawai'i at Mānoa who is affiliated with the Hawai'i Institute of Geophysics and Planetology (HIGP) and is the lead author of a recent paper about the findings. She said that she had suspected the model was too simple for a complex natural process, but "I was happily surprised that it made sense and could be used."

Effusive eruptions, characterized by lava flows, can go on and on. "It might only be a couple of days, but it can also be a year," Bonny said. "For people who live nearby, knowing when it will end can be important to knowing if they have to evacuate and, if they do evacuate, when they will be able to go back home."

"Wadge Curve"

British volcanologist Geoff Wadge came up with the 1981 theory that the rate of flow in an effusive eruption would follow an asymmetrical curve: an early cascade of lava, followed by a gradual decline.

Back then, measuring the rate of discharge involved difficult and dangerous fieldwork, and scientists might get only one or two measurements per eruption. However, since 2000, instruments aboard NASA's Terra and Aqua satellites have taken infrared thermal measurements of active volcanoes four times a day. From this, researchers readily calculate discharge rates. "Now we're lucky to have way more data sets than he had," Bonny said. "We wanted to use this [abundance] of data to see if the theory still makes sense."

In a paper published online in June in the *Bulletin of Volcanology* (http://bit.ly/end-lava-paper), she and her adviser, Robert Wright, associate director of HIGP, looked at 104 effusive eruptions that took place at 34 different volcanoes over the past 15 years. Of these, 32 eruptions followed the asymmetrical "Wadge curve," with an early peak and gradually slowing flow. Eight more were "double-pulse" eruptions: two initial bursts, followed by the same slow decline. Thirteen others she described as "half Wadge": an early peak, followed by a slow flow that continues for a long time.

The remaining 51 eruptions followed no pattern at all. "It's not perfect," Bonny said. "Sometimes it doesn't show the trend, but sometimes it does."

More Data Mean Better Forecasts

For eruptions that did follow the model, the scientists found that they could use satellite data to forecast in retrospect when eruptions would end.

It took 3 days' worth of observations to predict that the December 2005 eruption of Piton de la Fournaise on Reunion Island in the Indian Ocean would last for 9 days—it ended up stopping on the tenth day.

The model also worked for longer volcanic activity, like the eruption of the Kizimen volcano in Kamchatka, Russia, that began in March 2011. Bonny found that the longer she observed the volcano, the more accurate her prediction became. After 102 days of observations, the model predicted that the eruption would end after 210 days, just 2 days shy of the actual duration of 212 days. "About halfway through the eruption you could have a good prediction," she said. The prediction didn't change significantly after the halfway point.

What about eruptions that don't fit the pattern? The team didn't look at explosive eruptions. Those blasts generally offer little mystery about when they will end; most of the action typically ceases after that first, powerful bang.

> "About halfway through the eruption you could have a good prediction."

Among the remaining lava-exuding eruptions the team investigated, Bonny found that the model could still predict double-pulse eruptions simply by resetting the curve at the second peak of the eruption.

However, she and Wright found that the model could predict endings for neither the half Wadge nor random-pattern eruptions. Nonetheless, Bonny said that applying the model to satellite measurements of such eruptions can still yield valuable insights. In about the same amount of time it would take to forecast an eruption's duration, observers can figure out what type of eruption they're dealing with, she noted.

Public Safety Applications

Ben Kennedy, a volcanologist at the University of Canterbury in Christchurch, New Zealand, said that the Hawaii team took the kind of space-based observing, data analysis, and modeling that represents "the future of volcanology" and applied those tools to a practical, public safety problem.

"This paper is answering the right questions," Kennedy said. "Hazard managers need to know what are the likely impacts of the event. A massive part of the impact is the duration of the [eruption]; this affects all sorts of critical hazard management decisions."

Although the study reaffirmed that every eruption is different, it also made significant steps toward classifying effusive eruptions, Kennedy said. "It seems about 50% are behaving in a predictable way. And about 30% are behaving in a way that will allow accurate predictions during the eruption of when it might end."

For Bonny, that's the next step. So far, she has produced only retrospective predictions, but she is now making plans to test the model on volcanic eruptions in real time—maybe on a volcano close to home. Bonny said that a future eruption of the island of Hawai'i's Kīlauea volcano, which has threatened nearby towns with lava flows in the past, would be a good case study for the modeling method.

By **Ilima Loomis** (email: ilima@ilimaloomis.com), Freelance Journalist

Engineering New Foundations for a Thawing Arctic

Walk the streets of Inuvik, an Arctic town of about 3,000 people in northwestern Canada, and you'll notice that all the buildings hover above the ground. They rest on wooden stacks, metal scaffolding, or some variation of wood or steel pillars similar to those found beneath docks.

Residents of this town, situated about 100 kilometers south of the Arctic Ocean, raise their buildings to anchor them against the ever shifting permafrost (permanently frozen ground) that heaves and thaws beneath them each year. Some supports or pilings work better than others, evidenced by abandoned lots where houses or other buildings once stood.

Now, as climate change rapidly thaws permafrost, structures here and across the Arctic are increasingly slumping into the ground. Researchers at Inuvik's Aurora Research Institute (ARI) are joining a wave of new civil engineering efforts to address these structural challenges by testing out a new type of piling. They hope that their experiments will inform infrastructure innovation across the Arctic.

"We are really in a time when we are trying to figure out what types of foundational design[s] would increase the longevity of these buildings in light of climate change," said Erika Hille, manager of ARI.

Inuvik lies within the fastest warming region of the Arctic, so the need to stabilize buildings here is urgent, she said.

The Heat Is On

Winter temperatures in Alaska and western Canada have risen an alarming 3°C to 4°C during the past 50 years, according to a report from the Arctic Monitoring and Assessment Programme (AMAP). Quickly melting sea ice in this region may be a leading cause of this unprecedented change, said Hille. The exposed ocean has decreased albedo, or surface reflectance of the Sun, compared with sea ice. This darker surface warms water locally and amplifies melting and warming across the region in a feedback loop.

Climate models predict that the top 2 to 3 meters of nearly a quarter of the perma-

Beneath the Aurora Research Institute's two-story building in Inuvik, researchers have installed a series of experimental pilings and ground temperature monitors to test best practices in preserving the permafrost below and maintaining the structural stability of the building. Credit: Laura Poppick frost in Canada will thaw by 2100, the AMAP report also states. As the ground softens, the land will become soggy, and foundations will sink with it, Hille said.

Experimental Construction

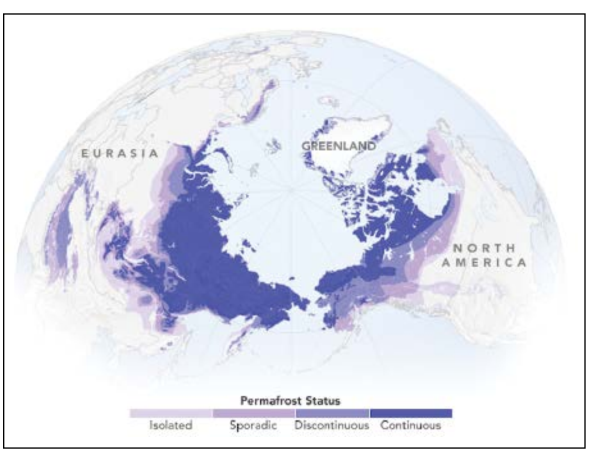
When ARI broke ground in 2011 on a new building, in part to replace old pilings, the now-deceased Canadian permafrost scientist Ross Mackay saw a research opportunity in the construction project. He proposed that ARI install three experimental pilings among the roughly 90 other traditional steel pilings that were planned to support the two-story building.

The traditional steel pilings measure roughly half a meter in diameter, are filled with a gravel slurry containing a mixture of sand and mud, and reach about 14 meters down—far below the site's 4-meter-deep active layer, the layer of soil that thaws each spring. The experimental pilings are exactly the same, except they are left hollow and have vents at the top. Mackay and others involved in the experiments wondered if a hollow pillar would stay colder longer than a filled pillar because it would collect and retain cold air through convection.

Many buildings in Inuvik and across the Arctic use traditional steel pilings as a foundation. Each pillar is filled with a slurry of gravel, sand, and mud that freezes in cold weather and then helps keep the permafrost in which it is buried frozen as the region warms again in the spring and summer. Credit: Laura Poppick

"The idea was that during winter, the cold air would force any warm air out of the pile and that the temperature within the pile would become colder than if it were backfilled," said Hille.

Next to these pilings, ARI installed ground temperature monitors at half-meter increments to collect readings twice daily. This installation was done to test the effectiveness of the new design and also to accrue valuable long-term data on ground temperature changes.



About 37 million square kilometers of permafrost exist in the Northern Hemisphere, but much of that will thaw during this century as Earth's climate warms. Credit: NASA Earth Observatory map by Joshua Stevens, using data from the National Snow and Ice Data Center

False Starts

With 6 years of data collected so far, the experimental pilings aren't working as expected. Convection does cool the pilings in the winter, but springtime ground temperatures have risen higher around the experimental pillars than the traditional ones. ARI researchers attribute this to premature warming of the air within the hollow pilings because of heat exchange through the steel casings of the pillars. The infiltrating springtime warmth more easily raises the temperature of an inner column of air than of frozen slurry, an effect the team hadn't foreseen.

Even so, the experiment and accompanying daily ground temperature data have provided useful information to researchers investigating best practices in piling design.

"I think it's great," said Yuxiang Chen, an environmental engineer at the University of Alberta in Edmonton who plans to use ARI's ground temperature data in models to determine the ideal depth to place pilings. "It's an urgent matter, looking at how to tackle this problem."

The Future of Pilings

In Inuvik, steel pilings filled with gravel slurry are steadily replacing the original pillars of wood used in buildings constructed in the 1950s, said Merle Carpenter, regional superintendent for the Department of Infrastructure of the government of the Northwest Territories. The jury is still out on the long-term value of hollow pilings, although they don't look like a viable option at the moment, he said. However, an even newer iteration, a steel piling shaped like a screw, shows greater promise, he noted. Screwing a piling into the ground displaces and disturbs less permafrost than the drilling required to install current pilings.

Hille said that it's hard to know what will work best in the long term because nobody in the Arctic has ever experienced the rate of exponential permafrost change occurring today. They won't know whether hollow pilings are a viable alternative until they have about 15 years of data, she said, so they will continue collecting temperature data twice each day. Doing so also adds value to the project because it is one of only a handful of long-term ground temperature monitors in Canada.

"We're just trying to figure out the best way to mitigate this change," she said.

By **Laura Poppick** (email: laura.poppick@gmail.com), Freelance Science Journalist

Quakes Pack More Punch in Eastern Than in Central United States

Earthquakes in the eastern United States and Canada are many times more severe than central U.S. earthquakes of human or natural origin, seismologists have found, highlighting a crucial need to separate the two regions when designing future earthquake hazard maps. A new study separated the regions along the Mississippi-Alabama border up to the base of Lake Michigan, approximately 87°W.

"People have never really compared these two regions very carefully," said Yihe Huang, assistant professor of Earth and environmental sciences at the University of Michigan in Ann Arbor and lead author of a paper published in *Science Advances* on 2 August (http://bit.ly/sci-advances-paper).

Because earthquakes have rarely occurred in the central and eastern United States until recently, seismologists have not studied those areas as closely as they have more high-risk ones like the U.S. West Coast. "They are always taken as one region in the hazard models, but...if you look closely, they actually [are] very different," Huang said. "We didn't really think about this before."

Her research shows that there is a fundamental and important difference in the stress released, and therefore in the hazard level, of central U.S. quakes compared with those in the eastern United States and Canada, said Gail Atkinson, professor of Earth sciences and Industrial Research Chair in Hazards from Induced Seismicity at Western University in London, Ontario, Canada.

Different Triggers, Same Shaking

Huang and her coauthors began their investigation questioning whether seismologists can use existing earthquake hazard models—developed using data from naturally occurring tectonic earthquakes—to accurately predict the severity of quakes induced by human activity.

They expected the trigger mechanism to be a major source of uncertainty in hazard prediction models, but they found instead that the biggest difference was geography. Earthquakes they analyzed from the eastern United States and Canada along the Appalachians released 5–6 times more energy than their central counterparts. Consequently, Huang argued that "we should treat the central and eastern U.S. tectonic earthquakes differently in our hazard prediction."

Their study confirmed that earthquakes in the central United States released similar amounts of energy and shook the ground the same way whether they were induced or natural. So seismologists can use the same models to study them all, report Huang and her colleagues.

"Within the central U.S., all of the earthquakes appear to be the same, and we're really comparing apples and apples," said William Ellsworth, professor of geophysics at Stanford University in Stanford, Calif., and a coauthor on the paper.

"We don't need to discriminate why the earthquake occurred to describe its shaking," he said.

A broken angel statue lies among other debris on the roof of the Washington National Cathedral in Washington, D. C., after a magnitude 5.8 earthquake that shook the eastern United States and Canada on 23 August 2011. Credit: AP Photo/J. Scott Applewhite

Different Types of Stress Relief

Why do the two regions produce earthquakes of such different severity? The reason, the researchers explained, is that the central and eastern regions release underground stress using different mechanisms. The way that ground layers shift and slide against each other to dissipate energy determines the violence of the stress release and the strength of high-frequency surface motion, the shaking most relevant for engineering safety and seismic hazard assessment.

Huang explained that in the central United States, all nine earthquakes they examined happened when chunks of Earth's crust slid horizontally against each other along strike-slip faults. Six of the eight eastern earthquakes they analyzed occurred at reverse faults, where the ground shifts vertically against the pull of gravity. Separating by region, Huang said, equates to separating by fault type.

A comparison of earthquake magnitudes in eastern and central regions underscores the greater power of eastern temblors, according to Huang. The team's list of natural events, reaching back more than 15 years, contains only one earthquake stronger than magnitude 5 (*M*5) in the central United States but three from the eastern United States. The strongest, an *M*5.8 quake in Mineral, Va., on 23 August 2011, caused significant property damage but only minor injuries.

Ellsworth explained that industrial processes in the central and eastern United States, like the disposal of wastewater from oil production and hydraulic fracturing, may simply be speeding up the normal geologic processes nearby by releasing underground pressure that builds up naturally. "We might be speeding up the processes by hundreds of thousands of years," he said.

The researchers noted in their paper that wastewater injection is likely acting as a trigger for stress release but that subsequent shaking follows natural tectonic physics. Because the shaking is similar, Huang said, existing ground motion prediction equations can be used to predict the severity of induced earthquakes as long as they first account for the fault type at work.

Improving Hazard Predictions Nationwide

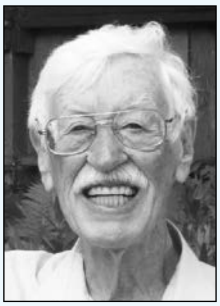
Now that this new work has revealed a significant difference in the types of earthquake-producing faults prevalent in the central and eastern regions, Huang said that she wants to conduct a broader investigation into seismic events nationwide to see whether there are other overlooked patterns related to earthquake strength.

In the meantime, the new recognition of an eastern versus central difference in typical fault type should help improve future hazard prediction maps and guide the construction of earthquake-safe structures, Ellsworth said.

"The more accurate we can make that forecast," he said, "the more it actually reduces the cost of ensuring seismic safety."

By **Kimberly M. S. Cartier** (@AstroKimCartier), News Writing and Production Intern

David S. Evans (1936–2016)


Susan B. Evans

David S. Evans

David S. Evans was one of the pioneers of rocket measurements over auroras. He is perhaps best known for his incisive research on plasma electron acceleration that produces vivid auroral displays. On 14 October 2016, he passed away peacefully at his home in Boulder, Colo., at age 80.

Dave was originally from Milwaukee, Wis., where he was born on 17 June 1936. He received a bachelor's degree in physics from the University of Michigan. His long and productive research career began with graduate research work at the Space Sciences Laboratory of the University of California, Berkeley; he then progressed to NASA's Goddard Space Flight Center (GSFC) in Maryland.

Dave moved to Boulder, Colo., in 1970, where he was a research scientist with the National Oceanic and Atmospheric Administration's (NOAA) Space Environment Center (later renamed the Space Weather Prediction Center) until he retired in 2003. Before he retired, Dave did two tours of duty at NASA headquarters in Washington, D. C., returning each time to Boulder.

During the 1960s, Dave worked with the Bendix Corporation to improve their "channeltron" electron multipliers by curving the channels to reduce ion feedback, which improved their gain and sensitivity dramatically. He used that technical knowledge and experience at GSFC to develop an "open windowed electron multiplier" to measure auroral particles.

Examining Auroras

This innovation also led to improvements in imaging detectors based on microchannel plates. To this day, nearly all space plasma observations are based on these devices. Sounding rockets launched from Canada carried instruments incorporating these imaging detectors. Dave used data from these instruments to perform some of the earliest measurements of the low-energy electron precipitation into the atmosphere that produces the aurora borealis and australis.

His work with the rocket data in the mid-1970s led to his most famous paper, in which he convincingly answered one of the most actively debated questions of that period. He proved for the first time that electric fields aligned parallel to magnetic field lines were responsible for energizing the electrons that form Earth's magnificent auroras. He did this by showing that auroral backscatter and secondary electrons from the atmosphere are trapped and that the observed characteristics of auroral electrons inevitably result. Satellite observations confirmed his prediction that such electrons flow to high altitudes in the absence of discrete aurora.

Dave's interests, and his views on auroras and the requisite electron acceleration, were perhaps best captured in a quote often attributed to him: "Waterfalls are turbulent. But turbulence doesn't make the water fall." He also disparaged Faraday's concept of magnetic field lines of force, believing these field lines to be a conceptual crutch that obscured a clear understanding of the electric fields produced by moving charged particles (electrical currents). He was critical of the idea that magnetic field lines act like rubber bands that can "reconnect." There is no doubt that his opinions on magnetic fields were controversial; he was not afraid to challenge the conventional wisdom. In doing so, he set an example for all of us scientists.

Many of us also know him for his statistical maps of auroral energy influx and characteristic energy. These maps became an operational product at NOAA, and scientists continue to use them today. His auroral maps are used in physics-based models of the upper atmosphere and in assimilative models of auroral electrodynamics.

From 1989 to 1991, during his first stint at the Space Physics Division at NASA in Washington, D. C., he reorganized the peer-review process for research proposals and coordinated many of the reviews over the following years. His mantra was, What's the science question you want to address? Why is it important? And how are you going to answer the question? The basis of his review process is still being used at NASA today.

A Passion for Science

Dave was a penetrating and insightful thinker on many subjects and issues, some political in nature. When one of us first met him, his office featured a "Nixon countdown calendar" that marked the days until the end of Nixon's term in office. During his tours at NASA Headquarters, his interests in space policy were ignited. He was an avid reader of policy-related works, notably *The Heavens and the Earth: A Political History of the Space Age* by Walter A. McDougall.

Many of us also know that Dave had a wry sense of humor. Upon receiving a book that had been on loan from his personal library for more than 20 years, he asked, "What happened to the $100 bill I was using for a bookmark?" One had to have a quick retort to match his quick wit.

Dave was passionate about science and very generous with his knowledge, wisdom, and guidance of early-career scientists. He never hesitated to share what he knew, which meant that many young scientists could build upon his accomplishments. Dave was a truly unselfish leader and motivator, and he loved to chat about physics, particularly over a beer! His scientific integrity and passion for physics have been an inspiration to the life and career of many scientists.

Dave was a family man, and he is survived by Susan, his wife of 57 years; 8 children; 15 grandchildren; and 5 great-grandchildren. Dave loved the Green Bay Packers, Judy Collins songs, and reading. He enjoyed constructing intricate models of World War II airplanes, and he loved riding his motorcycle along mountain back roads and Sunday drives with his family. He was especially fond of XXX IPA beer and sudoku at Southern Sun Pub & Brewery in Boulder's Table Mesa neighborhood, where the employees knew him affectionately as Doctor X.

Dave was a talented, unselfish, and courageous man who will be sorely missed by colleagues, family, and friends, both local and worldwide.

By **Thomas E. Moore,** Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, Md.; and **Tim Fuller-Rowell** (email: tim.fuller-rowell@noaa.gov), Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder; and Space Weather Prediction Center, National Oceanic and Atmospheric Administration, Boulder, Colo.

Red/Blue and Peer Review

The U.S. Environmental Protection Agency (EPA) and the Department of Energy have recently proposed to use an alternative approach to standard peer review for evaluating climate change science, one that is patterned after the red team/blue team exercises developed in the military. In this approach, a red team attempts to penetrate a blue team's defense. However, if the idea is to have the red team poke holes in the mainstream scientific community's (the blue team) consensus on climate change, it discounts that such challenges have already been applied thousands of times while that consensus was gradually developed. A little history of climate science explains why.

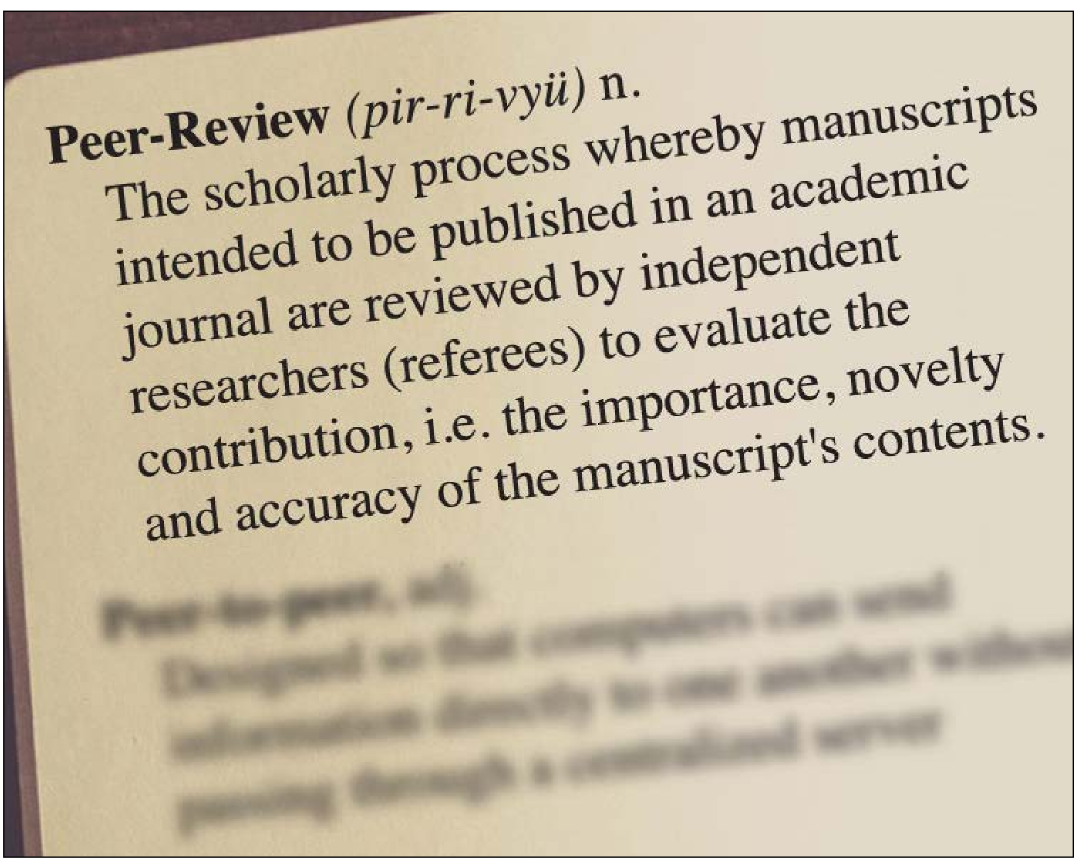
We are old enough to remember when many, if not most, scientists were skeptical that the human impact on climate could be distinguished from natural climatic variation. The journey from the healthy skepticism that existed 40 to 50 years ago to today's well-supported and widespread scientific consensus that humans are changing the climate is a remarkable story of the integrity of the scientific process.

The Long Journey from Skepticism to Consensus

Following theoretical predictions of the climatic effects of atmospheric carbon dioxide (CO_2) made by Swedish chemist Svante Arrhenius in the 1890s, the first good observational record of increasing atmospheric CO_2 began in the late 1950s as part of the International Geophysical Year. Modern climate science started in the 1960s, when general circulation models under development were modified to incorporate the effects of CO_2 and water vapor to understand their impact on climate [*Forster*, 2017]. Not long thereafter, scientists systematically considered what else might explain the new warming trends that started in the 1970s and that continue today.

A number of hypotheses were evaluated from the 1970s through the 1990s. For example, solar scientists concluded that although solar variation (sunspot cycles) does modestly affect climate from one decade to the next, the effect is far too small and too cyclic to account for a multidecadal trend in warming. Similarly, other skeptical scientists hypothesized that expanding cities—with all their asphalt, concrete, and steel—were causing a heat island effect that could be influencing temperature measurements, because weather observation stations that had at one time been outside cities had ended up being right in the middle of them. That hypothesis was also disproven, and surface temperature is now also measured on buoys in remote ocean locations to minimize such an effect. Volcanoes were also studied, both as warming agents from their CO_2 emissions and as cooling agents from the particles they eject into the stratosphere. Scientific analysis showed that the former effect is very small relative to burning fossil fuels and that the latter effect persists for only a few years after the very largest subaerial volcanic eruptions.

By the end of the 1990s, these alternate hypotheses and others to explain late 20th-century warming were carefully ruled out one by one, and consistent with an anthropogenic cause, early 21st-century warming continues unabated with fossil fuel burning.



Definition of peer review from www.yourdictionary.com. Credit: Pixabay/Free-Photos

At the same time, a multitude of climate change trends became clearer, including higher surface temperatures and heat waves, melting Arctic sea ice, receding glaciers, rising sea level, changing patterns of extreme weather events, bird migrations, freeze and thaw dates of lakes, and so on. Confidence in our understanding of the climatic effects of massive releases of CO_2 from burning fossil fuels since the beginning of the Industrial Revolution now converges from three independent lines of inquiry:

- theoretical calculations of the greenhouse effect based on well-known physics and chemistry
- fingerprinting the detailed patterns of climate change caused by different human and natural influences, such as differences among regional patterns of land surface warming, ocean heat content, and sea ice extent that are consistent with an anthropogenic effect

• growing confidence in globally distributed measurements of climate change and its impacts and greater skill in matching those observations to increasingly sophisticated computer models that include the various land, ocean, and atmospheric greenhouse gas sources, sinks, and feedbacks

The scientific community has gradually shifted, on the basis of evidence, from being predominantly skeptical in the 1970s that the human fingerprint on climate could be demonstrated to today being convinced that there are no other plausible explanations besides the cumulative effect of the last 150 years of burning fossil fuel for the recent extent of changing climate. Natural climatic variation is ongoing, but it cannot explain the current speed and amount of observed change. The science does not stand still; studies on how clouds may moderate the rate of climate change and how aerosols (particulate pollution) affect clouds and can offset some warming, for example, are still areas of active research in which hypotheses are being tested and challenged with characteristic scientific skepticism.

Healthy Skepticism Is in Scientists' DNA

The scientific process is built on healthy skepticism. To publish a paper in a scientific journal—whether in human health, geoscience, astronomy, or other areas—an author must openly declare any real or perceived conflicts of interest and convince a group of anonymous expert reviewers that the paper's conclusions are supported by the data. Expert reviewers are asked to evaluate the strength of the evidence presented, and they, too, must declare any possible conflicts of interest that could lead to a real or perceived lack of impartiality, such as a financial interest in the outcome or a familial or institutional affiliation with the author. These safeguards promote rigorous and objective review, and peer review remains the gold standard.

In addition to peer-reviewed journals, overview assessments are periodically conducted and published by scientific societies and academies. For example, the National Academies of Sciences, Engineering, and Medicine convene panels and review committees in response to requests from government agencies and others to summarize the existing state of scientific knowledge on topics of societal concern. The resulting peer-reviewed reports are usually not prescriptive but, rather, are intended to frame and inform considerations of policy options with current scientific evidence. Transparent protocols are followed to identify and avoid potential conflicts of interest of panelists, to confirm their credentials, and to include a diversity of experiences and perspectives.

> The state of climate science today includes… 50+ years of published papers and reports, each subjected to reviewers' skeptical eyes to ensure that published conclusions are supported by data.

The deliberative process generates a report of where consensus among experts was reached and where differences of opinion remained, including publishing minority views. An excellent recent example of how seriously the Academy takes peer review is its review [*National Academies of Sciences, Engineering, and Medicine,* 2017] of a draft report by the U.S. Global Change Research Program describing the current state of climate science. Another review of the impacts of climate change on the U.S. economy, environment, and human health is expected later this year.

Other nations have conducted similar deliberative processes through their respective academies of science, as has the Intergovernmental Panel on Climate Change (IPCC) through its series of five assessments since the 1990s [*Trenberth,* 2015]. The IPCC assessment reports are reviewed by science experts and by government representatives, following formal and transparent protocols that seek consensus.

Questions About a Red Team/Blue Team Approach

The state of climate science today includes the vast accumulation of 50+ years of published papers and reports, each subjected to reviewers' skeptical eyes to ensure that published conclusions are supported by data. On 31 July, 16 scientific societies sent a letter to EPA administrator Scott Pruitt (see http://bit.ly/Letter-to-Pruitt) to ask for clarification of what would be gained from a red team/blue team approach that peer reviewers didn't already find in the vast body of climate science publications.

Beyond that overarching question, new procedural questions must be answered before applying the approach to science:

• Will the team members be carefully and transparently screened by a neutral party for conflicts of interest, such as potential financial gain from influencing policies?

• What scientific credentials and communication experience will be required of team members, and how will candidates be solicited and nominated?

• Will the teams be encouraged to find scientific consensus where it occurs, and will there be a process for reconciling differences?

• Is the proposed television venue for a red team/blue team debate, where TV personas could overshadow substance and time limitations can impede deep and thorough analysis, really appropriate for such important deliberation?

• Will the team members be held to the highest standards of evidence in stating their positions, and, if so, who will do the fact checking?

• What sort of precedent will be established? Is this a one-off proposal targeting only climate science, or will it be applied to the scientific community's research on vaccine safety, nuclear waste storage, or any of a number of important policies that should be informed by science?

The United States should be proud of its long tradition of objectivity, rigor, and scholarship, going back to well before President Abraham Lincoln's signing of legislation that established the National Academy of Sciences. Our peer-review and Academy report processes are not flashy or entertaining, but they are inclusive and tried and true and have helped build great institutions of science. They provide the evidence-based analysis of climate science and all other scientific disciplines that are so important for informing the public policy decisions that we rely upon to protect our security, health, safety, environmental integrity, and economic prosperity.

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Shifting Winds Write Their History on a NEW ZEALAND LAKE BED

By Gavin B. Dunbar, Marcus J. Vandergoes, and Richard H. Levy

A belt of persistent westerly winds circles the Southern Hemisphere midlatitudes. These winds influence Earth's climate system on annual to millennial timescales.

Variations in the path and strength of these Southern Hemisphere Westerly Winds (SHWW) influence Southern Hemisphere rainfall and temperature patterns, Antarctic sea ice extent, and the ability of the ocean's life-forms to produce nutrients. The SHWW's interaction with the vast Southern Ocean (Figure 1) causes further-reaching effects, where wind-driven upwelling helps regulate the exchange of carbon dioxide (CO_2) between the deep-ocean carbon reservoir and the atmosphere.

The regional and global climatic significance of the SHWW demands a deeper understanding of the effects and history of their variability. But such an understanding is beyond the scope of the short period in which humans have had instruments to record scientific data.

Fortunately, nature has provided a much longer historical record in the form of sediment layers deposited sequentially, like pages in a book, on lake beds. Lake Ohau lies east of New Zealand's Southern Alps in the northern margin of the SHWW belt, but enough rain spills over these mountains into the lake's catchment to make the resulting river inflow

Aerial photograph of Lake Ohau and Lake Middleton (small lake at left) on New Zealand's South Island. For 17,000 years, rain has washed sediments down the slopes of New Zealand's Southern Alps, depositing them in Lake Ohau. Credit: David Wall/Alamy Stock Photo

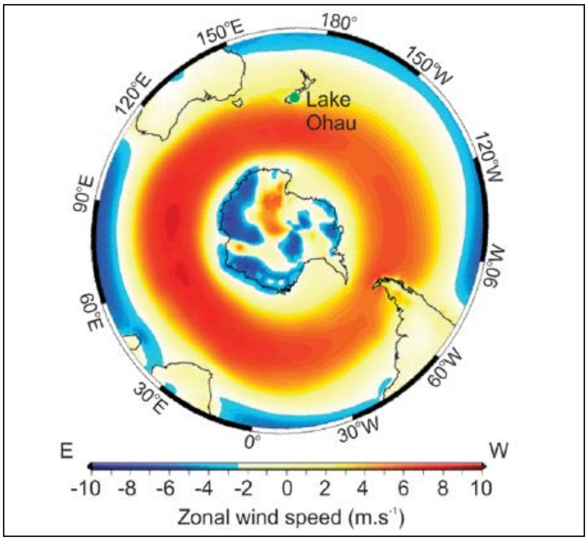

Fig. 1. Location of Lake Ohau (44°17'S, 169°55'E) relative to the Southern Hemisphere zonal wind flow at 10-meter altitude, highlighting the prominence of the westerlies at the midlatitudes. Modified after Mayr et al. *[2013].*

sensitive to variations in westerly wind flow. This relationship provides a connection between the SHWW, rainfall, flood frequency, and sediment accumulation in Lake Ohau.

Sediments deposited in the lake bed are known to vary from year to year in response to regional climate changes [*Roop et al.*, 2016]. Seismic profiles confirm that layered sediments have been accumulating on the lake bed (Figure 2) since the lake's formation at the end of the last ice age, around 17,000 years ago [*Putnam et al.*, 2013].

To learn more about the history of the SHWW, we conducted a drilling program in February–March 2016 to recover a complete sediment record spanning the late glacial period until recent times. We dubbed this effort the Lake Ohau Climate History (LOCH) project (see http://bit.ly/LOCH-NZ).

A Shift in the Winds

The SHWW are currently moving south in response to a changing atmospheric temperature profile caused by anthropogenic ozone. This effect is expected to diminish as the southern "ozone hole" becomes smaller. The consequences of this shift are evident in both southern New Zealand, where summer rainfall has decreased by as much as 40% in the past 3 decades, and the Southern Ocean, where the strength of winds is a contributing factor in the Southern Ocean's ability to absorb atmospheric CO_2.

Instrumental records of the SHWW span only a few decades, so we do not have a long-term perspective in which to place current changes.

For example, what is the natural magnitude of year-to-year variability during periods warmer than today? How did the SHWW respond to past periods of enhanced warming and cooling in the Northern Hemisphere's paleoclimate records? Climate models suggest that the SHWW belt responds to a number of forcing factors that vary on millennial to human timescales, but how well do they "hindcast" past SHWW movements?

The LOCH project aims to answer these questions.

Establishing a Record of Southern Hemisphere Westerly Winds at Lake Ohau

The SHWW flow over substantial topography in only two regions: southern South America and southern New Zealand. As moisture-laden westerly flowing air is forced over these north-south oriented mountain ranges, the air cools, and the moisture within it condenses into substantial amounts of precipitation [e.g., *Garreaud,* 2007]. The Ohau catchment receives enough rainfall spilling over the Southern Alps to provide a link between wind strength and precipitation.

Before we took a deep dive into a long sediment core to explore past precipitation patterns, we needed to understand what processes currently form sediment layers. Our monitoring program in Lake Ohau, which started 7 years ago, collects detailed instrumental data so we can observe how changes in rainfall patterns and river inflow are represented in the stratigraphy preserved on the lake floor.

Throughout the monitoring period, we observed two floods of a magnitude that has occurred only once every decade or so over the past 90 years. These floods deposited centimeter-thick, fine silt layers, in contrast to the millimeter-scale laminations that we typically see in sediment cores. These layers provide the basis for identifying past flood events.

Changes in the character of the millimeter-scale laminations over time are more complex. In addition to flood layers, we saw in existing short cores two other types of coarse- and fine-sediment pairings in the past century. Thinner than average couplets of fine and very fine silt correspond to drier summers, and thicker couplets or stacks of couplets deposited within a year represent wetter summers.

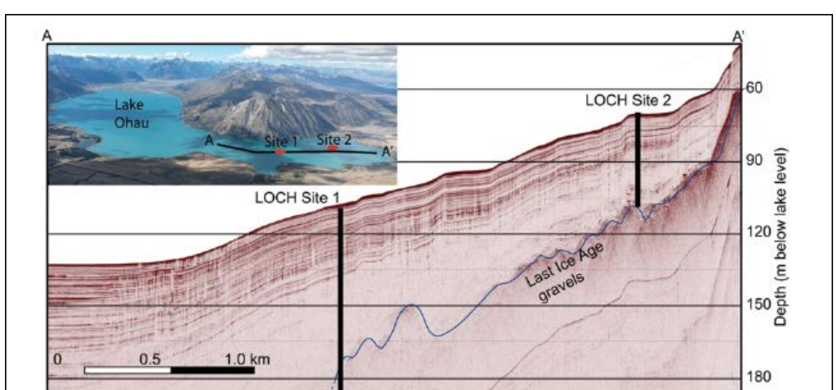

Fig. 2. Locations of drill holes are shown as bold black lines on this seismic (3.5-kilohertz) subbottom profile, taken along the line marked A–A´ in the inset. The acoustic basement, which represents the bottom of the sedimentary record, is conglomerate and gravel deposited during the last ice age, which ended about 20,000 years ago. The inset photo looks north toward the Southern Alps. Credit: Warren Dickinson

With this information, we hope to extrapolate what we know has happened to what may have happened in past centuries and millennia.

A wider view of lakes Ohau and Middleton. Recently extracted core samples from the lake bed show changes in vegetation and evidence of floods, adding to our understanding of past climates. Credit: Warren Dickinson

Collecting the Cores

We chose two drill sites (LOCH 1A/B, 105-meter water depth, and LOCH 2A/B, 68-meter water depth) in the sheltered southeastern arm of the lake (Figure 2, inset). Detailed bathymetric surveys performed by autonomous underwater vehicles, seismic profiling of the lake bed, and previously recovered short cores showed that these distal locations were free of prominent slumps and the centimeter- to decimeter-thick graded sand deposits that characterize the delta, margins, and central basin of the lake. Thus, these locations were ideal for observing sediment layers that have been relatively undisturbed since they were deposited.

The development of a new platform-corer combination was a critical part of the drilling initiative. This system had to be small enough to be transportable on a standard 40-foot (12.2-meter) container/flatbed truck but still able to recover high-quality cores in unconsolidated sediments at depths to 150 meters. The result was a system that combined technology based on Ocean Drilling Program hydraulic piston corer (HPC) principles (see http://bit.ly/ODP-coring) and a custom-designed barge, developed and operated by Webster Drilling and Exploration. Anchor lines hold the barge securely in position while it is drilling (see video at http://bit.ly/LOCH-video).

At both sites we aimed to double core or offset core the entire sediment sequence to provide overlap for the gaps of about 10 centimeters that occur between each 3-meter run of the HPC. At site 2 we were able to offset core the complete 42-meter-thick layered (laminated) sedimentary sequence. At the more exposed and deeper site 1, we offset cored the upper 60 meters, but only drill hole 1B extended down to the ice age gravels 80 meters below the lake floor.

Analyzing the Core Samples

To characterize the sediment layers as thoroughly as possible, we obtained X-ray images of cores on-site and subsequently scanned them using X-ray computed tomography (CT scan), which generates density data at about 600-micrometer resolution for the whole volume of the core. We're also in the midst of performing additional high-resolution layer measurements using X-ray fluorescence and nonvisible light reflectance, and we are analyzing paleomagnetic properties. These data will provide the layer-by-layer detail we need to unravel climatic changes preserved in the core stratigraphy at an annual scale.

We've also examined the core for palynomorphs (fossil pollen, spores, and charcoal) and diatoms. These examinations have been done initially at millennial resolution from core catcher samples, but planned improvements in this resolution will enable us to reconstruct detailed changes in temperature, rainfall, and lake hydrology over time.

We also plan to use a relatively new organic biomarker geochemical approach, namely, changes in the composition of a class of sugar alcohols called branched isoalkyl glycerol dialkyl glycerol tetraethers (brGDGTs) to quantify climatic changes. These compounds are produced by bacteria, and they show predictable variation with temperature [e.g., *Zink et al.*, 2016].

We hope to extrapolate what we know has happened to what may have happened in past centuries and millennia.

This combination of paleoclimate proxies is designed to yield the most quantitative reconstructions of temperature and rainfall and the nature of the surrounding environment at the highest possible resolution.

Preliminary Results

Radiocarbon dating of leaves and twigs embedded in the cores suggests that sedimentation rates at site 1 (Figure 2) have been uniform, although rates from the first 11,000 years appear to be slightly slower than those from the latter part of the core. This chronology will be further improved by additional radiocarbon ages and layer counting.

Our palynomorph data show vegetation progressions that seem to be in line with climate warming and cooling trends shown in other records of the region. The core stratigraphy—the sequence of glacial deposits, ice-rafted debris, and lake sediments—revealed in the CT images seems to reflect these changes too (Figure 3).

Close examination of the CT scanner data shows marked changes in the character of the fine layers down core, which suggests decadal to centennial changes in rainfall patterns. Interpreting the details of these changes will take time, but variations in the frequency of large flood events over the past 2,000 years stand out clearly.

Moving Ahead

We plan to integrate paleoenvironmental reconstructions based on LOCH drill cores with similar records from Antarctic ice cores and sediment cores from sub-Antarctic islands and Patagonia. Through these reconstructions, we will form a transect across the SHWW belt to investigate past variation in this wind system.

A high-resolution sediment record was recently recovered from an Auckland maar crater to the north of this wind belt [*Augustinus,* 2016]. Comparisons with the paleoclimate record from this site (and other lower-latitude sites in South America) will also allow us to investigate in detail the interaction between subtropical and midlatitude climate systems over the Holocene.

We hope to combine observations with global and regional climate model simulations to build a greatly improved understanding of the past causes, timing, and magnitudes of high-frequency climate variability in the Southern Hemisphere midlatitudes. With a firm knowledge of the past, we can better anticipate future behavior.

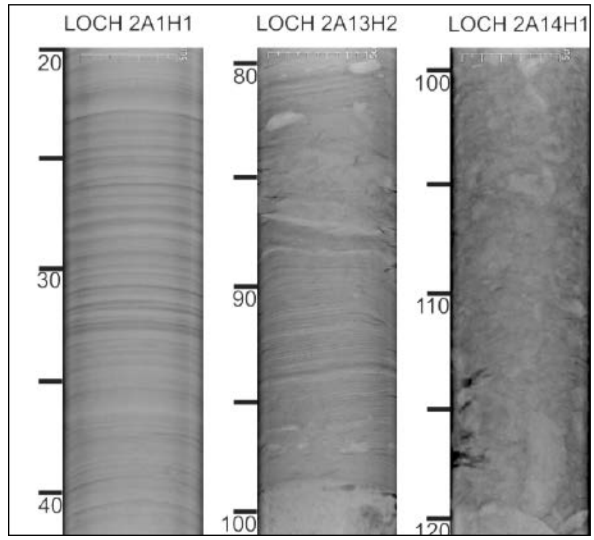

Fig. 3. LOCH 2A X-ray images from recent (1H1), deglacial (13H2), and ice age (14H1) intervals of core. Note the stones in 13H2, which were rafted in by ice and then dropped when the glaciers retreated. Scale is in centimeters.

Acknowledgments

The LOCH project is a collaboration between GNS Science, Victoria University of Wellington, University of Otago, Northern Arizona University, Istituto Nazionale di Geofisica e Vulcanologia, University of New South Wales, Indiana State University, and New Zealand's National Institute of Water and Atmospheric Research. Financial support for this project was provided through the GNS Science Global Change through Time program and the Royal Society of New Zealand Marsden Fund (GNS1302). The project has greatly benefited from the input of many people and organizations over the past 6 years (see http://bit.ly/LOCH-team). In particular, the authors thank Meridian Energy and the University of Otago Marine Sciences Department (Dunedin, New Zealand) for logistical support during drilling.

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GROWING MORE WITH LESS USING

CELL PHONES AND SATELLITE DATA

By Faisal Hossain, Nishan Biswas, Muhammad Ashraf, and Ahmad Zeeshan Bhatti

The Indus Valley, which extends from northeastern Afghanistan to Pakistan and northwestern India, once had the world's largest irrigation system using surface water as its source. That irrigation system still exists, but it no longer sustains the surrounding farms the way it did during the 1960s through 1980s. Many farmers in Pakistan's Indus basin look back to those days with nostalgia as they consider abandoning the farming profession that has been handed down to them from previous generations.

Representatives from the Pakistan Council of Research in Water Resources (PCRWR), who were looking for ways to support their nation's farmers, approached the Sustainability, Satellites, Water, and Environment (SASWE) research group of the University of Washington in August 2015. PCRWR, an agency with a mandate to serve its country's citizens through water research, sought to improve groundwater conservation and crop yield. It requested guidance on how to obtain and disseminate information about

A Pakistani farmer checks his cell phone for weather updates and estimates of how much irrigation water he will need over the next few days. The Pakistan Council of Research in Water Resources sends text messages with this information as part of a new program that helps 10,000 farmers optimize the amount of water they use for their crops. Credit: Faisal Hossain and PCRWR

A farmer in a semiarid region of the Indus basin of Pakistan prepares his field for cotton planting. Groundwater pumped from an aquifer fills his irrigation ditch. Credit: Faisal Hossain and PCRWR

crop water requirements based on environmental conditions and location for the entire Pakistan region.

Thus was born a collaboration, the PCRWR Irrigation Advisory campaign (see http://bit.ly/PCRWR-campaign), that brought 21st-century satellite data to bear on the ancient practices of farming, using cell phone networks to spread the information to farmers in remote locations. To see more about how this is being implemented and how farmers are reacting to the new technology, see http://bit.ly/farmer-phone-video.

Same Water Supply, More Crops

When the Indus Basin Irrigation System (IBIS; Figure 1) was designed 60 years ago [*Wescoat et al.,* 2000], the motivation was to bring more area under cultivation by farmers who typically planted one crop per year [*Jurriens and Mollinga,* 1996]. (For more detailed, higher-resolution, and up-to-date information on cropping pattern in local regions, see Figure 5 of *Cheema and Bastiaanssen* [2010].)

However, IBIS is now being used to support the cultivation of two to three crops per year. Aside from natural variations, the amount of surface water that is typically available in any given year has remained the same, but there is now more competition and demand for water among different sectors of the economy (including energy, food, and industry) and also with neighboring India, which is home to the Indus River headwaters and shares groundwater aquifers with IBIS. To address the increased demand for water, the region supplements the surface water of IBIS with pumped groundwater.

Irrigation Economics

A modest pricing scheme exists for farmers using the IBIS surface water irrigation system. However, the only cost to farmers irrigating their lands using groundwater is the cost of digging wells, the pump, and the fuel to run their pumping systems. As a result, groundwater now meets more than 60% of total annual water demand in this region [*Awan et al.,* 2016].

If farmers could be told specifically how much to irrigate, to ease the fears that cause them to overwater, then traditional mindsets could begin to change.

Although pumping groundwater incurs minimal monetary costs, the cost shows up in other ways. The more groundwater that is pumped for this inefficient irrigation approach, the more rapid the decline in the water table is,

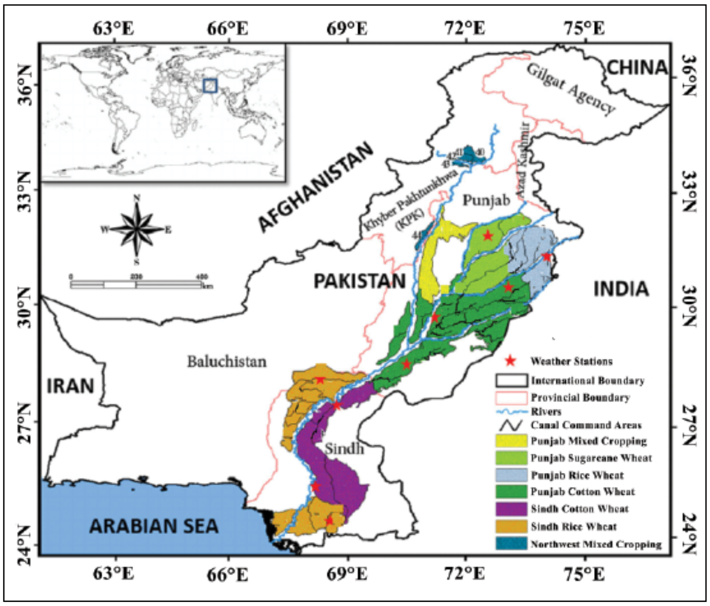

Fig. 1. Location of the Indus Basin Irrigation System in Pakistan. Punjab and Sindh refer to crop varietals. Modified from Usman et al. *[2015].*

and the more fuel it takes to pump water from greater depths.

The situation is further complicated by the fact that modern farmers lack knowledge of the most recent developments in crop water management, relying instead on farming knowledge that has been handed down from previous generations. For instance, the water requirements for rice, which consumes more than 60% of irrigation water in Pakistan, are 600 millimeters in Punjab Province and 1,400 millimeters in Sindh Province according to lysimeter measurements of the water released by plants through evaporation or transpiration (from PCRWR). In contrast, the farmers apply almost 2,200 millimeters, resulting in not only a substantial loss of water but also lower crop yields and an increase in fuel costs to pump water.

The water use efficiency of rice averages 0.45 kilogram of rice per cubic meter of irrigation water in Pakistan compared with the world average of 0.71 kilogram per cubic meter [*Soomro et al.*, 2015]. In a few irrigation districts of the Indus region, this efficiency is as low as 0.08 kilogram per cubic meter. Because overwatering reduces crop yield and increases the cost of maintaining the supply of groundwater, it is no surprise that many farmers find farming not profitable enough to sustain their livelihood.

Estimating Water Requirements for Crops Using Satellite Data

Scientists at the University of Washington's SASWE research group and PCRWR started with the following thoughts: If farmers could be told specifically how much to irrigate, to ease the fears that cause them to overwater, then traditional mindsets could begin to change. The groundwater pumping component of irrigation could then be driven by actual crop water demand and not by practices dating back to when farmers cultivated one crop per year using only surface water, which was abundant because of the lower demand.

One quantitative measure, the crop water requirement for a specific crop, is essentially a proxy measure of the reference evapotranspiration rate (ET_0) that can be calculated for standard crops in well-watered and ambient conditions. PCRWR contacted the SASWE research group, and together they set up an end-to-end ET_0 calculation system, which met PCRWR's specifications for acquiring data once per day over 10-square-kilometer grids for the entire Pakistan region. This system visualizes the dynamic crop water requirement for easy interpretation.

ET_0 was estimated on the basis of a method for computing crop water requirements from the *Food and Agriculture Organization of the United Nations* [1998], which is essentially a modification of a well-known equation [*Monteith and Unsworth*, 1990] using temperature, humidity, wind speed, and solar radiation as inputs.

The computations produced "nowcasts" of how much water a square meter of rice field needed in a given week. The nowcast inputs were obtained from a global Numerical Weather Prediction (NWP) modeling system called the Global Forecast System (GFS). PCRWR performed an independent validation of the nowcast inputs against lysimeter-based ET_0 data, and they found acceptable agreement.

Supply and Demand

For consistent and data-driven messaging, PCRWR set up a Short Message System (SMS) to push text messages with this crop water requirement information out to farmers' cell phones.

But before we could advise farmers on how much to irrigate according to actual requirements (and reduce reliance on groundwater when possible), we first had to provide the actual rationale for following this advice. As was mentioned earlier, farmers typically use a combination of surface water and groundwater irrigation to meet the crop water demand in IBIS. The surface water supply scheme is quite rigid and has little room for flexibility in dynamic adaptation. It is a “use it or lose it” system, unlike groundwater pumping, which can be started or stopped as the farmer desires. However, the groundwater source can be easily conserved if precipitation from the sky has been adequate to meet the crop water demand.

Our rationale is therefore based on comparing demand with supply. We based the demand for water on the crop- and location-specific evapotranspiration (ET) data (Figure 2). The supply was precipitation, supplemented with groundwater pumping.

We obtained the precipitation data from NASA’s Global Precipitation Measurement (GPM) data product called IMERG, available at 10-square-kilometer grid resolution. Whenever supply from precipitation exceeded crop water demand estimated from ET, we sent farmers messages reassuring them that they could pump less or no groundwater. Similarly, when crop demand exceeded the precipitation supply, this information was communicated to farmers as an irrigation amount that they were encouraged to comply with by making sure the groundwater supplemented the surface water irrigation from IBIS.

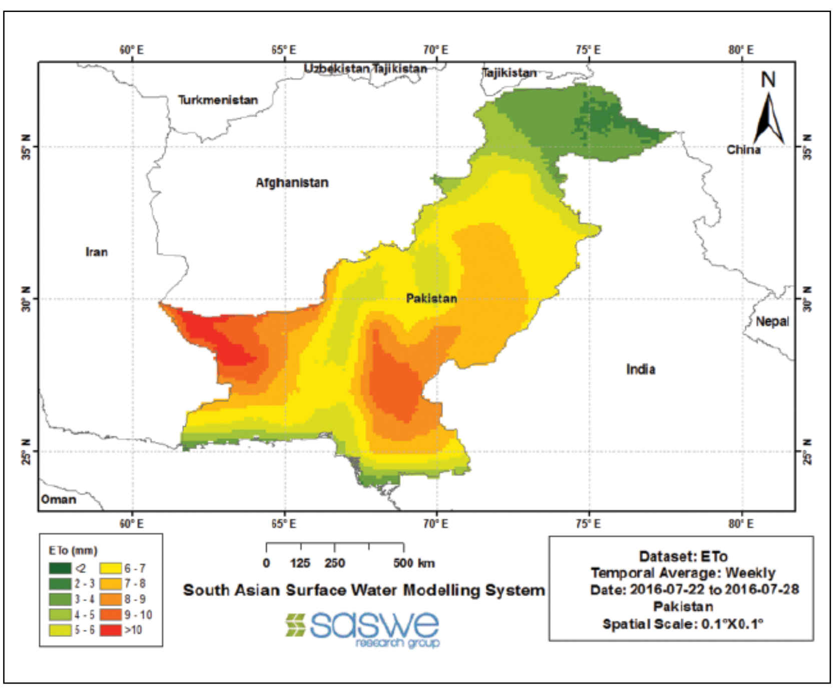

Fig. 2. Sample evapotranspiration (ET_0) map produced by the SASWE group using satellite and numerical weather prediction data from the Global Forecast System. The example is a weekly average based on the preceding seven daily ET_0 calculations. Red areas indicate where farmers will need to pump groundwater to irrigate their fields; green areas are locations where precipitation is adequate to cover crop needs.

A typical message on a farmer’s cell phone would look like this:

> Dear farmer friend, we would like to inform you that the irrigation need for your banana crop was 2 inches during the past week.

or this:

> Dear farmer friend, we would like to inform you that your wheat crop does not need irrigation due to sufficient rainfall during the past week.

These messages are customized according to location and crop type.

Crawling the Web for Rain Reports

Anyone who has worked extensively with multisensor satellite-based precipitation data products knows that the errors associated at scales of land application (such as flood forecasting) can often render the data inaccurate for prime-time operations. In addition to bias and random errors, satellite precipitation data based on passive microwave sensors can have significant detection errors (i.e., inaccurately detecting the rain at a grid cell) [*Hossain and Huffman*, 2008].

The short-latency IMERG data product (available within 12 hours of satellite observation) had similar kinds of errors. There is also a research-grade gauge-adjusted IMERG product that we found to be quite skillful, but adjusted data become available only about a month after collection. This, of course, is too long a lag time for viable nowcasts.

Therefore, SASWE researchers had to address the accuracy issue of the short-latency IMERG product by developing a real-time precipitation correction system based on Web analytics. Essentially, the researchers wrote a Web crawler script to search the Web each day to identify the bona fide agencies (government meteorological services) of the region that post daily in situ (gauge) precipitation data. After downloading the Web-crawled in situ precipitation data, we used a spatial bias map to adjust the IMERG data in an automated fashion.

Currently, the SASWE-based Web-crawling system scours in situ precipitation information from about 70 meteorological stations for the Indus region. PCRWR feedback revealed that this real-time correction system significantly improves precipitation estimation and the overall irrigation advisory.

Progress to Date

Starting in April 2016, 700 farmers began receiving weekly irrigation notifications via text message. The farmers grow banana, wheat, rice, and cotton crops in the Indus Valley. After completing the pilot project, PCRWR conducted an impact analysis and surveyed the farmers' perceptions of this resource. This information helped to inform PCRWR's plan to scale the program up to 10,000 farmers, which it did in January 2017. It plans to launch this program nationwide once cell phone operators expand coverage.

Before we can scale this system up further, we now require quantitative evidence of what actions farmers took and how these actions saved water and fuel. PCRWR is currently conducting such an impact analysis, and this analysis will be used in scaling up the system to millions of farmers.

Muhammad Ashraf, whose farm is near Sargodha, Pakistan, called on 11 May to provide such feedback.

"I had grown wheat on my 12 acres land this season and continuously received irrigation advisory messages from PCRWR system," he said, speaking in his native Urdu. "Keeping in view the advised water consumption and rainfall forecast, I only applied three irrigations, whereas my neighboring farmers applied six to seven irrigations. I have recently harvested my crop and got 48 maunds per acre [4,742 kilograms per hectare] yield, whereas my neighbors could get 42 maunds per acre [4,149 kilograms per hectare]."

For Ashraf, along with many others, the text alerts worked. He continued, "I am thankful to PCRWR for their advice, which not only let me get better yields but the irrigation cost was substantially reduced."

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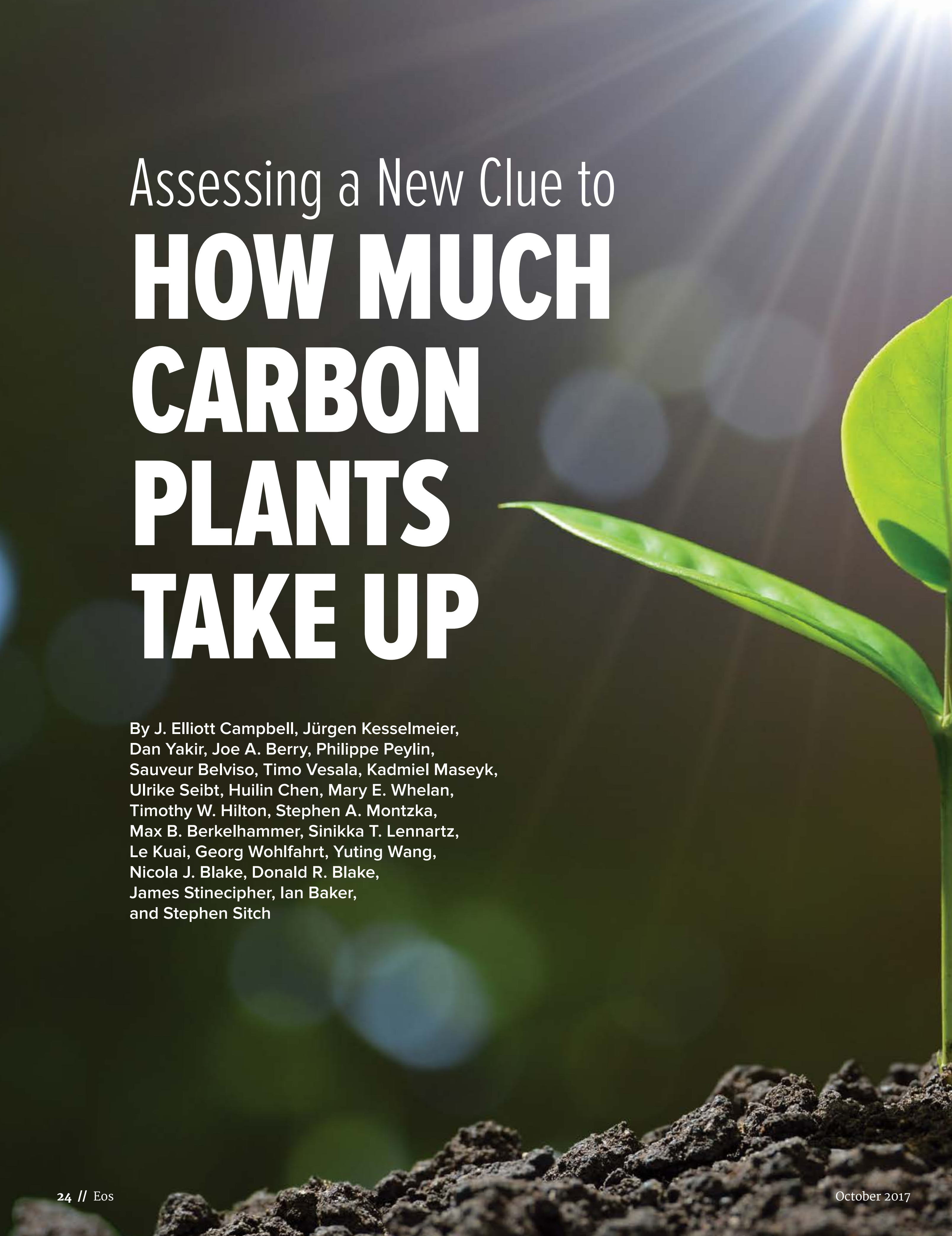


Assessing a New Clue to HOW MUCH CARBON PLANTS TAKE UP

By J. Elliott Campbell, Jürgen Kesselmeier, Dan Yakir, Joe A. Berry, Philippe Peylin, Sauveur Belviso, Timo Vesala, Kadmiel Maseyk, Ulrike Seibt, Huilin Chen, Mary E. Whelan, Timothy W. Hilton, Stephen A. Montzka, Max B. Berkelhammer, Sinikka T. Lennartz, Le Kuai, Georg Wohlfahrt, Yuting Wang, Nicola J. Blake, Donald R. Blake, James Stinecipher, Ian Baker, and Stephen Sitch

Credit: amenic181

Current climate models disagree on how much carbon dioxide land ecosystems take up for photosynthesis. Tracking the stronger carbonyl sulfide signal could help.

Climate change projections include an Achilles heel: We don’t know enough about feedbacks from the terrestrial biosphere. Plants and other organisms take in carbon dioxide (CO_2), which they use to manufacture their own food, using photosynthesis. This process lets ecosystems sequester atmospheric CO_2, creating one of the largest known feedbacks in the climate system. But models of the global climate system differ greatly in their estimates of carbon uptake, leading to critical uncertainties in global climate projections.

This predicament has inspired a search for new approaches to studying the photosynthetic uptake of CO_2. In response, atmospheric scientists, biogeochemists, and oceanographers have proposed measuring a gas called carbonyl sulfide (COS or OCS) to help quantify the contribution that photosynthesis makes to carbon uptake. COS is similar

Measuring carbonyl sulfide in the atmosphere may be a way to track terrestrial photosynthesis, potentially filling a critical gap in current climate models. This alpine study area near Boulder, Colo., where the carbonyl sulfide signal was first detected 10 years ago, is part of the NOAA air monitoring network. Credit: B. Bowman

to CO_2 in structure and composition, with a sulfur atom replacing one of CO_2's oxygen atoms.

Ten years ago, scientists discovered a massive and persistent biosphere signal in atmospheric COS measurements. In these data, COS and CO_2 levels follow a similar seasonal pattern, but the COS signal is much stronger over continental regions, suggesting that the terrestrial biosphere is a sink for COS [*Campbell et al.*, 2008; *Montzka et al.*, 2007]. This remarkable discovery led scientists to wonder, could COS be used as a tracer for carbon uptake?

An explosive growth in COS studies followed as scientists attempted to answer this question, including a COS record from the present to the Last Glacial Maximum, satellite-based maps of the dynamics of COS in the global atmosphere, and measurements of ecosystem fluxes of COS.

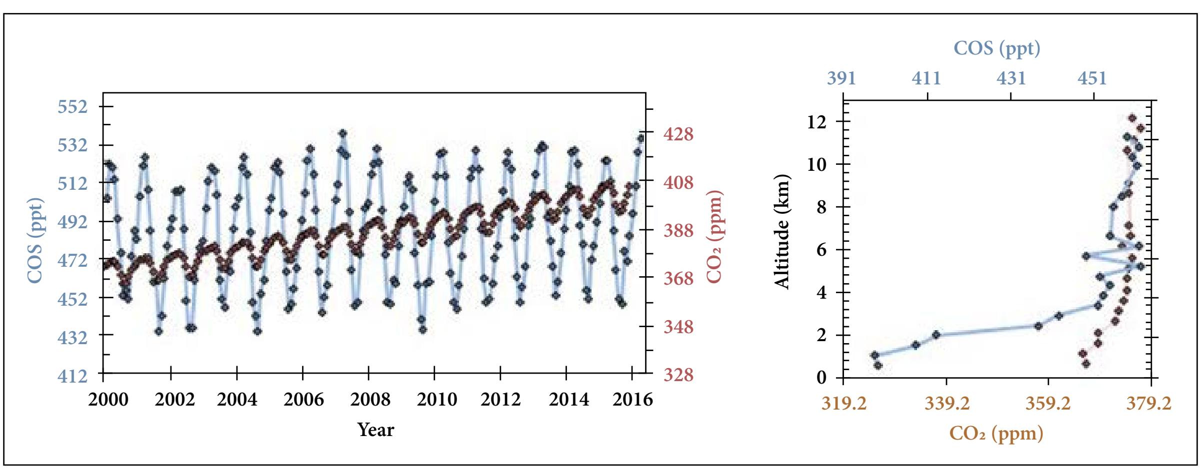
The accumulated research has led to heightened expectations of COS as a viable tracer of carbon uptake but also has pointed to new complexities. Now the scientific community is at a crossroads. Will analysis of COS prove to be a dead end, or will these new data provide a road map to a critical line of evidence for global change research? A wide range of studies now under way may provide the answers.

Regional Photosynthesis and Climate Projections

Photosynthesis is a key climate forcing process in the terrestrial biosphere. It removes CO_2 from the atmosphere and stores carbon in plants, slowing the rate of climate change. This photosynthetic CO_2 uptake is known as gross primary production (GPP).

At the same time, higher global CO_2 concentrations, caused by human activities, may stimulate GPP and carbon sequestration by ecosystems, creating a negative feedback in the climate system. Climate projections must take this "CO_2 fertilization effect" into account. So GPP process models that simulate this effect are embedded in global climate models.

However, the quantitative representation of the CO_2 fertilization effect has a high uncertainty and varies dramatically in different global models. This uncertainty contributes to the size of the range of changes seen in climate projections using various models from the Coupled Model Intercomparison Project (CMIP)



(Left) The concentrations of tropospheric carbonyl sulfide (COS, blue) and carbon dioxide (CO_2, orange) show a similar pattern of seasonal variations over North America; however (right), the seasonal amplitude and vertical drawdown over continental regions are 6 times larger for COS than CO_2, on a relative basis (ppt and ppm are parts per trillion and parts per million, respectively). Data are from Campbell et al. *[2008],* Dlugokencky et al. *[2001], and* Montzka et al. *[2007].*

[*Friedlingstein et al.*, 2006; *Mahmood et al.*, 2016; *Marland et al.*, 2003].

The root of this problem is scale. Extensive experiments have provided reasonable estimates of GPP at leaf level and site scale (on the order of 1 square kilometer). However, we lack robust measurement-based approaches for estimating GPP at regional to global scales.

Hence, the GPP process models embedded in global climate models rely on spatially extrapolated data for calibration. Large uncertainties in extrapolation propagate to critical uncertainties in the CMIP global climate projections.

The Carbonyl Sulfide Signal

Variations in atmospheric COS could help to track GPP and help quantify CO_2 sources and sinks. COS and CO_2 vary in a similar way with the seasons, but the strength of the signal is 6 times larger for COS than for CO_2. This makes satellite and atmospheric surveys more readily able to detect variations in COS than CO_2, while at the same time measurements are scalable to CO_2 and thus GPP in the terrestrial system.

The regional COS signal is consistent with plant growth chamber measurements that show a close relationship between COS plant uptake and GPP [*Sandoval-Soto et al.*, 2005; *Stimler et al.*, 2010]. The plant uptake of COS is controlled largely by its passage through leaf pores (stomatal conductance), which is also a strong control on GPP. In turn, the signal is also consistent with canopy-scale measurements [*Asaf et al.*, 2013] and global process-based models [*Berry et al.*, 2013].

Ten years ago, scientists discovered a massive and persistent biosphere signal in atmospheric carbonyl sulfide measurements.

A Photosynthesis Tracer

Several unique aspects of global atmospheric COS budgets encourage the proposed use of COS as a GPP tracer. First, COS sources and sinks are generally separated in space. The dominant global source is the oceans, and the dominant global sink is linked to GPP over the continents.

However, researchers have observed additional continental sources and sinks, which suggests that COS observations do not provide a direct measurement of GPP. Nonetheless, at a regional scale, COS plant uptake is larger than these other continental sources and sinks.

Second, model analyses of atmospheric observations suggest that the terrestrial plant sink drives the seasonal cycle of atmospheric COS concentrations in the Northern Hemisphere. This observation is supported by the relatively small seasonal variations in COS from the ocean source compared with the relatively large seasonality of the plant COS sink [*Launois et al.*, 2015a, 2015b].

The dominant source of COS is in the ocean, far from most terrestrial plants that serve as the main sink. COS emissions are quantified using global measurements made at facilities such as the atmospheric observatory at Tudor Hill, Bermuda. Credit: M. Berkelhammer

Finally, nearly the entire global reservoir of COS is in the atmosphere. COS stays in the atmosphere for 1–3 years, a "sweet spot" for inferring global GPP from COS concentrations measured in air samples taken from ice cores and firn (uncompressed glacial snow) [*Campbell et al.*, 2017]. The lifetime is long enough for COS to be globally well mixed but not so long as to obscure the dynamics of sources and sinks over the industrial era.

Measurement Capacity

In recent years, the capacity for COS measurements has expanded greatly. Ice core analysis took the COS record through a glacial cycle [*Aydin et al.*, 2016], multiple satellites yielded the first global COS maps, and new spectroscopy techniques enabled flux tower measurements.

In addition to these advances, the National Oceanic and Atmospheric Administration (NOAA) has continued to make COS measurements through its global air monitoring network (http://bit.ly/ESRLbaseline). The network has created an ongoing 16-year COS record at 12 global background sites and additional less remote surface sites and has complemented these with measurements from aircraft.

New Complications, Heightened Expectations

Although several recent discoveries have introduced new complications in COS budgets, others have enhanced the promise of COS as a GPP tracer.

Global anthropogenic sources of COS are a potentially complicating factor for using COS to assess global GPP. However, these sources are increasing over China and declining over the rest of the globe, which supports many regional applications of the COS tracer [*Campbell et al.*, 2015].

Laboratory and field studies have revealed diurnal variations in the ratio of plant uptake of COS relative to plant uptake of CO_2 [e.g., *Stimler et al.,* 2010; *Wehr et al.,* 2017], which complicates the use of COS for canopy-scale estimation of GPP. However, regional-scale trends in COS measurements are remarkably insensitive to these short-term dynamics, and the analysis of these trends is primarily related to regional GPP [*Hilton et al.,* 2017]. Furthermore, the daily-integrated relationship between plant uptake of COS and CO_2 is remarkably consistent across independent measurement techniques [*Berkelhammer et al.,* 2014; *Kesselmeier and Merk,* 1993; *Maseyk et al.,* 2014; *Sandoval-Soto et al.,* 2005; *Wohlfahrt et al.,* 2012].

Additional complicating factors include ecosystem sources of COS to the atmosphere and nighttime plant uptake [*Bloem et al.,* 2012; *Commane et al.,* 2015; *Maseyk et al.,* 2014]. Although these newly discovered ecosystem processes have not been shown to be significant at regional scales, they should be quantified, understood, and included in models that use COS observations to infer regional GPP [*Sun et al.,* 2015; *Whelan et al.,* 2016].

Advances in laser spectrometry have enabled the first continuous measurements of the flow of COS between land and atmosphere at monitoring sites such as this one at the Hyytiälä Forestry Field Station in Finland. Credit: K. Maseyk

COS Budget Gaps

Addressing gaps in the COS budget will require additional experiments. For example, few COS studies have explored tropical ecosystems, but multiple Amazon studies now under way will produce regional airborne and tall-tower measurements as well as detailed ecosystem measurements. These studies are needed to address the dominant role of tropical ecosystems in the biogeochemical cycles of both COS and CO_2.

Recent comparisons of global top-down and bottom-up studies have revealed a missing source in the global COS budget. New analysis suggests that the missing source may be associated with ocean emissions in the Pacific warm pool region or industrial activity in China. Progress in these two regions is critical for closing gaps in the global budget and improving conclusions related to GPP on large scales.

The Outlook

Increased awareness of the potential of COS as a tracer, as well as improved measurement technology, has motivated a wave of new COS studies that will greatly improve our understanding of the role of COS during photosynthesis.

At the same time, we know of no one technique that can provide complete information about GPP. Given the complexity of the carbon cycle and its importance for understanding climate change, it is imperative to use a diversity of approaches. Pursuing multiple lines of evidence, including the COS technique, may yet provide a tractable path for addressing the pressing concern of carbon processes within the climate system.

Given the complexity of the carbon cycle and its importance for understanding climate change, it is imperative to use a diversity of approaches.

Acknowledgments

This perspective is based in part on discussions at an international workshop at the Hyytiälä Forestry Field Station in Finland, with support from the European Geosciences Union and Aerodyne Research, Inc. (http://www.cosanova.org). Additional support from the U.S. Department of Energy Terrestrial Ecosystem Science program (DE-SC0011999) is acknowledged.

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2017 Class of AGU Fellows Announced

Each year since 1962, AGU has elected as Fellows members whose visionary leadership and scientific excellence have fundamentally advanced research in their respective fields. This year, 61 members will form the 2017 class of Fellows.

AGU Fellows are recognized for their scientific eminence in the Earth and space sciences. Their breadth of interests and the scope of their contributions are remarkable and often groundbreaking. They have expanded our understanding of the Earth and space sciences, from volcanic processes, solar cycles, and deep-sea microbiology to the variability of our climate and so much more. Only 0.1% of AGU membership receives this recognition in any given year.

On behalf of AGU's Honors and Recognition Committee, our Union Fellows Committee, our section and focus group Fellows committees, AGU leaders, and staff, we are immensely proud to present the 2017 class of AGU Fellows.

We appreciate the efforts of everyone who provided support and commitment to AGU's Honors Program. Our dedicated AGU volunteers gave valuable time and energy as members of selection committees to elect this year's Fellows. We also thank all the nominators and supporters who made this possible through their dedicated efforts to nominate and recognize their colleagues.

The AGU College of Fellows

This past summer, AGU also formally launched an initiative to better engage our nearly 1,400 living Fellows. The new College of Fellows' mission is to foster excellence, integrity, and interdisciplinary collaboration in the Earth and space sciences, provide expert and strategic advice to the Union on global scientific issues, and support the professional development and engagement of scientists at all career stages and from all backgrounds (see http://bit.ly/CoFellows). The program will engage AGU's Fellows in the following primary activities: a town hall session at the 2017 Fall Meeting, mentorship, a distinguished traveling lecture series, and participation in events and activities commemorating the AGU Centennial in 2019.

Honor and Celebrate Eminence at Fall Meeting

At this year's Honors Tribute, to be held Wednesday, 13 December, at the 2017 AGU Fall Meeting in New Orleans, we will celebrate and honor the exceptional achievements, visionary leadership, talents, and dedication of 61 new AGU Fellows.

Please join us in congratulating our 2017 class of AGU Fellows, listed in alphabetical order:

M. Joan Alexander, Northwest Research Associates
Jeffrey Alt, University of Michigan
David D. Breshears, University of Arizona
Bonnie J. Buratti, Jet Propulsion Laboratory, California Institute of Technology
Wei-Jun Cai, University of Delaware
Josep Canadell, Commonwealth Scientific and Industrial Research Organisation
Don P. Chambers, University of South Florida
Kelly Chance, Harvard-Smithsonian Center for Astrophysics
Marc Chaussidon, Institut de Physique du Globe de Paris
Alan D. Chave, Woods Hole Oceanographic Institution
Wang-Ping Chen, China University of Geosciences
Hai Cheng, Xi'an Jiaotong University
Peter G. DeCelles, University of Arizona
Gerald R. Dickens, Rice University
Paul A. Dirmeyer, George Mason University
Claudio Faccenna, Università Degli Studi Roma Tre
John C. Foster, MIT Haystack Observatory
Roger Francois, University of British Columbia
Arthur Frankel, Earthquake Science Center, U.S. Geological Survey
Helen Amanda Fricker, Scripps Institution of Oceanography
Jonathan Gregory, University of Reading
Stephen M. Griffies, Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration
Nancy B. Grimm, Arizona State University
George R. Helffrich, Tokyo Institute of Technology
Susan S. Hubbard, Lawrence Berkeley National Laboratory
Erik R. Ivins, Jet Propulsion Laboratory, California Institute of Technology
Fortunat Joos, University of Bern
Samantha Benton Joye, University of Georgia
Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère, Centre National d'Études Spatiales
Alan Knapp, Colorado State University
Matthew J. Kohn, Boise State University
Ronald Kwok, Jet Propulsion Laboratory, California Institute of Technology
Upmanu Lall, Columbia University
Murli H. Manghnani, University of Hawai'i at Mānoa
Barry H. Mauk, Johns Hopkins University Applied Physics Laboratory
Klaus Mezger, University of Bern
Alberto Montanari, University of Bologna
Louis Noel Moresi, University of Melbourne
Scott Lawrence Murchie, Johns Hopkins University Applied Physics Laboratory
Teruyuki Nakajima, Japan Aerospace Exploration Agency
Richard Norby, Oak Ridge National Laboratory
John M. C. Plane, University of Leeds
John C. Raymond, Smithsonian Astrophysical Observatory, Harvard University
Steven W. Roecker, Rensselaer Polytechnic Institute
Eelco Johan Rohling, Australian National University
Ares J. Rosakis, Graduate Aerospace Laboratories, California Institute of Technology
Yinon Rudich, Weizmann Institute of Science
Lynn M. Russell, University of California, San Diego
Daniel J. M. Schertzer, École des Ponts Paris Tech

Walter H. F. Smith, National Oceanic and Atmospheric Administration
Robert J. Stern, University of Texas at Dallas
Paul J. Tackley, ETH Zurich
Margaret S. Torn, Lawrence Berkeley National Laboratory and University of California, Berkeley
Gregory E. Tucker, University of Colorado Boulder
Susan Ustin, University of California, Davis
Richard M. Vogel, Tufts University
Patricia L. Wiberg, University of Virginia
Teng-fong Wong, Chinese University of Hong Kong
Roger V. Yelle, University of Arizona
Youxue Zhang, University of Michigan
Edward J. Zipser, University of Utah

By **Eric A. Davidson,** President, AGU; and **Samuel Mukasa** (email: unionfellows@agu.org), Chair, Honors and Recognition Committee, AGU

Returning Fall Meeting Chair Looks to New Orleans and Beyond

Denis-Didier Rousseau gives a presentation at the 2016 AGU Fall Meeting. Rousseau has been reappointed chair of the Fall Meeting Program Committee for the 2017–2019 meetings. Credit: Gary Wagner

Denis-Didier Rousseau, senior research scientist at France's Centre National de la Recherche Scientifique (CNRS), École Normale Supérieure (ENS), has been reappointed chair of the AGU Fall Meeting, and his term will extend through the 2019 Fall Meeting. Denis began his first term as Program Committee chair, Fall Meeting, in 2014.

We sat down with Denis to find out his thoughts on these past 3 years and to learn what he and his committee have in store for this year's Fall Meeting and beyond. His responses have been edited for length and clarity.

AGU: *What has the Program Committee accomplished during your previous term?*

Rousseau: I was the only non-U.S. scientist applying for the 2014 appointment, and I had some apprehension about the review process. However, AGU followed a very coherent, fair, and professional call for candidates and selection process for the Program Committee chair.

Once I was appointed, I was given carte blanche to develop the project I had proposed in my application. My proposal was in line with AGU strategy, and I received ample support from the Program Committee and AGU leadership and staff in carrying out my ideas. I wanted to introduce new session formats, get more transdisciplinarity, and involve disciplines that had been less represented at the Fall Meeting.

I wanted all our fellow committee volunteers to feel comfortable, listened to, and truly part of the whole process. We succeeded in making the Fall Meeting Program Committee a real team effort. For example, we now schedule a group outing to watch a baseball game each year during the committee's September scheduling meeting. This gives us a break from the section and focus group contingencies, where we can express our enthusiasm in a different environment.

Another change was our introduction of new session formats into the main program after they were successfully tested at the section or focus group level: the new "Great Debate" Union session, for example. AGU showed its support for the next generation of scientists with the "New Generation of Scientists" Union session, which we also introduced.

We introduced a virtual program, now called On-Demand (see http://bit.ly/AGU-On-Demand), that allows anyone to register for access to selected Fall Meeting sessions from anywhere via live streaming or on-demand services. The current version of this program is more selective, streaming sessions closely aligned with AGU fields to make the program more attractive to viewers.

Although these changes occasionally generated some logistical problems, the AGU meetings staff was remarkably adaptive in solving them. I made myself available as much as possible, involving myself in most of the processes affecting the Fall Meeting. Putting the meeting together is a gigantic puzzle: The scientific program is an important piece but not the only one.

Response to the new session formats and the organizational improvements has been very positive; my colleagues appreciate the scientific quality in what remains the biggest meeting in our field. In addition, more and more high-level VIPs are accepting our invitations to deliver stimulating and enthusiastic lectures at Fall Meetings.

So many good friends told me that I was crazy to apply for such a duty. They could have been right, and this is perhaps why I applied for reappointment.

Putting the meeting together is a gigantic puzzle: The scientific program is an important piece, but not the only one.

AGU: *What do you expect to accomplish in the next term? What ideas do you have for Fall Meeting in the future?*

Rousseau: I want to continue introducing new session formats, especially for the poster sessions. Even though this meeting is a gigantic endeavor, I want it to seem like a small village, fostering opportunities for attendees to speak and exchange together.

The meeting is in a transition phase. We are meeting in the larger convention centers in New Orleans and Washington, D. C., during the expansion and renovation of our traditional meeting site at San Francisco's Moscone Center. After returning to an expanded Moscone Center, we will be well situated to propose a different organization of the meeting for the years to come. New technologies could help the transition, and I am delighted that the AGU meetings staff is considering the investment.

My term is ending with the celebration of the AGU Centennial in 2019, and I am planning already for a grand "fireworks" celebration. In addition to what the dedicated Centennial Task Force has already scheduled, we want the scientific program to assemble the largest community of Earth and space sciences.

Because I've had a lot of freedom to implement my ideas, I don't want to anticipate what my successor will propose and implement. However, we must maintain our commitment to the Fall Meeting so that it remains the place to be for the upcoming generations, because this is our home.

AGU: *What aspects of the 2017 Fall Meeting most excite you?*

Rousseau: We will have to adapt to our new meeting facilities in New Orleans (and next year's location in Washington, D. C.) in a very short time. Although more space will be available in New Orleans, this does not mean more rooms for sessions.

However, more space makes it easier to implement the mini lounges that we call "pods," which the AGU staff successfully introduced in San Francisco. Conveners can meet with interested participants in pods after their sessions. Attendees can gather in the pods to exchange ideas and brainstorm collaborative endeavors, adding to the "small village" aspect of this big meeting.

We will also experiment with the poster sessions, organizing the poster hall as a journey of scientific discovery, from "deep Earth" to "farthest space." In addition to an improved version of last year's "lightning" poster presentations, we will test a new format this year: iPosters, presented on dedicated large monitors.

We cannot ignore political changes occurring in the United States and worldwide, and this important topic deserves visibility at the Fall Meeting.

Following last year's experiment, I am working on implementing a complementary program with more sessions oriented toward public policy, from the present AGU Policy Action Center initiative. We cannot ignore political changes occurring in the United States and worldwide, and this important topic deserves visibility at the Fall Meeting. My colleagues and I are apprehensive about this U.S. administration, which plans to reduce research funding and has appointed science skeptics to key positions. This important topic deserves visibility at the Fall Meeting. We are not only scientists but also citizens, so I think that nowadays, resisting is part of our duty.

AGU: *What does Fall Meeting mean to you as an attendee?*

Rousseau: The Fall Meeting is the biggest meeting worldwide in my field and the main opportunity to meet colleagues from around the world. For me, the meeting really starts in the plane flying in from abroad, where I have plenty of time for discussion with colleagues in an environment with no telephone and no Internet. The Fall Meeting is also the place where I present my research, where I position my research within the state of the art in my field.

Fall Meeting is also an excellent opportunity to learn quite quickly about numerous fields. The development of more transdisciplinarity in the program creates a true brainstorming environment from which amazing ideas emerge.

The special lectures are a source of inspiration. The careful selection of the speakers in past years has made these lectures an event within the event, complementing nicely the Union session program.

AGU: *How will the change of venue for Fall Meeting affect the science and attendance?*

Rousseau: The change of venue shouldn't affect the science because we perform the science in our labs. However, the different space configuration will allow implementing new session formats. The New Orleans region is affected by different natural hazards than those that affect California, and session proposals could relate more to the Gulf Coast region, as well as having global relevance.

Although many of us love San Francisco, the relocation to New Orleans should be interesting or even exciting. I'm keen to discover how my native French language is spoken in New Orleans, and the distinctive cuisine should attract our attendees.

Flying to New Orleans can be more complicated for foreigners than flying to San Francisco, but I hope that this does not significantly affect attendance. I think that attending the Fall Meeting in a new environment, with more space, in a city well known for welcoming visitors will be a great experience.

AGU: *What are your other thoughts regarding the Fall Meeting and your reappointment as Fall Meeting chair?*

Rousseau: To me, the Fall Meeting program chairmanship is not an honorary position, but a great chance to make something amazing happen. This is a team

My term is ending with the celebration of the AGU Centennial in 2019, and I am planning already for a grand "fireworks" celebration.

effort, and the first key job is to build the necessary team spirit among science representatives of sections, the focus groups, and AGU staff.

Many applicants responded to the public call for a program chair this year, and I didn't receive any privileged treatment, even though I was the outgoing chair. When I received the good news of my reappointment, I felt very honored that AGU and my peers were satisfied with my previous chairmanship and my work.

I am modestly proud to remain the first non-U.S. scientist in charge of the biggest meeting in our field and also the first to be reappointed. I want to recognize the sacrifices my wife and daughters have made to support me in this effort. My frequent travel has left me with less time to spend at home with my family, but they know that this effort is important to me.

Crazy, as my friends said? Certainly not! Rather, I am passionate, something I don't consider exceptional. I do my duty, like others who contribute to our science in many ways.

The Fall Meeting allows me to work and collaborate with remarkably nice, efficient, dedicated, and fantastic colleagues: the scientists and AGU staff. I sincerely recommend this experience to my young AGU fellows. The Fall Meeting requires a lot of work and dedication, a lot of organization, but more sincerely, a lot of fun, especially by working for my community.

By **Nicole Oliphant,** Manager, Scientific Programs, Meetings, AGU

Communities and Experts Collaborate for Climate Resilience

Climate change is global, but its effects are felt locally. Although many communities try to plan for anticipated changes and want strategies for bouncing back when disasters occur, they simply don't have the level of technical expertise that such planning can require. Also, what works in one place may not work somewhere else, further compounding the challenge.

The Resilience Dialogues project aims to make it easier for communities to reduce their climate-related risks and build community resilience. The project does this by connecting community stakeholders with climate experts through online facilitated dialogues. The project, which is comanaged by the U.S. Global Change Research Program and AGU's Thriving Earth Exchange, launched in late 2015 with a pilot phase that included five communities. Building on the success of those dialogues, 10 more communities held dialogues during the first half of 2017.

The facilitated online dialogues have been useful to a variety of groups, including local governments, county managers, urban planners, community organizations, private-sector stakeholders, and public health professionals. Communities that participated in the dialogues say they came away with new knowledge, useful connections, and practical next steps for decreasing their vulnerability to climate change. Each community received a final report summarizing key vulnerabilities as well as opportunities and resources for climate resilience planning that were identified during the discussions. Here are a few examples of communities that have benefited from Resilience Dialogues.

Florida City Plans for Rising Sea Levels

Projections indicate that sea levels around Hallandale Beach, Fla., will rise more than 3 feet (0.91 meter) over the next 40 to 80 years. This anticipated increase will leave the city vulnerable to beach erosion and flooding, as well as saltwater intrusion that could contaminate its drinking water supply. Community leaders applied and were selected to participate in the Resilience Dialogues so they could better understand these potential risks and find ways to communicate with community residents and stakeholders about these risks.

Susan Fassler, the green initiatives coordinator for the city of Hallandale Beach, served as the team lead for the Hallandale Beach dialogue, which included 18 participants from the city, businesses, nonprofits, and the federal

Rising sea levels in Hallandale Beach, Fla., could lead to increased beach erosion. The damage shown here occurred after Hurricane Sandy in 2012. Normally, beach sand reaches the top of the dark area on the concrete wall at left. The orange structures are drains. Credit: City of Hallandale Beach

Community members in Whitefish, Mont., want to protect the area's rivers and lakes, including Whitefish Lake, pictured here. Credit: Joe Mabel, CC BY-SA 2.0 (http://bit.ly/ccbysa2-0)

government. She said that one key takeaway from the dialogues was learning how to use sea level rise visualization tools such as the National Oceanic and Atmospheric Administration's Sea Level Rise Viewer. These free online tools can be used to communicate risk and potential solutions to residents.

"The dialogues captured an incredible amount of information in a relatively short amount of time," said Fassler. "With the currently available staff time and resources, the city could never have compiled the list of communication, visualization, implementation, planning, networking, education, and outreach tools included in the final summary document."

Part of the discussion focused on how a one-size-fits-all communication strategy falls short for Hallandale Beach. Even though the city covers only about 4 square miles (6.44 square kilometers), its four distinct districts each have different needs related to climate change and will likely require individualized communication strategies. The city plans to keep this in mind as it builds a communication strategy centered upon climate adaptation education and training for city staff and the public. The city also plans to identify local champions who can build trust and excitement around community resilience and will use the dialogues to inform the city's 5-year sustainability action plan.

"The dialogues served as an incredible networking opportunity," said Fassler. "City staff who participated in the process can now reach out to experts from the county, region, private or nonprofit sectors, and federal government for guidance."

Fassler recommends that cities thinking about taking part in a future Resilience Dialogue identify a team of dedicated, interdepartmental staff members who want to be a part of a learning experience. "Team members do not necessarily need an in-depth understanding of sustainability or resilience because a large part of the dialogues centered upon establishing an introductory level of understanding of key concepts. However, they should be willing to expand their vision beyond the scope of their daily activities and be open-minded to breaking down potential silos that exist in routine government work," Fassler said.

Montana Town Seeks to Safeguard Recreation and Tourism

Whitefish, Mont., located just outside of Glacier National Park, depends on summer visitors to the park and winter skiers to support its economy. Community members, including Steve Thompson, chairman of the public-private partnership Climate Smart Glacier Country, are concerned about what climate change will mean for their community and tourism. They are already experiencing some warmer winters that affect ski conditions, and smoke from wildfires has put a damper on outdoor activities and tourism in the summer.

Members of the community are also concerned about protecting the area's clean water and fisheries. Last year, low water levels and high water temperatures in another part of the state led to a parasite outbreak that killed thousands of fish and shut down the Yellowstone River to all recreational use. Similar conditions are starting to occur in some of the Whitefish area's rivers, and residents are becoming anxious.

"We have very little capacity beyond volunteers, and we thought that the Resilience Dialogues would bring some outside perspective and expertise," said Thompson, the community lead for the dialogues. "However, the dialogues did more than that. They provided a structured format that allowed community representatives from Whitefish and Glacier National Park to have some of our first discussions about preparing for climate change—conversations that we've been wanting to have for a long time."

The Whitefish Resilience Dialogues brought together a diverse group of community members, including representatives of several nonprofit organizations interested in climate change, the superintendent of Glacier National Park, and engineers working for the city of Whitefish.

"I liked that the online format of the dialogues allowed people to participate on their own time," said Thompson. "It was not just an academic exercise, but it helped us to look at specific steps we can take and how we can communicate about climate change with the broader community."

Through the dialogues, Thompson connected with Anna Tuttle, a climate change expert from Montana State University in Bozeman, who is part of a group of researchers compiling the state's first climate assessment. Thompson and other community members are now working with Tuttle to plan a climate science day in Whitefish, during which scientists from the university system will present findings from the assessment. The public event will focus on long-term solutions to community challenges.

"We want to develop community panels to respond to what was presented by the scientists," said Thompson. "We are also reaching out to potential cosponsors. We'd like a good diversity of nonprofit and business groups as well as city and county government. This event will be a good opportunity to broaden the discussion by focusing on people's interests."

Wisconsin Tribe Seeks to Protect Natural Resources

Since the 1850s, the Menominee Indian Tribe of Wisconsin has been managing 235,000 acres (about 95,000 hectares) of forest by drawing upon contemporary forestry science and traditional tribal knowledge. Today, its community members are concerned about how climate change might affect the forest—one of the biggest sources of employment on the Menominee reservation—and the tribe's other natural resources.

Gregory J. Gauthier Jr. of the College of Menominee Nation's Sustainable Development Institute (SDI) was the team lead for the Menominee Resilience Dialogues. SDI has been working on climate change research that incorporates numerous initiatives, including tapping traditional knowledge underlying the Menominee Tribe's forest management practices. Gauthier, who came to SDI as part of the AmeriCorps VISTA Tribal Resilience program, saw the dialogues as an opportunity to bring together the Menominee Tribe, SDI, and community members, who all want to increase community resilience to climate change.

"Throughout the Resilience Dialogues process, discussions about important climate-related vulnerabilities centered on the reservation's natural resources," said Gauthier. "We also talked about how climate changes could affect the landscape and how we can be better equipped to handle those changes."

Gauthier pointed out the importance of the framing step that starts the Resilience Dialogues process. "This step gives a sense of place to the subject matter experts so they have an idea of how to proceed with that community," he said. "For the Menominee community, this emphasized the historical importance of the forest and land that the Menominee occupy. Without that understanding, there might have been comments or conversations that community members would not have liked."

Gauthier said that the dialogues clarified areas that need to be addressed before community leaders can proceed with new climate resilience initiatives. The discussions also stressed ways to keep various community stakeholders, including tribal leaders, elders, and the community's young people, involved in the decision-making process.

"I have been working very hard on trying to build relationships within the community and with external partners about climate resilience by establishing a platform to address the issues that tribal nations are and will be facing," said Gauthier. "The Resilience Dialogues provided the needed direction and foundation to continue with resilience planning for the Menominee Nation. We continue to provide climate literacy education and move forward with training sessions for departments of the Menominee Indian Tribe of Wisconsin, Menominee County, and other community groups that would like to participate."

The Menominee Indian Tribe manages a diverse forest in a transition zone between Wisconsin's central and northern hardwood forests. Thirteen types of trees, including northern hardwood, white pine, swamp conifers, aspen, and red oak, grow on the managed land. Credit: Gregory J. Gauthier Jr.

By **Nancy D. Lamontagne** (email: ndlamontagne @gmail.com), Freelance Science Communicator/ Contributing Writer for Creative Science Writing and the Thriving Earth Exchange

Editor's Note: AGU executive director and CEO Chris McEntee focuses on the Resilience Dialogues in an 11 July From the Prow *blog post (see http://bit.ly/rd-ftp). She discusses how partnerships with federal and nongovernmental collaborators are critical to the success of the program to help diverse communities with climate adaptation and resilience planning.*

Natural Resource Exploitation Could Reach New Depths

A sea cucumber among manganese nodules in the Pacific Ocean's Clarion–Clipperton fracture zone. Credit: ROV Kiel 6000, GEOMAR

Buildings, infrastructure, mobile phones, batteries, and electric cars contain valuable metals such as copper, zinc, silver, and gold. With the seemingly insatiable demand for products enabled by these materials, new sources are needed, particularly as land-based reserves become scarce or are located in places too difficult, dangerous, or costly to access.

These metals exist, however, in mineral deposits on rocky submarine mountains, on abyssal plains, at mid-ocean ridges, and around underwater hydrothermal vents. For example, it has been suggested that nodules of manganese found in places such as the Clarion-Clipperton zone, an extensive area on the Pacific Ocean floor, could satisfy current demand for decades.

Beaulieu et al. reflect on a session at the 2017 American Association for the Advancement of Science annual meeting that posed the question, Should we mine the seafloor? As scientists, they wanted to approach the question with objective, scientific evidence.

The question is not without controversy. Although some people see the oceans as the last untapped resource on Earth, others see them as a precious natural asset to be protected.

The authors note that exploitation of the shallow seafloor already takes place, with the dredging of sand and gravel and extraction of tin, gold, and diamonds from shallow reserves. Technology also enables the oil and gas industry to operate on seabeds up to 3 kilometers below the surface.

It is not yet possible to mine reserves that lie deeper, but the authors point out that that may become a reality. As of mid-2017, 27 licenses for exploration have been granted by the International Seabed Authority, a United Nations body established in 1984 with responsibility for regulating deep seabed mining.

The main thrust of discussion explores whether deep seafloor mining is economically feasible, technologically possible, environmentally appropriate, ecologically sustainable, and legally manageable. However, the authors' attempt to make an objective assessment was limited because this topic is mired in so many uncertainties.

Because little is known about the quantity and quality of resources in existence, the resources may not even be worth exploiting. No one yet knows whether extraction from the ocean could be competitive with land-based mining.

Technological uncertainties also abound. For example, will equipment work effectively in the extreme environment of the deep oceans? Although technologies to map and mine these resources have developed significantly, much further testing remains.

And perhaps most important, not enough is known about the ecological implications of deep seafloor mining. Deep-sea environments aren't well studied, and even less is known about the vulnerability or resilience of marine ecosystems to such interference.

But the authors see a key opportunity: Unlike most other forms of natural resource exploitation in human history to date, scientists could work with lawyers to put a legal framework in place before large-scale exploitation starts, thereby ensuring a responsible and regulated approach. There are developments to this end; for example, the International Seabed Authority is currently working with scientists on a first draft of environmental regulations for mining in areas beyond national jurisdictions.

However, with a lack of accurate scientific information and so many economic, technological, and environmental uncertainties, is it even possible to create effective environmental regulations? To this end, the researchers suggest that when exploration and testing contracts are granted, those executing the contracts not only survey potential resources and try new technologies but also use the opportunity to study ecosystem responses and provide valuable data to researchers. They also call for a transdisciplinary approach, drawing on the expertise of researchers from across different fields in the physical and social sciences to inform such international agreements.

Recent years have seen a shift from speculation to limited exploration of the deep seafloor, but at some point, the authors stress, resource exploitation will become a reality. (*Earth's Future,* https://doi.org/10.1002/2017EF000605, 2017) **—Jenny Lunn, Contributing Writer**

Are Humans to Blame for Worsening Heat Waves in China?

At least 40 people died during China's record-breaking 2013 heat wave, when temperatures spiked to more than 41°C (105°F). The deadly event was just one of a string of intensifying heat waves that have hit the country over the past 50 years, and a new study finds that these events can be attributed in part to human-caused climate change. Under business-as-usual carbon emissions, such extreme temperatures will become the new normal across roughly 50% of China's landmass, the authors warn.

Sun et al. investigated heat waves across China from 1961 to 2015 using daily temperature and precipitation data from more than 2,400 monitoring stations across the country. The researchers then used computer models to assess past and future changes in heat waves. In some simulations, they included only natural drivers of heat waves and drought, including climatic oscillations such as El Niño, and volcanic eruptions. In other simulations, they included known human contributions to heat waves, through warming caused by greenhouse gas emissions.

The simulations that most closely resembled China's real heat wave history were those that included the human influences, showing that natural causes alone were not enough to explain the country's observed heat waves. In fact, including factors such as rising greenhouse gas emissions from burning fossil fuels led to a more than tenfold increase in the likelihood of the most intense heat waves occurring again in the future, the scientists found.

Under even a "moderate" future emissions scenario, the Intergovernmental Panel on Climate Change's Representative Concentration Pathway 4.5, the authors expect that these once unusual heat waves will occur more frequently, last longer, reach higher temperatures, and occur in more regions of China. (*Geophysical Research Letters,* https://doi.org/10.1002/2017GL073531, 2017) **—Emily Underwood, Freelance Writer**

Local people cool off in a water park in Suining in China's Sichuan province during the 2013 heat wave. New research suggests that carbon emissions may worsen heat waves like this one. Credit: STR/AFP/Getty Images

A New Model for River Meanders

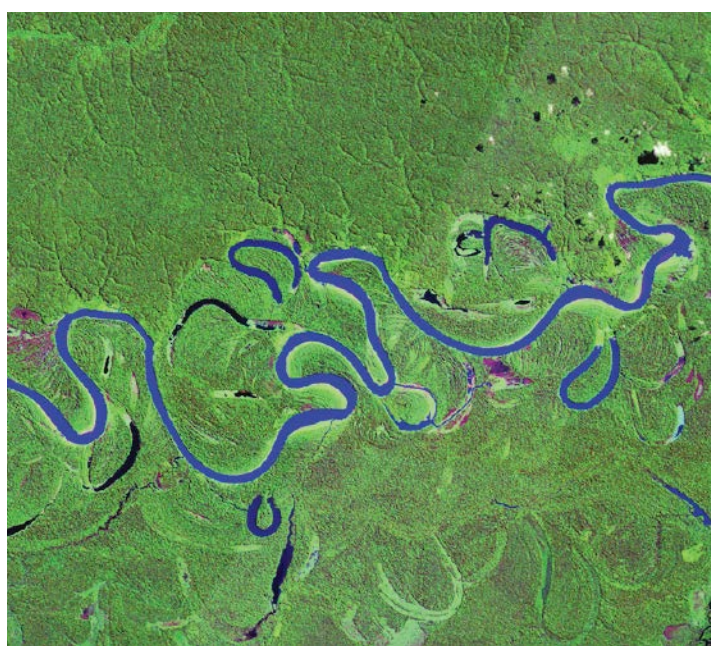
Every time a river floods, it subtly or drastically changes its path. Scientists have long strived to capture this complex process in mathematical models because it includes many variables, including the softness or hardness of the soil the river erodes, groundwater, and the vegetation within and along its shores.

A new computer simulation of how rivers evolve over time comes one step closer to capturing that complexity. The finding could help scientists better predict how floods will remodel a river's banks and affect the people in its path.

A realistic simulation of river evolution must be able to reproduce a wide variety of meanders: the horizontal and vertical detours a river makes as it travels downstream. These meanders are formed by the removal and deposition of silt, sand, mud, and rocks along the outside and inside of bends, which build up characteristic features such as scroll bars—ridges of sand and mud that accumulate on a river's inside curve—and oxbow lakes, crescent-shaped lakes that form when a river's main stream cuts off one of its meanders.

In their mathematical model of how a meandering river and floodplain interact over time, *Bogoni et al.* attempt to simulate how scroll bars and oxbow lakes form and affect meanders by tweaking variables such as the softness of the soil. At first the model river flowed in a straight line, but as the scientists made the floodplain easier or harder to erode, it wobbled, producing meandering undulations.

The most realistic meanders formed when the scroll bars and oxbow lakes left behind in previous floods were harder to erode than the surrounding floodplain, the team reports. The finding illustrates how a river's history affects its present and future course. The traces a river leaves behind define the route it can take. (*Water Resources Research,* https://doi.org/10.1002/2017WR020726, 2017) **—Emily Underwood, Freelance Writer**



Meanders in Brazil's Juruá River, a tributary of the Amazon. A new model of meanders shows that the scroll bars and oxbow lakes that a river leaves behind after floods can define the future route the river can take. Credit: Landsat, USGS/NASA

Can Water Vapor Help Forecast When a Volcano Will Blow?

Ash cloud from an explosion at Sabancaya volcano on 16 November 2016. Credit: OVI INGEMMET

The magma that bursts out of volcanoes is propelled upward largely by dissolved gases, which are released into the atmosphere once the molten rock approaches the surface. The most abundant of these gases is water vapor, and scientists have long searched for a way to accurately measure volcanic water vapor emission rates.

Kern et al. present a possible new method to do just that based on research conducted at the 6,000-meter-high Sabancaya volcano in Peru. Six months prior to the onset of the volcano's current eruptive crisis, which began in November 2016, the team measured the volcanic water vapor output using a method called passive visible-light differential optical absorption spectroscopy (DOAS). DOAS instruments measure the absorption of sunlight by gases in the atmosphere and the volcanic plume above them. The technique is widely used to measure sulfur dioxide emissions, but these were the first successful DOAS measurements of volcanic water vapor.

The team found that prior to the current eruptive phase, the Sabancaya plume contained an exceptionally high ratio, 1,000:1, of water vapor to sulfur dioxide, about an order of magnitude higher than typically found in volcanic gases. They hypothesize that as Sabancaya's buoyant magma rose to shallower depths, it likely began to boil off water stored in the volcano's underground network of fluid-filled cracks and fissures, called its hydrothermal system.

This commonly happens prior to volcanic eruptions, but scientists hadn't thought to use DOAS to detect a possible preeruptive release of water vapor, the team writes. They suggest that visible-light DOAS stations be set up around the world to detect when other active volcanoes are emitting more steam. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014020, 2017) **—Emily Underwood, Freelance Writer**

Hubble Reveals Less-Studied Regions of Jupiter's Auroras

Perhaps the most distinguishable feature of any planet in the solar system is Jupiter's Great Red Spot: a swirling storm of gases twice the size of Earth. In recent years, using the Hubble Space Telescope, scientists have been able to study yet another rare and beautiful atmospheric phenomenon of this gas giant: auroras.

Jupiter's auroras, just like the northern lights, form when high-energy particles enter the atmosphere near the poles and collide with gas atoms, producing an eerie glow.

Astronomers studying these extraterrestrial auroras have mapped out several main regions: the central emission (also known as the main auroral oval), one polar emission near each of the two poles, and outer emissions. The outer emissions, in turn, are made up of moon footprints (bright spots caused by electric current from Jupiter's moons), injections of hot plasma, and a second auroral oval. This secondary oval, located closer to the equator than the main oval, becomes visible to earthly observers when hot plasma injections act as a source of energy for wave-particle interactions, setting the region alight.

In a recent study, *Gray et al.* surveyed the secondary auroral oval with greater insight than ever before by examining images taken from Hubble's Space Telescope Imaging Spectrograph in the first 16 days of 2014.

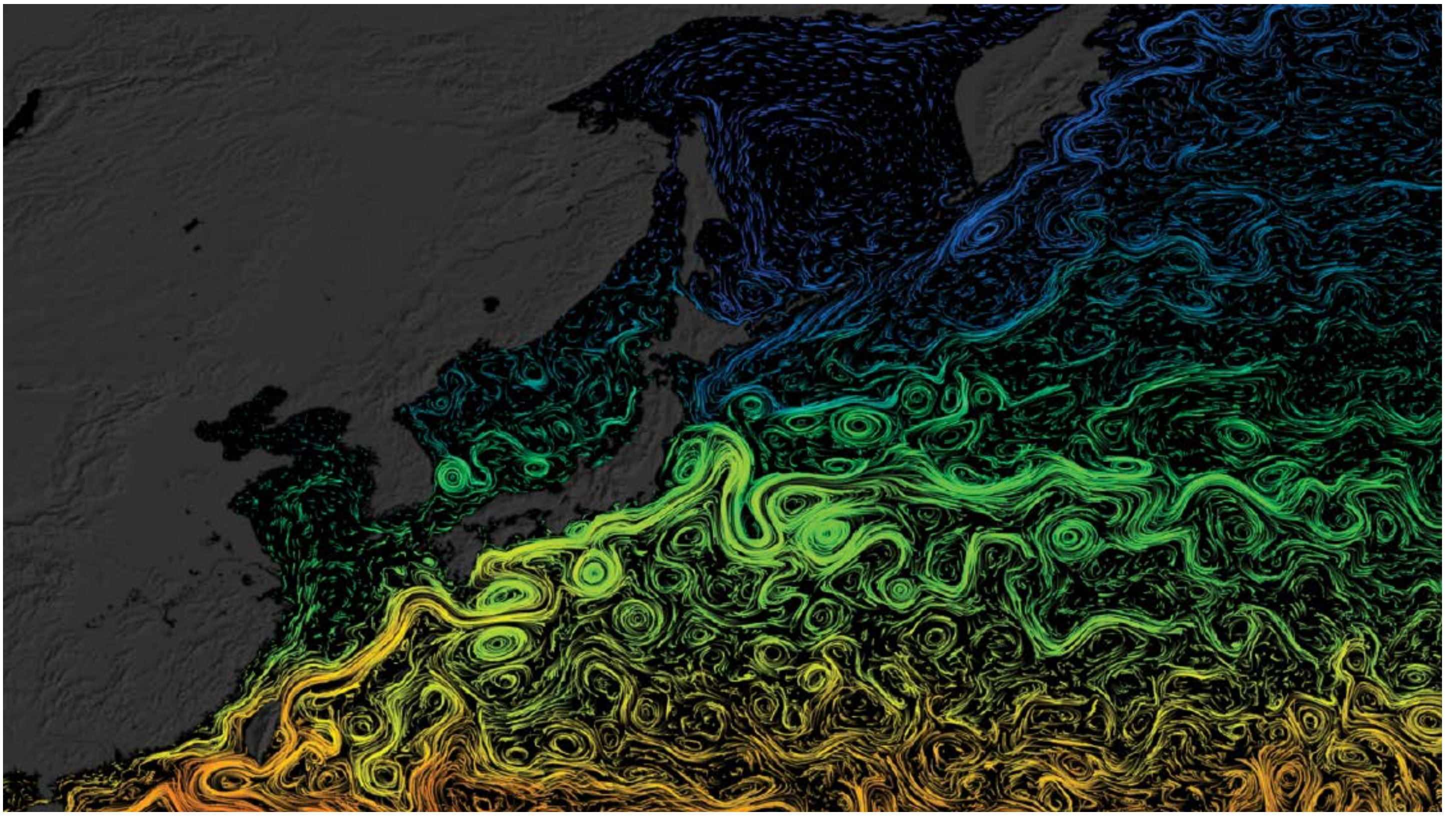
The researchers identified an aurora formation—an arc of ultraviolet light—located in the secondary auroral oval. The arc lies between two moon footprints, Ganymede and Europa, corresponding to an area called the pitch angle distribution (PAD) boundary in the region around Jupiter. Beyond the PAD boundary, scientists believe, electrons are scattered in a pattern causing auroral precipitation.

Auroras leave behind signatures that allow scientists to retroactively determine the energy levels of the scattering electrons. Through the images they studied, the authors found that the auroral arc became bigger and brighter in the few days after a large plasma injection. They also found that the electrons causing auroral precipitation had higher energy and smaller fluctuations than the electrons generating large plasma injections.

The researchers concluded that the scattering of electrons in the secondary auroral oval is caused by wave-particle interactions. They also believe plasma injections can cause temperature changes and enhance wave intensity, scattering electrons into the upper atmosphere for days at a time. Overall, the study tells us more about the nearby gas giant and the far-reaching activities of its vivid auroras. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1002/2017JA024214, 2017) **—Sarah Witman, Freelance Writer**

Auroras shine bright blue over Jupiter. Credit: NASA, ESA

Sediment Cores Reveal the Black Current's Past Life



The swirling flows and eddies of the Kuroshio Current (the Black Current) funnel water through the Okinawa Trough between Taiwan and Japan and hug Japan's east coast, seen through a model that brings together satellite and direct observations. Colors indicate sea surface temperatures; dark blue is 0°C, and orange is about 26°C. Credit: NASA/SVS

Unlike the black currant (a small, sour berry often made into jellies and jams), the Black Current is a strong, northeastward flowing ocean current between the Philippines and Japan. Also called the Kuroshio Current, this massive flux of heat, salt, and moisture from low latitudes up the western edge of the Pacific Ocean plays a pivotal role in the weather and climate of this region.

Today, the Black Current flows through a waterway called the Okinawa Trough to a number of marginal seas, such as the East China Sea and the Yellow Sea. However, some studies suggest that this may not have always been the case. For example, dips in sea level and a theorized land bridge between Taiwan and Japan's Ryukyu Islands during the Last Glacial Maximum (when ice sheets were most recently at their greatest extension, around 30,000 years ago) could have allowed the current to bypass the trough, and these seas, completely. Meanwhile, other recent studies say that such a shift is unlikely to have happened.

To further decode the Black Current's murky past, *Lim et al.* examined samples of mercury from cores of sediment extracted from several active hydrothermal vents in the seafloor of the Okinawa Trough. Each core is a time capsule from the past 20,000 years; the mercury encased within each one was deposited by natural sources, such as volcanic and geothermal activity, whereas modern mercury levels are influenced by human activity, such as fossil fuel combustion.

By comparing the levels of mercury in these cores to modern levels, the researchers were able to probe past climate and geological changes in the region.

First, they found anomalously high levels of mercury in the sediment deposits from the Holocene epoch, which encompasses the past 12,000 years. Of particular interest was a sharp spike around 10,000 years ago. Because most of the mercury in the samples probably came straight from the hydrothermal vents on the ocean floor, the researchers think this spike must have been caused by the Black Current passing through the area, triggering deepwater circulation.

Furthermore, they noticed a big dip in the mercury levels around 3,000–5,000 years ago, which aligns with a known cold period associated with the regrowth of glaciers during the late Holocene. This suggests that the Black Current was temporarily interrupted by the cold period, weakening or halting deepwater circulation.

Overall, the researchers found substantial evidence to support the idea that the Black Current experienced changes in its intensity and route during past glacial and interglacial periods. Not only did the study show hydrothermal mercury to be an effective tool for reconstructing paleoenvironmental conditions, but also it shed light on the prehistory of a major ocean current underlying East Asian climate and many aquatic ecosystems. (*Paleoceanography,* https://doi.org/10.1002/2017PA003116, 2017) **—Sarah Witman, Freelance Writer**

Tsunami Records Show Increased Hazards for Chile's Central Coast

In the early morning of 8 July 1730, residents of central coastal Chile felt what would later be known as the largest earthquake to strike this region since the beginning of local written history (around 1540). The tremor destroyed buildings along more than 1,000 kilometers of the coast. Researchers previously thought that the quake may have reached a magnitude of M_w 8.5 to 9.0.

Now *Carvajal et al.* suggest that this historic quake was even larger than previous estimates and likely reached a magnitude of more than M_w 9, meaning that it was a truly giant event.

Despite the 1730 tremor's strength, few people were killed, thanks to a strong foreshock that prompted many to leave their homes before the big one hit. People also survived by fleeing to higher ground when they saw seawater receding—a warning sign of the ensuing tsunami that inundated residential areas.

In fact, historical observations of this tsunami, which also reached Japan, were what prompted the authors to reexamine the quake's magnitude.

In one account, a Jesuit priest in the historical city of Concepción reported the flooding of several religious and public buildings. In Valparaíso, about 500 kilometers north, firsthand and secondhand accounts describe the flooding. Records from Japan detail damage to barriers, rice fields, and desiccation ponds where salt was harvested but report no human injuries or deaths.

The researchers used these reports to reconstruct the tsunami's height and the extent of flooding. They then investigated the size and depth of an earthquake required to generate such a tsunami.

Using contemporary knowledge of tsunami generation and progression, the scientists ran simulations of tsunamis produced by hypothetical earthquakes of varying magnitudes, depths, and slip amounts off the coast of central Chile. They found that a quake of M_w 9.1–9.3 best fits the historical tsunami records in both Chile and Japan.

According to the best fitting simulation, this earthquake would have occurred along a rupture 600–800 kilometers in length, with an average slip amount of 10 to 14 meters. The tsunami records and additional evidence of coastal uplift suggest that the depth of this slip was shallower toward the northern end of the rupture and deeper to the south.

The researchers note that since 1730, tremors in the same region have involved little slip at shallow depths. Slips at shallow depths are widely agreed to pose the most tsunami hazards, so a lack of shallow slip since 1730 may indicate that stress along the shallow portion of the fault has built up for nearly 300 years.

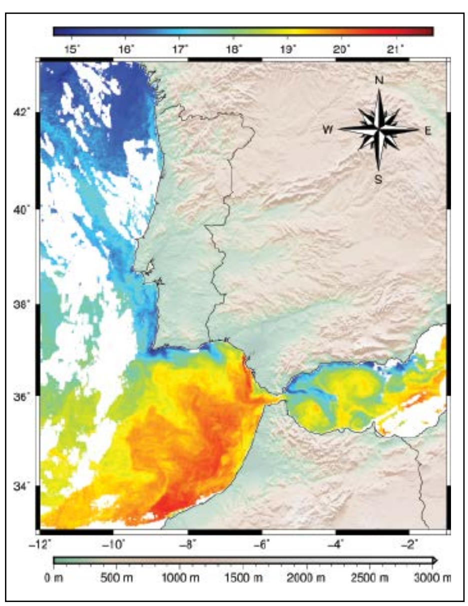
If this potential shallow stress buildup is released in a future earthquake, the subsequent tsunami could be devastating. The authors point out that such a shallow quake might cause only moderate shaking, which could give the local population a false sense of security.

The researchers recommend that this possibility be used to inform disaster prevention plans in the area, which is home to most of Chile's coastal population. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1002/2017JB014063, 2017) **—Sarah Stanley, Freelance Writer**

A Powerful New Tool for Research

The open-source Generic Mapping Tools (GMT) software is widely used to process, manipulate, and display geoscience data sets in multiple dimensions. Although earlier versions of GMT provided basic grid input/output for MATLAB®, a separate "mapping toolbox" and programming language developed by MathWorks, the two products could not directly share their data or methods.

Now *Wessel and Luis* have developed a simple and flexible interface between the two programs that increases their interoperability and extends the capabilities of both tools. The GMT/MATLAB Toolbox provides GMT users with full access to MATLAB's robust computational abilities while also allowing MATLAB users to access GMT's specialized applications, including those that produce publication-quality illustrations. The new toolbox is able to access not only the core components of the GMT software package but also custom extensions installed by the user, including one specially developed for the Global Seafloor Fabric and Magnetic Lineation Data Base Project. These advances are made possible by the GMT library, which enables similar interfaces for Octave, Julia, and soon Python.



Sea surface temperatures near the Strait of Gibraltar, derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellite and processed through the NASA OceanColor site. The researchers used a 1 × 1 arc minute global relief grid (ETOPO1) to visualize the land and overlaid political boundaries and color bars. MATLAB assists with data processing, and GMT makes a publication-ready PDF map. Credit: Wessel and Luis *[2017]*

In addition to an overview of the new toolbox, the researchers provide several detailed examples of how it can be applied to data sets of interest to the geoscience community, including an analysis of crossover error that could not easily be accomplished by either program alone. The GMT/MATLAB Toolbox, which the team describes as "a giant step forward in interoperability," is freely available online for all computing platforms at the University of Hawaii's GMT website. (*Geochemistry, Geophysics, Geosystems,* https://doi.org/10.1002/2016GC006723, 2017) **—Terri Cook, Freelance Writer**

ATMOSPHERIC SCIENCES

Multiple Tenure-Track Positions in the Dept. of Atmospheric and Oceanic Sciences, Peking University

The Dept. of Atmospheric and Oceanic Sciences of Peking University invites applications for multiple tenure-track faculty positions in atmospheric and oceanic sciences. Two 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. Four positions are available in atmospheric sciences, particularly in the areas of climate dynamics and modeling, synoptic and meso-scale meteorology, radiation and remote sensing, 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 semi-annually (in spring and fall), until all positions are filled. The deadline for this round of recruiting is September 24, 2017. For application qualifications, benefits, required materials, and contact information, visit http://www.atmos.pku.edu.cn/rczp/455.htm.

Section Head, Atmosphere Section, National Science Foundation

Section Head, Atmosphere Section
National Science Foundation
Deadline 9/29/17
Job announcement number: AGS-2017-0014

For the full announcement and to apply, visit www.usajobs.gov/GetJob/ViewDetails/477146100. Only resumes submitted according to the instructions on the job announcement listed at www.usajobs.gov will be considered.

This position may also be filled on a one-to-three year Senior Executive Service (SES) Limited Term Appointment or on an Intergovernmental Personnel Act (IPA) assignment basis. Under the provisions of the IPA, assignees remain on the payroll of his/her home institution and the institution continues to administer pay and benefits. The National Science Foundation (NSF) will reimburse the home institution for NSF's negotiated share of the costs.

Duties

Serves as a member of the Division leadership team and as the Directorate's principal spokesperson in the area of lower atmosphere research. Responsible to the Director, Division of Atmospheric and Geospace Sciences, for the overall planning, management and commitment of the budgeted funds for the Section, which includes programs in Atmospheric Chemistry, Climate and Large-scale Dynamics, Physical and Dynamic Meteorology, and Paleoclimate. The incumbent also serves as the Division's primary source of guidance concerning research priories and program development.

The incumbent is responsible for the day-to-day operations of the Section, including developing and executing management plans for assigned projects and evaluating and ensuring the effective use of Section staff and resources in achieving organizational goals. He/she also develops and maintains effective liaison with officials in the scientific community; other federal, state, and local governments, and the private sector to represent Foundation and Division activities and interests and represents the Division on committees, boards, and panels in areas of expertise.

BIOGEOSCIENCES

Tenure track Assistant Professor in Weathering and Soil, University of Lausanne

The Faculty of Geosciences and Environment at the University of Lausanne seeks to appoint an

Tenure track Assistant Professor in Weathering and Soil Development (100%)

The position will focus on processes in the critical zone that link the impact of weathering to the Earth's climate and to the evolution of landscape and biomass. Research approaches that integrate different temporal and spatial scales to identify mechanisms of soil development and the quantification of rates and fluxes involved in weathering processes are highly recommended.

Expected start date: August 1st, 2018

Contract length: 6 years, tenure and promotion to the rank of Associate Professor expected after 5-6 years

The successful candidate will join the Institute of Earth Surface Dynamics (IDYST) and have an active research program with external funding, He or she will teach courses in the Bachelor of Geosciences and Environment, contribute to the Faculty's masters programs, including the MSc of Biogeosciences and will supervise masters and doctoral students.

Candidates need to demonstrate an ability to conduct research of high quality, to obtain competitive research grants and to publish in international scholarly journals, combining research in areas of weathering, soil development, biogeochemical cycles and landscape evolution. An aptitude for teaching and for supervising master's and doctoral theses is required.

Application deadline: October 15th, 2017

All details and apply button on: www.unil.ch/emplois, externe, req ID 11463.

The University of Lausanne seeks to promote an equitable representation of men and women among its staff and strongly encourages applications from women

GEOCHEMISTRY

Postdoctoral Scholar in Stable-Isotope Geochemistry, Lawrence Berkeley National Laboratory

The isotope geochemistry group at the Lawrence Berkeley National Laboratory (LBNL) invites applications for a postdoctoral research scientist to make use of state-of-the-art analytical and experimental facilities at LBNL and the Department of Earth and Planetary Science at the University of California, Berkeley to study the processes that control the isotopic composition of methane, including isotopologues with multiple rare isotopes (i.e. 'clumped' isotopes), in order to improve our understanding of the conditions under which methane forms, migrates, and is stored in the Earth's surface. This work will be conducted with Prof. Daniel Stolper and will involve use of high-temperature and pressure equipment at LBNL and a high-resolution isotope-ratio mass spectrometer housed on UC Berkeley's campus in the Department of Earth and Planetary Science. Expertise in isotope geochemistry and/or high pressure/temperature equipment is desirable. This position will provide opportunities to interact with and engage both UC Berkeley and Lawrence Berkeley National Laboratory scientists. The position has funding for two years with the potential for a third year. Please apply by 10/31/17 for full consideration. More information on the position can be found at: http://50.73.55.13/counter.php?id=108713.

HYDROLOGY

Assistant Professor of Earth and Planetary Sciences, Washington University in St. Louis

The Department of Earth and Planetary Sciences at Washington University in St. Louis invites applications for a tenure-track Assistant Professor position in the field of surface hydrology. The candidate is expected to perform basic research in hydrologic processes at or near Earth's surface. Areas of interest include but are not limited to fluvial, lacustrine, and/or estuarine systems, fluvial geomorphology and sediment transport, flooding, and relationships to ecological and climate systems. The ideal candidate will employ quantitative tools and will integrate computational approaches with direct and remotely sensed observations.

The successful candidate is expected to develop a vigorous, externally funded research program, maintain a strong publication record, advise students, provide outstanding teaching over a broad range of undergraduate and graduate courses, and participate actively in departmental governance and university service. We seek candidates who will strengthen existing research programs in geology, climate science, and remote sensing, as well as foster collaboration with scholars across the Washington University community.

Candidates must have a Ph.D. in Earth science, or a related field, at the time of appointment. Complete applications include a cover letter, curriculum vitae, statements of teaching and research interests, and the names and contact information of at least four references as a single PDF, and should be sent to Professor Philip Skemer, Hydrology Search Committee Chair, Department of Earth and Planetary Sciences, Washington University, Campus Box 1169, 1 Brookings Drive, St. Louis, MO 63130, or via e-mail: hydrologysearch@eps.wustl.edu. Applications must be received by October 15, 2017 to ensure full consideration. Washington University is an Equal Opportunity Employer.

All qualified applicants will receive consideration for employment without regard to race, color, religion, age, sex, sexual orientation, gender identity or expression, national origin, genetic information, disability, or protected veteran status.

INTERDISCIPLINARY

Dean, Nicholas School of the Environment, Duke University

Duke University seeks candidates for Dean of the Nicholas School of the Environment. The Dean of the Nicholas School is the School's chief academic and administrative officer and reports to the Provost and the President. The School's mission is to create knowledge and leaders of consequence for a sustainable future; to further understanding of basic earth and environmental processes and human behavior related to the environment; and to serve and inform society about environmental challenges. The successful candidate will be a respected scholar in a field relating to environmental or earth science or policy, and will have significant administrative experience in the academic, government and/or nonprofit sectors; superb strategic planning and financial management skills; a track record of successful fundraising; and a demonstrated commitment to advancing diversity and inclusion in professional life. Applications and nominations for the Nicholas Dean search, as well as questions pertaining to the search, should be sent to the confidential address: NicholasDean@spencerstuart.com. Applications should include a current CV; nominations should include contact information for the candidate. The search committee will begin reviewing applications October 9, 2017, and submit its recommendation to the Provost and President by December 31, 2017. Additional information can be found at https://nicholas.duke.edu/dean-search

Duke University is an Affirmative Action/Equal Opportunity Employer committed to providing employment opportunity without regard to an individual's age, color, disability, genetic information, gender, gender identity, national origin, race, religion, sexual orientation, or veteran status.

NATURAL HAZARDS

Assistant Professorship in Natural Hazards, Simon Fraser University

The Department of Earth Sciences at Simon Fraser University invites applications for a tenure track Assistant Professorship in Natural Hazards commencing as early as September 2018. A PhD is required, and post-doctoral research, teaching or industry experience is desirable. Qualified candidates will be considered for a Tier 2 Canada Research Chair (see below). The research activities of the successful candidate will complement the existing natural hazards research interests within the Department, while contributing to the expertise of the Department as a whole. Candidates with expertise in remote sensing, risk assessment and mitigation, field-based observation and/or laboratory-based studies examining natural hazards, in particular, geological hazards, are encouraged to apply.

The successful candidate will develop a strong, externally funded research program, and supervise both Master's and doctoral students. Teaching responsibilities will include undergraduate and graduate level courses, to support the environmental geoscience curriculum, for example, by teaching courses in Quaternary geology or environmental geoscience. The successful candidate is expected to eventually take on a leadership role in the Centre for Natural Hazards Research.

For additional information about this position, see http://www.sfu.ca/earth-sciences/.

All qualified candidates are encouraged to apply; however, Canadian Citizens and Permanent Residents will be given priority. Simon Fraser University is committed to employment equity and encourages applications from all qualified women and men, including visible minorities, Aboriginal peoples, persons with disabilities, and LGBTQ persons. The University acknowledges the potential impact of career interruptions on a candidate's record of research productivity, and encourages qualified candidates to explain any impact career interruptions may have had on their record of research achievements.

Applicants are requested to submit a curriculum vitae, a statement of research and teaching interests, and the names, addresses, phone numbers, and email addresses of three referees. Electronic applications are preferred. Review of applications will begin November 1, 2017.

CRC Tier 2 Chairs

- Tier 2 chairs are intended for exceptional emerging scholars (i.e., candidates must have been an active researcher in their field for fewer than 10 years at the time of nomination).
- Applicants who are more than 10 years from having earned their highest degree (and where career breaks exist, such as maternity, parental or extended sick leave, clinical training, etc.) may have their eligibility for a Tier 2 chair assessed through the program's Tier 2 justification process. Please contact the research grants office for more information. 2
- Please consult the Canada Research Chairs website for full program information, including further details on eligibility criteria.

http://www.chairs-chaires.gc.ca/program-programme/nomination-mise_en_candidature-eng.aspx#s5

Please note that under the authority of the University Act personal information that is required by the University for academic appointment competitions will be collected. For further details see: http://www.sfu.ca/vpacademic/Faculty_Openings/Collection_Notice.html.

Applications or requests for further information should be directed to:

Dr. Brent Ward
Chair, Department of Earth Sciences
Simon Fraser University
8888 University Drive

Ocean wave modeling postdoctoral position
Naval Research Laboratory (NRL),
Stennis Space Center, MS

U.S. NAVAL RESEARCH LABORATORY

NRL is seeking applications for postdoctoral positions with the Oceanography Division, for numerical modeling of wind-generated ocean waves. The postdoctoral fellow will be developing, applying, and evaluating the phase-averaged wave models WAVEWATCH III® and SWAN.

Applicants must be experienced with Fortran and able to work efficiently on Linux-based computing systems. Strong proficiency in either MATLAB or Python is also required. Familiarity with numerical modeling (e.g. CFD methods), model optimization, parallel processing, and relevant physics would be beneficial.

Stipends are competitive relative to other labs. Applicants must be U.S. citizens or permanent residents at the time of application. NRL is an Equal Opportunity Employer.

For a quick overview of some of the research done by our group, please peruse recent publications at:
https://www7320.nrlssc.navy.mil/pubs.php

For this wave modeling opportunity, please email a resume and description of research interests to:
contact_wavesjobs@nrlssc.navy.mil

RICE | EEPS
Earth, Environmental and Planetary Sciences

WIESS POST-DOCTORAL RESEARCH FELLOWSHIP

The **Department of Earth, Environmental and Planetary Sciences** at Rice University is inviting applications for the Wiess Post-Doctoral Research Fellowship. We are seeking candidates with independent research interests that intersect with one or more faculty within our department. Applicants must have a Ph.D. awarded within three years of the time of appointment.

The research fellowship will be supported for two years, pending satisfactory progress during the first year. It covers an annual stipend of $60,000 with a benefits package and an additional annual discretionary research allowance of $3,500.

Applicants are requested to develop a proposal of research to be undertaken during the fellowship period. The principal selection criteria are scientific excellence, a clearly expressed research plan to address questions at the forefront of their field of study, and research synergies with at least one faculty. The proposed research should, however, encompass independent research ideas and explore new directions beyond the applicant's Ph.D. Preference will be given to applicants whose proposals demonstrate independence and originality, and also the potential for collaboration with one or more faculty in the Department of Earth, Environmental and Planetary Sciences.

Applicants are required to submit:
(1) A cover letter
(2) A research proposal of no more than 3 pages (single-spaced), including figures
(3) A current CV, including a list of publications

All three documents should be submitted as a single PDF file to the chair of the fellowship search committee (esci-postdoc@rice.edu) by 10 November, 2017. In addition, letters of reference should be submitted by three referees to the same email address and by the same deadline.

The highest ranked applicants will be invited to visit Rice in early 2018. Following acceptance, the appointment may begin anytime before 1 January, 2019. For further information or questions contact the chair of the search committee at esci-postdoc@rice.edu.

Rice University is located in Houston, Texas, and is a private, coeducational, nonsectarian university that aspires to path-breaking research, unsurpassed teaching, and contributions to the betterment of our world. Rice fulfills this mission by cultivating a diverse community of learning and discovery that produces leaders across the spectrum of human endeavor.

Rice University is an Equal Opportunity Employer with commitment to diversity at all levels, and considers for employment qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national or ethnic origin, genetic information, disability or protected veteran status.

https://earthscience.rice.edu/open-positions/

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

FACULTY OF GEOSCIENCES

As one of Europe's leading research universities, Ludwig-Maximilians-Universität (LMU) in Munich is committed to the highest international standards of excellence in research and teaching. Building on its more than 500-year-long tradition, it offers a broad spectrum that covers all areas of knowledge within its 18 Faculties, ranging from the humanities, law, economics and social sciences, to medicine and the natural sciences.

The **Faculty of Geosciences** invites applications for a

Professorship (W2)
(6 years/tenure track)
of Geochemistry

commencing on **October 1, 2018**.

This Professorship of Geochemistry should strengthen the Faculty of Geosciences in research and teaching in the area of Mineralogy, Petrology and Geochemistry. This professorship is aimed at enhancing interdisciplinary cooperation in geochemical dynamics of lithospheric processes (e.g. magmatic and volcanic systems) on the basis of geochemical experiments and/or field observations. We expect a willingness to explore synergies with experimental volcanology, with the research and teaching unit in mineralogy, petrology and geochemistry, as well as with the Munich Geocenter. The establishment of research funding in national and international contexts is expected. In the Bachelor program "Geosciences" and the Masters Programs "Geomaterials and Geochemistry", "Geology" as well as further teaching responsibilities in geochemistry must be met in a manner which is complementary to existing teaching strengths of the department. The Faculty of Geosciences is located in the heart of Munich and provides excellent opportunities for collaboration within the research campus of the Munich area. The Chair of Mineralogy and Petrology provides access to modern experimental and analytical facilities. Additional large-scale research infrastructure is located in the Department of Earth and Environmental Sciences, the Faculty of Geosciences and the Munich Geocenter.

LMU Munich seeks to appoint a highly qualified junior academic to this professorship and, therefore, especially encourages early-career scholars to apply. Prerequisites for this position are a university degree, a doctoral degree or a comparable specific qualification. With an excellent record in research and teaching to date, prospec-tive candidates will have demonstrated the potential for an outstanding academic career.

The initial appointment will be for six years. After a minimum of three years, it can be converted into a permanent position pending a positive evaluation of the candidate's performance in research and teaching as well as his or her personal aptitude and if all legal conditions are met.

Under the terms of the "LMU Academic Career Program", in exceptional cases and subject to outstanding performance in research and teaching, the position may be converted from a W2 into a W3 Full Professorship at a later date.

LMU Munich makes a point of providing newly appointed professors with various types of support, such as welcoming services and assistance for dual career couples.

LMU Munich is an equal opportunity employer. The University continues to be very successful in increasing the number of female faculty members and strongly encourages applications from female candidates. LMU Munich intends to enhance the diversity of its faculty members. Furthermore, disabled candidates with essentially equal qualifications will be given preference.

Please submit your application comprising a curriculum vitae, documentation of academic degrees and certificates as well as a list of publications to the **Dean of the Faculty of Geosciences, Luisenstr. 37, 80333 Munich, Germany**, no later than **15. November 2017**. Please mail the application electronically to **dekanat@geo.uni-muenchen.de** as a pdf-file (<10 MB).

Burnaby, BC V5A 1S6
Phone: 778-782-4229
E-mail: eascsec@sfu.ca

PALEOCEANOGRAPHY AND PALEOCLIMATOLOGY

Assistant Professor–Late-Quaternary Climate Science, Syracuse University

The Syracuse University Department of Earth Sciences seeks applicants for a tenure-track Assistant Professor position in climate change science, who will hold the Thonis Family Endowed Professorship. Scientists with expertise in observational approaches to late-Quaternary paleoclimatology and with established links to the climate modeling community are strongly encouraged to apply. The department welcomes applicants with expertise collecting, characterizing and calibrating quantitative records of past temperature, sea level change, glacial dynamics, hydroclimate, and terrestrial responses to natural and anthropogenic forcing. The ideal candidate will collaborate across traditional disciplinary boundaries within the Department of Earth Sciences and the greater SU community, which includes expertise in energy, sustainability, and water resources. The successful applicant will arrive with or establish a strong, externally funded research program and develop a portfolio of excellence in teaching at the graduate and undergraduate levels. Active public engagement on issues of a changing climate is an essential part of the appointment. Applicants will teach a large, introductory-level class in Earth Science, contribute to existing courses in paleoclimatology and develop new undergraduate and graduate courses in the science of climate change.

The Department of Earth Sciences at Syracuse University (http://earthsciences.syr.edu) currently has 15 full-time faculty with broad research strengths in the solid earth, geochronology, hydrology and paleoclimatology. The Department has an outstanding array of analytical facilities and recently renovated laboratories, and the University has an established track record of supporting research infrastructure.

Applicants should submit a cover letter, curriculum vitae, statements of research and teaching interests, copies of three relevant publications, and the contact information for three referees to https://www.sujobopps.com/postings/70988, preferably by November 15, 2017. The search committee will be available to meet with candidates at the GSA and Fall AGU meetings; the search will remain open until the position is filled.

Dartmouth

Earth and Environmental Geoscience Informatics
Dartmouth College

The Department of Earth Sciences at Dartmouth College invites applications for an **assistant or associate rank tenure-track position** in the area of earth and environmental geoscience informatics with specific application to one or more of our core research areas: ice and climate systems, watershed and soil processes, or environmental (bio)geochemistry. We are especially interested in candidates who combine a focus on understanding fundamental physical and/or geochemical processes in modern or ancient systems using innovative analyses of big and/or broad datasets and to candidates who provide synergy with ongoing research activities within the department and elsewhere at Dartmouth.

The successful candidate will help develop curricular and research opportunities in the analysis of big and/or broad data. Teaching responsibilities consist of three courses per year at both introductory and graduate-levels.

To submit an application, please visit **http://apply.interfolio.com/43899**

Application review will begin **November 1, 2017**, and continue until the position is filled.

Appointment will be effective **July 1, 2018.**

Dartmouth College is an equal opportunity/affirmative action employer with a strong commitment to diversity. In that spirit, we are particularly interested in receiving applications from a broad spectrum of people, including women, minorities, and individuals with disabilities, veterans or any other legally protected group.

Syracuse University is interested in candidates who have the communication skills and cross-cultural abilities to maximize their effectiveness with diverse groups of colleagues, students and community members. Women, military veterans, individuals with disabilities, and members of other traditionally underrepresented groups are encouraged to apply. Syracuse University is an equal opportunity employer, as well as a federal contractor required to take affirmative action on behalf of protected veterans.

VOLCANOLOGY GEOCHEMISTRY AND PETROLOGY

2018 Carnegie Fellowships for the Geophysical Laboratory. The Geophysical Laboratory of the Carnegie Institution of Washington invites applications for postdoctoral fellowships. The Geophysical Laboratory emphasizes interdisciplinary experimental and theoretical research in fields ranging from geoscience, microbiology, chemistry, to physics. The Laboratory supports world-class facilities in high-pressure research; organic, stable isotope and biogeochemistry; mineral physics and petrology; and astrobiology.

Carnegie Postdoctoral Fellowships are awarded once a year. The deadline for submitting an application is 1 December 2017 and the position begins the following summer or autumn.

Carnegie Fellowship applications must include a curriculum vitae, brief description of thesis research, three-to-five page research proposal, list of publications, and three letters of reference sent by those familiar with your work.

If you are not familiar with our current research, we suggest that you look at our recent publications listed on the home page, Carnegie Institution Yearbooks, and/or speak with staff members and current postdoctoral associates.

The fellowship committee evaluates research proposals for evidence of original thinking and to determine a candidate's ability to develop and carry out a research project that can be accomplished at the Laboratory. You are encouraged to contact a Geophysical Laboratory Staff Member about the suitability of your project.

Also, please see our listing of personnel, research areas, and major facilities.

Completed applications for a Carnegie fellowship should be submitted through this website: https://jobs.carnegiescience.edu/jobs/2018-carnegie-fellowships-for-the-geophysical-laboratory/ no later than 1 December 2017.

The Carnegie Institution of Washington is an equal opportunity employer. All qualified applicants will receive consideration for employment and will not be discriminated against on the basis of gender, race/ethnicity, protected veteran status, disability, or other protected group status.

Electron Microprobe Operator, University of Oklahoma

The Office of the Vice President of Research supports an electron microanalysis laboratory built around a Cameca SX100 microprobe as a core research facility of the university (https://ors.ou.edu/Microprobe/OUEMPLHome.html). This includes a fully funded, twelve-month annual staff position as Electron Microprobe Operator. That position is now open until filled with a starting date of October 1, 2017, and no later than January 1, 2018. Duties include daily operation of the microprobe and sample preparation for all clients, daily lab maintenance, periodic instrument maintenance (filament, roughing vacuum, etc.), coordinating major service with Cameca engineers, scheduling and bookkeeping of usage by clients, billing and payments, and an annual summary report of laboratory activity.

Minimum qualifications for the position include a master's degree in geosciences or a relevant discipline and some experience in electron beam methods of analysis and microprobe operation. Applicants must submit (1) a cover letter that includes career goals and prior experience in electron microprobe analysis, (2) a CV that includes employment history and responsibilities, (3) complete transcripts of baccalaureate and master's degree courses, and (4) letters from two individuals who are qualified to comment on the suitability of the applicant for the position.

In 2014, OU became the first public institution ever to rank #1 nationally in the recruitment of National Merit Scholars. The 277-acre Research Campus in Norman was named the No.1 research campus in the nation by the Association of Research Parks in 2013. Norman is a culturally rich and vibrant town located just outside Oklahoma City. With outstanding schools, amenities, and a low cost of living, Norman is a perennial contender on the "Best Places to Live" rankings. Visit soonerway.ou.edu for more information.

Applicants must submit an ONLINE application at https://jobs.ou.edu for job requisition number 172628. Computers and personal assistance are available at the Office of Human Resources, 905 Asp, Rm.205, Norman, OK 73069.

The University of Oklahoma is an Affirmative Action, Equal Opportunity Employer. Women and minorities are encouraged to apply. Protected veterans and individuals with disabilities are encouraged to apply.

Department Head - Geosciences

The Department of Geosciences at The Pennsylvania State University invites nominations and applications for a dynamic, innovative, and visionary leader for the position of Department Head. The successful candidate is expected to be dedicated to promoting inclusion, cohesion, and excellence in the research and educational programs within the Department and across the College. The successful candidate is also expected to continue their strong record of cutting-edge scholarship and be qualified for appointment with tenure. The position is open to any area of research interest within Geosciences. Previous experience in academic or professional leadership is desirable. Women and members of under-represented groups are strongly encouraged to apply. Penn State Geosciences includes multiple top-ranked research and educational programs, and faculty who are international leaders in a broad array of fields. The Department has strong ties to programs across the University, including the Huck Institutes of the Life Sciences, the Penn State Institutes of Energy and the Environment, and the Materials Research Institute, numerous leading disciplinary programs, and interdisciplinary training programs in Energy, Astrobiology, Biogeochemistry, and Climate Science. More information is available on our website (www.geosc.psu.edu). To apply, applicants should upload the following materials through the PSU jobs website: 1) a letter describing how they would lead the Department and contribute to its teaching, service, and research programs; 2) a complete curriculum vitae; 3) names and addresses (including e-mail) of three referees. Review of applications will begin October 15, 2017, but applications will be accepted until the position is filled. Questions about the position should be directed to Dr. Kate Freeman, Chair, Department Head Search Committee, Department of Geosciences, at mailto:khf4@psu.edu.

Apply online at **http://apptrkr.com/1060594**

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.

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.

Postcards from the Field

Greetings from Paradise!

Tiera is taking notes on samples collected for grain-size analysis and X-ray fluorescence/X-ray diffraction (XRF/XRD) analysis on top of the fluted cliffs of the Na Pali coast of Kauai, in a quest to understand how weathering of the basalts renders them erodible. Friends claim we are just using geology as an excuse to go hiking in Hawaii, but we deny it.

—**Jerry Osborn** and **Tiera Naber,** Department of Geoscience, University of Calgary, Alberta, Canada.

View more postcards at
http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.