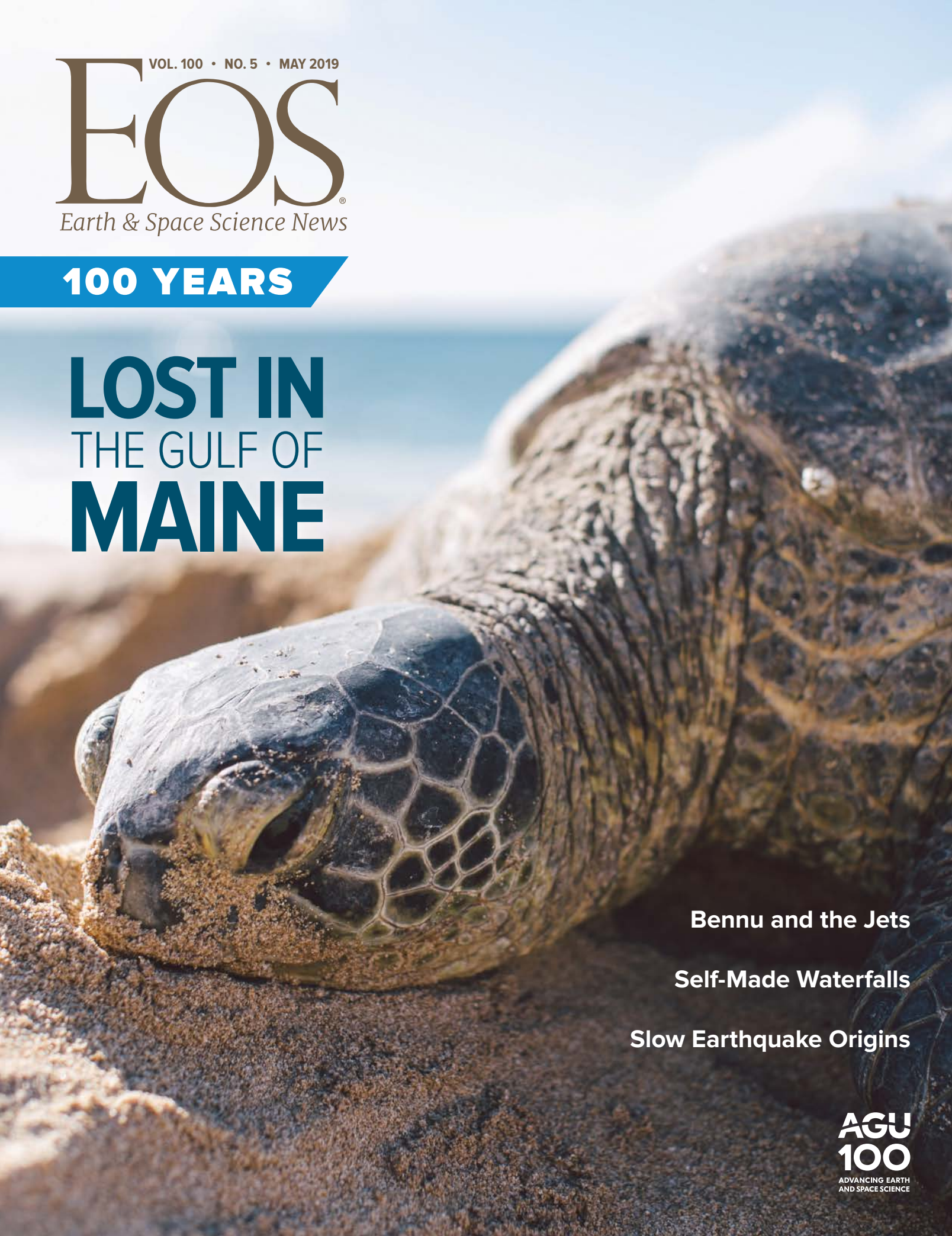
VOL. 100 • NO. 5 • MAY 2019

EOS

Earth & Space Science News

100 YEARS

LOST IN THE GULF OF MAINE



Bennu and the Jets

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Earth's Ripple Effect

No one was hoping to find the Gulf of Maine in the top 1%.

Recently, sea animals have been washing up stranded, many injured or dead, in record numbers on the beaches of Maine, New Hampshire, and Massachusetts. One scientist, Andrew Pershing, was studying the rate of warming in the Gulf of Maine and thought it was unusually high. He discovered something astounding when he compared the rate with global data: The gulf area is warming faster than 99% of the oceans.

Opposing currents wind past each other through the Gulf of Maine—the Labrador Current, which brings cold water south from the Arctic and along the shore, and the Gulf Stream, bringing warmer water north from the equator.

Climate change is wrecking the delicate balance of these streams. Rapidly melting ice in Greenland is pushing cool, fresh water into the Labrador. This less dense water is causing the current to lose steam as it reaches the Gulf of Maine, allowing the warm, northerly Gulf Stream to push closer to shore. Read more in our cover story on page 26 about Pershing's and other scientists' research as they race to predict the future that sea life faces in the Gulf of Maine.

The theme of our May issue covers instances like these, in which our planet's oceans interact with the ice, land, and air around them, as we continue AGU's Centennial celebration of the Earth and space sciences. The study of these dependent actions was pioneered by scientists like Roger Revelle, one of the first to connect the idea that the carbon dioxide accumulating in the atmosphere from fossil fuel burning was being absorbed by the ocean. "The Earth itself is a spaceship," he famously said while delivering testimony to the U.S. Congress in 1957. As these ocean studies show, poisoning the air of that ship will have cascading effects on our life support systems.

Tsunamis are another important area of study when it comes to ocean–land interactions. The events are often catastrophic, but their relative rarity can cause challenges for communities that need to invest in mitigation and preparedness. In the Caribbean, tsunamis happen on average every 25 years but arrive with only a few hours' notice to an area that is home to 40 million people. On page 32, read about a group of scientists and policy makers that recently pushed for the creation of an international collaboration focused on tsunami hazard assessment. The initiative now includes 47 countries and territories in the Caribbean and Gulf of Mexico area, working to quantify risks and apply that research to action plans such as evacuation maps. If these scientists can use research to keep the issue alive in the region's collective memory, they'll likely save many lives—if not in this generation, then in the next.

Ocean interactions affect us in myriad ways, from regional events like ocean current dynamics or earthquake-induced tsunamis to issues that impact neighborhoods. On page 39, read about a grassroots group that is educating its community about how sea level rise is causing recurrent flooding in the town of Virginia Beach. AGU's Thriving Earth Exchange connected the group, Stop the Flooding NOW, with a local coastal resources scientist, and together they've been working with their neighbors to find ways to protect thousands of homes. In February, the Virginia legislature even issued a resolution praising their work.

In this issue, *Eos* recognizes the work of scientists, policy makers, and community members who see the connections between ocean, ice, air, and land. This "spaceship" of ours needs you more than ever.

Heather Goss, Editor in Chief

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Eos (ISSN 0096-3941) is published monthly by AGU, 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; service@agu.org.

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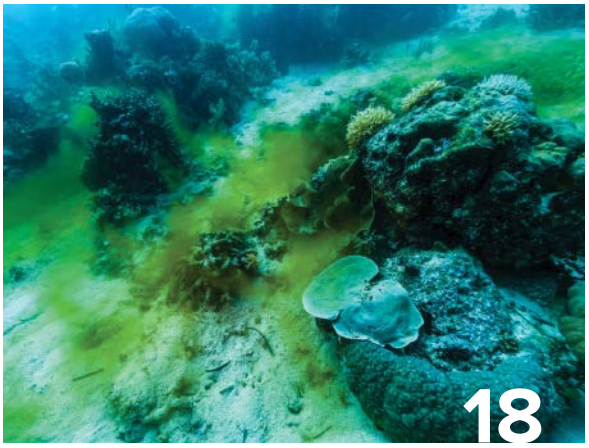
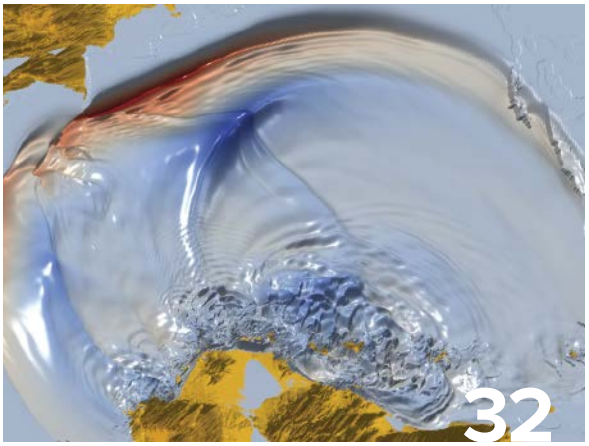
Christine W. McEntee, Executive Director/CEO



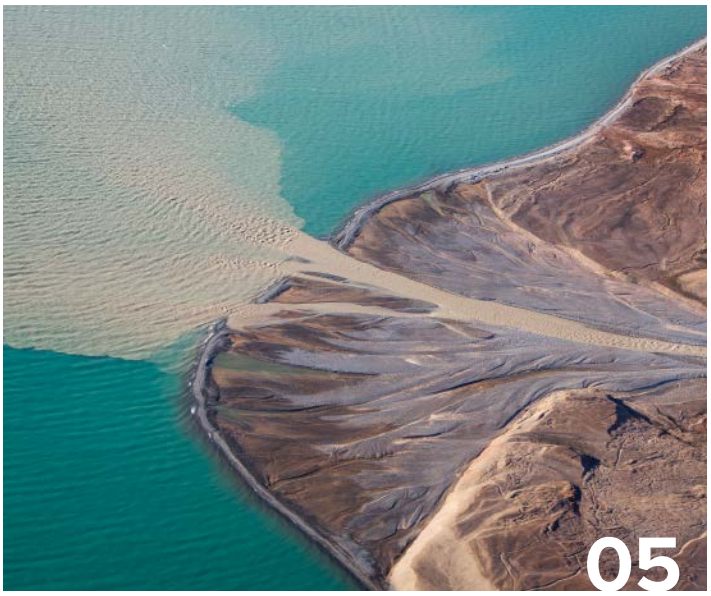


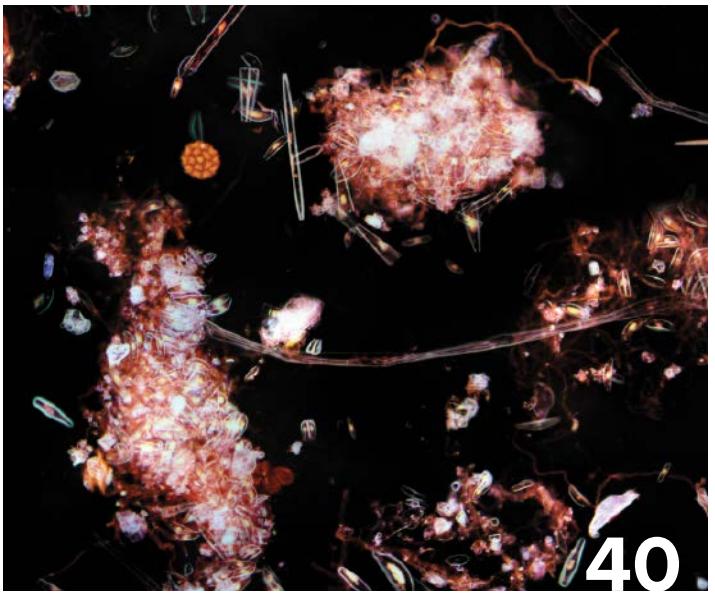
Cover Story

On the Cover

A sea turtle rests its head on the sand. Credit: Keith Champaco/Unsplash.com

Features





Columns

Pristine Collection of Soft-Tissue Fossils Discovered

Thousands of rare soft-tissue fossils from the Cambrian period have been unearthed along a riverbank in China. More than half of the taxa of these fossils, collectively called the Qingjiang biota, are new to science.

"The Qingjiang biota is 10 million years older than the Burgess Shale, closer to initial diversification of metazoans," or multicellular animals, said Xingliang Zhang, a geologist at Northwest University in Xi'an, China, and lead researcher on the project. The new fossil deposit shows "lots of potential," he said. "We [have] just started to work on so many new taxa."

The team published this discovery on 21 March in *Science* (bit.ly/Qingjiang-biota).

A Unique Window into Early Animal Life

Soft-tissue fossils are very rare because skin, eyes, guts, and brains are much more difficult to preserve than skeletons. There are only a few deposits worldwide where the mineralogy of the rocks supports the preservation of these soft tissues.

These types of fossils from the Cambrian period (541–485 million years ago) give clues about the earliest years of animal life and the largest diversification of life on Earth, called the Cambrian explosion.

Zhang and his team discovered the Qingjiang biota along the banks of the Danshui River in the Hubei Province of China. During four field campaigns, researchers collected 4,351 specimens that represent 101 multicellular taxa and eight algal forms.

The Qingjiang biota is roughly 518 million years old. It is about the same age as the nearby Chengjiang biota and slightly older than those at Canada's Burgess Shale, the location for which these types of fossils are named.

The team found that Qingjiang rivals, and might even exceed, the Burgess Shale deposits in terms of its taxonomic diversity. Only a few of the species found in Qingjiang were previously discovered in other locations, and 53% of the animals represent previously unknown taxa.

"The Qingjiang biota is remarkable in how it so dramatically opens up another, and yet unique, window to the beginnings of diverse animal life on Earth's surface," said Emma Hammarlund, a geobiologist at Lund University in Sweden who was not involved with this research. "What we can see through this window is nothing short of astounding."

Jellies, Combs, Sponges, and Tentacles

Researchers found that the Qingjiang fossils are in a more pristine condition than those from Burgess Shale and Chengjiang.

"This is where the Qingjiang biota is truly remarkable, and certainly worthy of attention, by how it presents its members with amazing detail of shapes, antennas, or eyes," Hammarlund said. "The rocks are much less weathered than at Chengjiang and less cooked than at Burgess Shale."

"As if that wasn't enough," she continued, "the biota has also preserved its flimsy ones, so both jellyfish, sometimes even with tentacles, and comb jellies appear preserved. This contribution from the Qingjiang will certainly add to our understanding of the evolution, and resilience, of also the most primitive animals."

What's more, the biota includes fossils of the same taxa spanning larval, juvenile, and adult developmental stages. This discovery could give an unprecedented look into the development of individual species, the team writes.

More than a third of the Qingjiang biota are cnidarian fossils, stinging creatures like jellyfish, box jellies, and anemones that are thought to have been abundant during the early Cambrian but are underrepresented in the fossil record.

The array of cnidarians "provide[s] the tantalizing prospect of illuminating some of the lowest branches of the animal tree," according to Ross Anderson, a paleobiologist at All Souls College at the University of Oxford in the United Kingdom who was not involved with this study.

Neighboring Fossils, Different Paleoenvironments

The Qingjiang and Chengjiang biotas are the same age and from the same paleogeographic region but have only an 8% overlap in their taxa. That distinction could suggest that the two deposits developed in response to different paleoenvironmental conditions, the team writes.

"The differences in the biological composition of Qingjiang versus the neighboring Chengjiang biota really highlight the ecological diversity of early animal ecosystems," Anderson said. "Burgess Shale–type deposits are of vital importance to our understanding of early animal evolution. The Qingjiang biota might just be the best yet discovered."

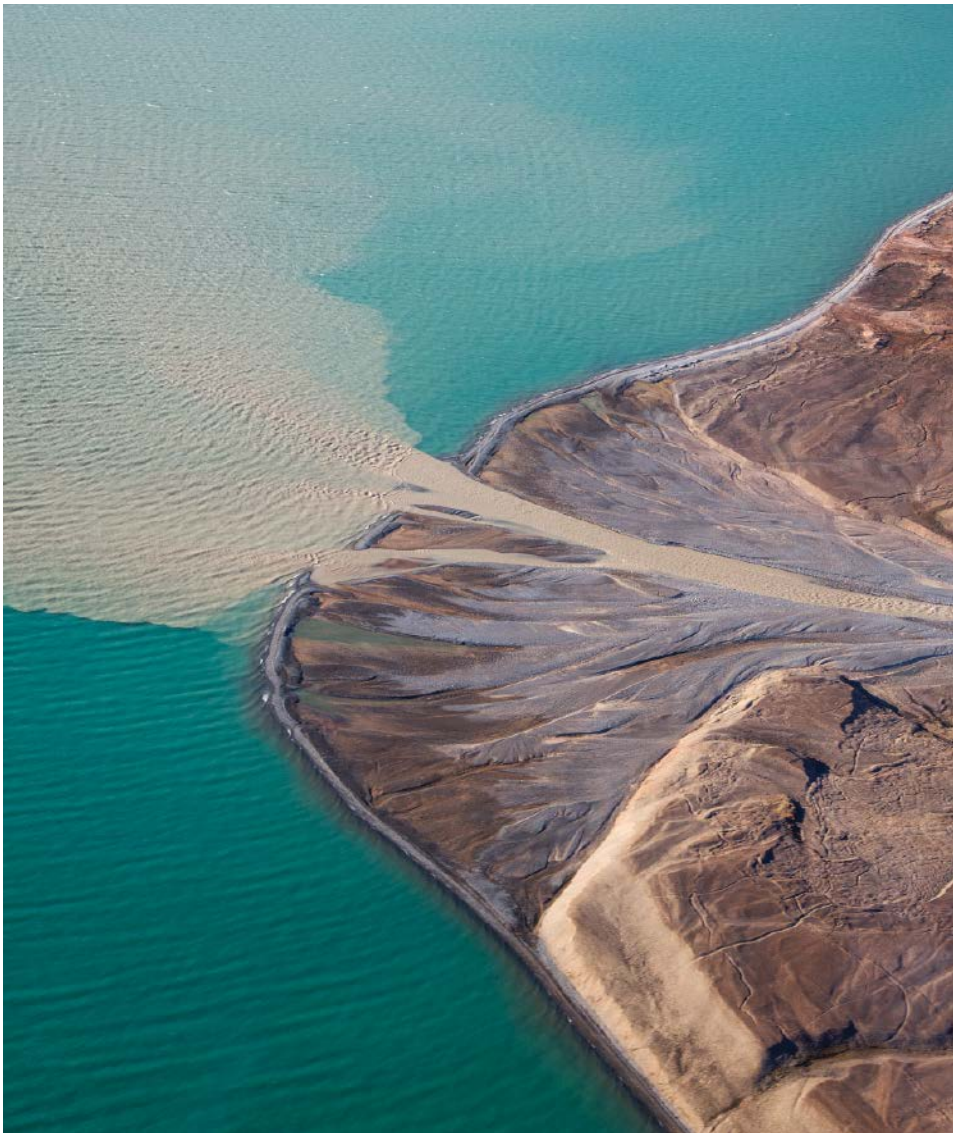
With two very different fossil deposits discovered so close together, Zhang and his team continue to hunt for more.

"I have been working on Burgess Shale–type fossils for many years and keep searching for good fossil localities and collecting fossils every year," Zhang said. "If we can find Burgess Shale–type preservation in the first 20 million years of the Cambrian anywhere in the world, it would be great!"

Researchers dig up a Qingjiang fossil on a bank of the Danshui River, near its junction with the Qingjiang River in China's Hubei Province. Credit: Dong King Fu

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

Sand from Greenland's Melting Ice Sheet Could Be Big Business



Water muddied with sediment flows into the ocean off Greenland. Credit: Nicolaj Kroeg Larsen

The Arctic is warming twice as fast as other parts of the globe, and the hot temperatures are leaving their mark: In Greenland, the ice sheet that covers 80% of the country is rapidly shrinking.

The melting ice brings more than just water to the coastline. Ice melt delivers tons of sand and gravel particles offshore, and a paper published in *Nature Sustainability* in February (bit.ly/Greenland-sand) suggests that Greenland could profit from this resource.

"Contrary to the general trend that the Arctic is facing a lot of problems because of climate change, we actually suggest that Greenland can benefit from it by exploiting [its] sand," lead author Mette Bendixen of the University of Colorado Boulder told *Eos*. Sand harvesting could be one antidote to both the country's stagnant economy and the growing global sand shortage.

But other scientists may not be convinced, citing environmental concerns.

"High-latitude marine ecosystems are among the last, most pristine places on Earth," Whitman Miller, a research scientist at the Smithsonian Environmental Research Center in Edgewater, Md., told *Eos*. Greenland must engage in "comprehensive and forward looking planning" to avoid damage from mining, he warned.

Sand Dollars

Sand underlies nearly every aspect of urban life: Highways, skyscrapers, dams, bridges, and other infrastructure all contain sand and gravel. Booming cities in Asia are buying sand by the boatload, and China used more cement between 2011 and 2014 than the United States did in the past century.

But the world is running out of sand. Global demand is projected to increase by nearly a third by the end of the century, but resources are limited.

Only certain types of sand, like those found in rivers, beaches, and seafloors, are well suited as construction material. The economic value of these types of sand has had troubling environmental and social consequences, including the disappearance of 2 dozen islands in Indonesia and the emergence of "sand mafias" in India.

Meanwhile, Greenland's economy faces a host of problems: An aging population and a 10% unemployment rate have the country looking for new sources of income.

"They're really short of money, and they have sought for decades to diversify their economy," Bendixen explained.

A Shore Thing

Climate change clears the way for sand mining in Greenland in several ways. Not only does increased melting bring more sand and gravel to the coastline of Greenland (where it can be mined by boat), but warmer temperatures are also clearing bays and outlets of sea ice, making them accessible nearly year-round.

The researchers recommend that Greenland focus on mining several regional hot spots. One such hot spot is the Sermeq Outlet, which sits just 100 kilometers away from the country's capital city of Nuuk. The outlet collects one quarter of the sand coming off Greenland and is accessible by boat nearly all year. This single outlet could supply double the amount of sand needed for construction in San Diego County, California, every year, the paper notes.

The Sermeq Outlet is an "interesting and economically feasible site," Bendixen said.

The Greenland workforce may also be well poised to kick off a sand mining industry, according to the paper.

"Greenland's industry is mostly focused on fishing. They have good skills in terms of maritime knowledge and [knowing] how to navigate these pretty difficult Arctic waters," she explained.

If Greenland went forward with the idea, it wouldn't need to worry about the sand running out anytime soon.

"As long as global warming is continuing, the ice sheet is going to melt, and with the melt come more sand and gravel," Bendixen said. The steady stream of sand will continue "for centuries to come," the authors write.

An "Unsustainable Option"

And yet environmental concerns loom large. Sand mining could "locally enhance or even amplify" the disruption to local ecosystems from climate change, according to the paper. Norpadzlihatun Manap, a visiting researcher at Imperial College London, calls sand mining an "unsustainable option" for Greenland.

"Sand acts as a sink to contaminants," she explained. Manap noted that unleashing those contaminants may in turn have a negative impact on Greenland's domestic revenue, which comes largely from the fish and shellfish industry.

The introduction of bulk carrier ships could bring contaminated ballast water to the sensitive Arctic region as well, added Whitman Miller. "The potential for high-impact invasions is a serious concern and requires the institution of robust biosecurity measures," he said.

> "As long as global warming is continuing, the ice sheet is going to melt, and with the melt come more sand and gravel."

Bendixen agreed that a "thorough environmental impact assessment" must be completed before any sand extraction begins. She said that the next step will be establishing a team of Greenlandic and Danish researchers to investigate outstanding questions and engage with the Greenlandic population.

"They know their country the best," Bendixen said. "We just want to offer the opportunity to Greenland so that they can decide for themselves."

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

Bennu and the Jets

Asteroid 101955 Bennu regularly ejects plumes or jets of particles from its surface. This discovery reveals that Bennu, a near-Earth asteroid currently playing host to an orbiting spacecraft, is one of a rare class of active asteroids, of which only about a dozen are known.

A jet of particles (center) coming off of asteroid 101955 Bennu on 19 January. This image combines a long exposure from OSIRIS-REx's navigational camera with a short exposure of the asteroid surface. Mission scientists did not expect Bennu to be an active asteroid. Credit: NASA/Goddard/University of Arizona/Lockheed Martin

"The discovery of plumes is one of the biggest surprises of my scientific career," said Dante Lauretta, principal investigator of NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) mission. OSIRIS-REx has been orbiting Bennu since 31 December 2018.

Mission scientists, including Lauretta, discussed this and other first discoveries from OSIRIS-REx at a press conference on 19 March.

Satellite Creation

The OSIRIS-REx team first detected a jet of particles on 6 January. The flight navigators noticed bright spots in the craft's navigational camera that could not be image artifacts. After consulting with mission scientists, the team realized the spots were, in fact, small rocks. The navigation team quickly created new analysis tools to detect the particles and set up a dedicated monitoring campaign between 11 January and 18 February.

"We have seen about 11 such events over that time period, and more are being discovered as we get better at analyzing and processing the data," Lauretta said. "Three of those events have been substantial, with dozens or over a hundred particles being ejected clearly into the asteroid environment."

The ejected particles are centimeters to tens of centimeters in size and leave the surface at speeds ranging from tens of centimeters per second to a few meters per second, according to the team.

"Some of them have been observed to fall back onto the surface," Lauretta said. "Basically, it looks like Bennu has a continuous population of particles raining down on it from discrete ejection events across its surface."

Some slower moving particles "are ending up in orbit around Bennu. It's creating its own set of natural satellites," he said. "That has never been seen before in any solar system object in history."

Unexpected and Exciting

The team said that despite the unexpected discovery of particle jets, there is a very low probability that one of the particles will strike OSIRIS-REx in orbit. The researchers are continuing to monitor Bennu for more ejection events, hoping to discover where the ejections are coming from, when they might happen, and what might be causing them.

"This is incredibly exciting," Lauretta said. "We don't know the mechanism that is causing this right now. In fact, we're still learning how to process the data, analyze the information, and make sense of what's going on at this asteroid."

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

Self-Made Waterfalls

Eaton Canyon Falls, seen here, might be one in a sequence of self-formed waterfalls in California's San Gabriel Mountains. Credit: Michael Huey, CC BY-NC-SA 2.0 (bit.ly/ccbyncsa2-0)

When it comes to creating waterfalls, some rivers are opting for the "do-it-yourself" approach. A study published in March in *Nature* suggests that for some rivers, natural streamflow mechanisms can form waterfalls without any external factors (bit.ly/self-made-waterfalls). The conditions that lead to these autogenic waterfalls might be common in mountain runoff streams and should be further studied, the authors of the study said.

"Identifying autogenic waterfalls in the field is quite tricky," said Joel Scheingross, a geoscientist at the University of Nevada, Reno who led the study. The team set up a scaled-down synthetic river in a lab to study autogenic waterfalls in isolation. "Experiments allow us to control for constant rock type, water discharge, sediment supply, et cetera, and let us test the autogenic formation mechanism in the simplest possible scenario without the added complications that exist in nature," he said.

DIY Waterfall

Externally forced waterfalls can form when water flows from one rock type to the next, glaciers retreat, landslides reroute a river, or tectonics abruptly shifts the landscape, for example. Past laboratory studies of waterfall formation have simulated one or more of these factors, the team said, or used materials that erode with water alone without the presence of sediment.

In this study, Scheingross and his team set up a synthetic riverbed made from polyurethane foam to mimic a uniform bedrock, and they flowed water and sediment down its surface. They chose the experiment parameters to mimic mountain streams where waterfalls are common. The test lasted just under 4 hours, but when the model is scaled up, it represents 100–10,000 years of river evolution.

> Autogenic waterfalls tended to form a series running along the length of a river.

The researchers found that the flow carved out a series of repeating steps in the bedrock, similar to past experiments. Some steps gradually migrated downstream, like an escalator, as the water eroded rock from the edges of the steps.

Occasionally, however, a step built up a deposit of gravel that protected it from rapid erosion. The step below it continued to abrade and eventually became a drop steep enough to form a free-flowing jet and a plunge pool beneath—an autogenic waterfall. The team found that autogenic waterfalls tended to form a series running along the length of a river, and each fall lasted about 20 minutes (10–10,000 years in nature).

The team is conducting further tests to explore the range of conditions that might form an autogenic waterfall.

"If we can form autogenic waterfalls in many different experiments, we can also explore [whether] there's a morphologic 'fingerprint' of autogenic waterfalls," Scheingross said, like the ratio of different step heights.

Naturally Formed, Found in Nature

The researchers point out two regions in California that might have autogenic waterfalls: the central Sierra Madre block of the San Gabriel Mountains and Bridalveil Creek in Yosemite National Park. Both sites have a series of waterfalls, something predicted by this experiment.

The San Gabriel Mountain site is "intriguing" Scheingross said, because "erosion rates and uplift rates have been in balance over decadal to million-year timescales, so it seems unlikely that tectonics could be causing waterfall development." And while Yosemite's famous Bridalveil Fall formed from glacial carving, smaller falls upstream might be autogenic, he said.

This study is a "proof of concept," Scheingross said. "The hope is that once we can conclusively distinguish between self-formed and externally forced waterfalls in nature, we can then start to more critically evaluate how to use waterfalls and knickzones in interpreting Earth history."

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

Westward Expansion, Technology, and Tornado Fatalities

The swirling winds of tornadoes can loft train cars and rip roofs from houses, leaving swaths of destruction in just minutes. Scientists now have a long-term perspective of the deadly nature of tornadoes, thanks to new results of the number of tornado fatalities per capita in the United States from 1808 to 2017. The researchers found a steady rise in the death rate until around World War I and then sevenfold decline from then to the evolution of technology that has improved tornado predictions, detections, and warnings.

> People died at a higher rate because towns sprang up that put people closer together when a tornado hit.

Up and Then Down

Ernest Agee and Lindsey Taylor, atmospheric scientists at Purdue University in West Lafayette, Ind., when this research was conducted (Taylor is now at the University of Washington in Seattle), assembled records of tornado fatalities from 1808 to 2017. Agee and Taylor mined data collected from newspapers, journal accounts, and the National Oceanic and Atmospheric Administration's Storm Events Database for tornado-related deaths and retrieved population records from the U.S. Census Bureau. They focused on a 21-state region stretching from the Gulf of Mexico to the Canadian border that includes notorious hotbeds of tornado activity. The researchers then assembled a death per population index (DPI) by dividing the number of tornado fatalities in a given region by that region's average population. The scientists repeated this process for each of the 21 states for six different time periods, each roughly 35 years long.

Agee and Taylor found that the average DPI value steadily increased during the first three time periods, spanning from 1808 to 1915. The researchers attributed this finding to, among other factors, land rushes that saw large populations move westward into tornado-prone areas—it wasn't simply that more people died overall but that they died at a higher rate because towns sprang up that put people closer together when a tornado hit.

But the trend started to reverse just after the turn of the 20th century and then began a sharp decline when technology like radar evolved from World War II, followed by computers, satellite imagery, better emergency planning, and social media. In fact, the most recent DPI (for 1984–2017) is even lower than that recorded in the first pre-westward expansion era of 1808.

A tornado in Arkansas in 2013. Credit: iStock.com/clintspencer

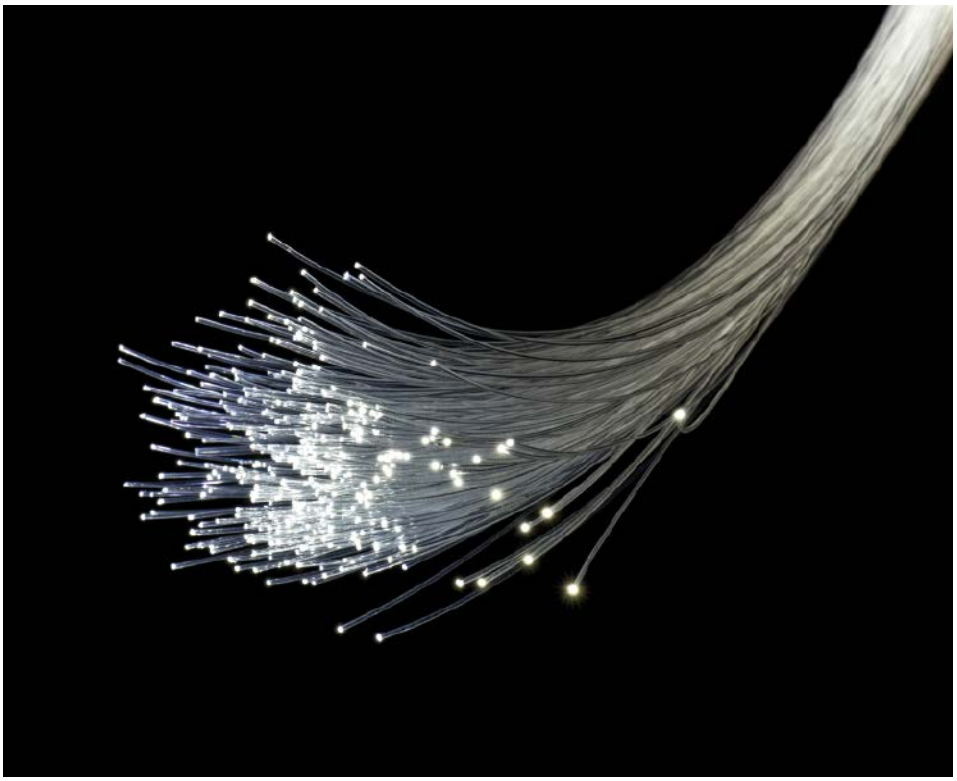
Catastrophic Events

But significant danger still lurks, said Agee, illustrated by the devastating events on 3 March in Alabama, when, even with advanced warning of the severe storms, 23 people died when a tornado touched down in Lee County. The researchers' report points out the vulnerabilities of tightly packed communities built with modular or other weak structures, as was the case in Alabama, or even when tens of thousands of people gather in one spot for an event like a sports match or concert.

"Even though [the overall lowered rate of tornado fatalities] is encouraging, we also have an increased risk of catastrophic events," said Agee, who vividly remembers experiencing his first tornado in central Kentucky in the 1950s. These results were published in January in *Weather, Climate, and Society* (bit.ly/tornado-fatalities).

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

Reusing Fiber-Optic Cables as Earthquake Detectors



A bundle of fiber-optic cables. Credit: iStock.com/tiero

During the 1990s, telecommunications companies installed thousands of kilometers of fiber-optic cables underground in anticipation of the dot-com boom. What can we do now with all of that unused dark fiber? Turn it into an extensive seismic activity sensor, according to a recent study.

The team used a relatively new technique called distributed acoustic sensing, or DAS, to measure how seismic waves affect the underground cables. "The neat thing about the technique is that you can use it to measure seismic waveforms at a very large number of locations on an existing fiber," Jonathan Ajo-Franklin, lead author on the study, told *Eos*. "Dark fiber is just a term for fiber that has been installed as part of a network but isn't currently used for communications," he explained.

When applied to existing dark-fiber networks, DAS gives the same data at a lower cost than a comparable number of above ground seismic stations, he said.

Earthquakes Near and Far

In a fiber-optic cable, pulses of light that contain data travel along glass or plastic fibers. The fibers are designed to perfectly reflect and trap the signal within the filaments, but if a filament has any imperfections, a small amount of light scatters back toward the source. By studying changes to the backscattered light in underground cables, scientists can infer how movement in the ground—say, from seismic waves—strains the fibers. This technique, DAS, has been used to study localized seismic activity in Alaska, California, and Iceland.

The team used ambient seismic noise from cars, trucks, and a nearby train line to map the subsurface.

Ajo-Franklin, a geophysicist at Lawrence Berkeley National Laboratory in Berkeley, Calif., and his team have now demonstrated that DAS can detect and monitor seismic activity across a much larger region and also detect distant quakes. "We knew that we could do distributed acoustic sensing, and we knew the fiber was in the ground, so we had a good feeling that we would be able to record something," he said. "The big question was what the quality of the data would be and what kind of applications it could be used for."

The researchers studied a 27-kilometer stretch of dark fiber near Sacramento, Calif. They recorded 7 months of passive seismic data and got measurements of the seismic wave field 500 times per second every 2 meters along the cable.

The sampling rate let the researchers monitor both low- and high-frequency seismic activity. With this, the researchers detected earthquakes that ranged from 4.4 to 8.1 in magnitude and some that were more than 7,700 kilometers away. They looked closely at the *M*8.2 earthquake that struck Chiapas, Mexico, in September 2017 to measure post-event seismic activity at low frequencies.

The team also used ambient seismic noise from cars, trucks, and a nearby train line to map the subsurface. "There's a train that runs colinear to the cable, and we were using energy from that train to do seismic imaging underneath the cable," said Ajo-Franklin. The high spatial density of the measurements let the researchers create a 2-D map of the seismic wave field beneath different sections of cable and also measure the depth of groundwater along the fiber.

The team published these results in February in *Scientific Reports* (bit.ly/dark-fiber).

Seismic Networks of Opportunity

The results show that "there is quite a bit more variability in the subsurface than what could have been observed through direct measurements in a well," according to Eileen Martin, an assistant professor of computational modeling at Virginia Polytechnic Institute and State University in Blacksburg who was not involved with the research. "It would not be affordable to drill test wells with this kind of [spatial] density, and the ambient noise analysis of dark fiber provided a cost-effective solution to resolve this subsurface variability," she told *Eos*.

This study "is a road map to applying DAS technology," Herbert Wang, a professor of geomechanics at the University of Wisconsin–Madison, told *Eos*. "DAS can unlock the telecommunications infrastructure to be seismic networks of opportunity on local and regional

scales and maybe on up to continental and ocean-basin scales," said Wang, who was not involved with this study.

The technique's potential application to earthquake monitoring is "compelling," Martin said. "These high-density, continuous measurements increase the likelihood that a sensor is near any small earthquake source. This hopefully means finding more small earthquakes and fixing the current biases in small quake observation counts, [as well as] faster detection of earthquakes for early earthquake warning systems."

A Versatile Seismic Tool

The team noted that the combination of dark-fiber networks and DAS in general could provide high-quality monitoring for many seismically interesting phenomena. Subsurface hydrology, melting ice sheets, and maybe even geodetic studies might benefit from dark-fiber seismology, Ajo-Franklin said.

Ajo-Franklin said that DAS also shows a lot of potential for measuring seismic activity offshore. Many seismically active areas 20–30 kilometers offshore don't have any offshore monitoring, he said, but fiber cables installed offshore could help monitor those areas in situ.

Dark-fiber networks preferentially run beneath highways and train tracks, Ajo-Franklin noted, so DAS would be particularly useful for studying subsurface geology and seismology in urban areas. Seismology with DAS could also be beneficial in areas that are not tectonically active but experience induced seismicity from human activity, he said.

> "DAS can unlock the telecommunications infrastructure to be seismic networks of opportunity on local and regional scales."

"There's a lot of fiber already in the ground for telecom applications," Ajo-Franklin said. "Fiber with no information on it is not very valuable at all."

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

Youth Gather to Demand Action on Climate Change

Nadia Nazar, cofounder of Zero Hour (a youth-led organization that focuses on climate change), was one of the featured speakers at the Washington, D.C., Youth Climate Strike protest. Credit: Randy Showstack

An enthusiastic crowd of mostly high schoolers gathered in front of the U.S. Capitol Building on 15 March for a spirited and Sun-drenched protest about climate change. The protest was part of the US Youth Climate Strike. There were an estimated several hundred strikes and other protests held on the same day in the United States and upward of 1,600 around the world.

The US Youth Climate Strike movement is drawing attention to climate change and support for the Green New Deal, an ambitious proposed congressional resolution to achieve net-zero greenhouse gas emissions by 2050, among other goals.

"We are striking because our world leaders have yet to acknowledge, prioritize, or properly address our climate crisis," the mission statement of the movement declares.

An Enthusiastic Protest at the U.S. Capitol Building

At the event in Washington, D.C., the crowd roared chants for protecting the environment, including "No more coal, no more oil, keep your carbon in the soil."

To politicians, the youth also chanted pointed warnings that they will soon be of voting age. "We are the future, we're standing strong; we'll vote you out so watch your back, because it won't take us long," the crowd shouted.

Their handmade signs mixed urgency with humor. Signs included "The climate is changing, why aren't we?," "Denial is not a policy," "Climate change: The real national emergency," and "Climate change is worse than homework."

A Message from Generation Z

The speakers in Washington, D.C., addressed the need for action and the need for change.

"Today is a day [when] elected officials all over the planet will hear the youth. They will hear our feet marching across the world; they will hear our chants and our voices growing louder and louder as we demand climate action for a livable planet," said Nadia Nazar, a 16-year-old Marylander who is a junior in high school.

"We, Generation Z, are the first generation that will be impacted by climate change. And we're also the last generation that can actually do something about it," said Nazar, cofounder of Zero Hour, a youth-led organization that focuses on climate change.

Generation Z generally refers to people born from the mid-1990s to the early 2000s.

"We demand that elected officials, businesses, and adults all around the world not only stand in solidarity with us, but [also] act on climate change."

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

NASA's Carbon Monitoring System Gets Rescued

A U.S. climate research program has survived a near-death experience. NASA's Carbon Monitoring System was launched in 2010 to build the scientific capacity needed for monitoring and enforcement programs that many people believe will be necessary to address climate change. But last spring, after Congress's 2018 budget bill did not explicitly fund the program, the Trump administration moved to quietly kill it.

In response, both the House and the Senate passed appropriations language explicitly funding the program in fiscal year 2019. That language became law when President Donald Trump signed a spending bill for NASA and other agencies on 15 February.

"The program has pushed carbon cycle science forward in a way that was desperately needed," said Lucy Hutyra, an environmental scientist at Boston University. "I'm thrilled to see it continue."

> "The changing climate has profound impacts and opportunities for us and for our adversaries."

Useful Numbers

The Carbon Monitoring System (CMS) isn't a satellite or an instrument but a program that funds research that converts measurements of carbon dioxide and methane from existing instruments into usable information for policy makers seeking to curb global warming. The program "sits on top of the mountain of data that NASA collects," said George Hurtt, a carbon scientist at the University of Maryland in College Park who leads the program's science team.

Created by congressional mandate in 2010, CMS funded some 65 grants of up to $500,000 a year for 3 years before it was halted. It has had several major successes, says Hurtt. One is close to home for him: The program funded Maryland's Department of Natural Resources (DNR) to build a computer model that combines tree measurements gathered by laser-equipped aircraft and on-the-ground crews to predict how much carbon the state's forests can sequester in the future. Last fall, the state officially adopted the methodology to support its Greenhouse Gas Emissions Reduction Act, which requires a 40% cut in carbon emissions by 2030.

"If they eliminated NASA's Carbon Monitoring System, it definitely would make this effort, if not impossible, much, much more difficult," said DNR ecological economist Elliott Campbell.

Hurtt's team is now extending the methodology to forests in the other eight northeastern states that have joined the Regional Greenhouse Gas Initiative, a market-based effort to limit carbon emissions. He hopes to eventually provide forest carbon monitoring capabilities for other countries using data from NASA's recently launched Global Ecosystem Dynamics Investigation, a laser mounted on the International Space Station that will measure tropical and temperate forests around the world. But first, he said, "we got to walk the walk. If we can't talk about carbon in our backyard, how can we talk about carbon in their backyard?"

The U.S. Forest Service is tasked with monitoring the nation's forest carbon. Its national forest inventory is world renowned, but it has long struggled to incorporate the vast and nearly inaccessible boreal forests of interior Alaska, said Christopher Woodall, a forest scientist who led the service's carbon research until 2016. CMS grants have enabled the service to study how laser-equipped airplane flights and field measurement campaigns could fill this gap.

A U.S. Department of Agriculture Forest Service worker takes measurements for the national forest carbon inventory in Alaska. Credit: USDA Forest Service

Leaky Gas

CMS-funded research has also focused on methane, the second most important greenhouse gas after carbon dioxide. Harvard University atmospheric chemist Daniel Jacob has shown that methane measurements from satellites and ground-based instruments can be used to test and improve values reported by the U.S. Environmental Protection Agency (EPA) based on estimated methane emissions rates from different sources. EPA has used Jacob's methods to produce improved methane emissions maps and may incorporate such techniques into its official methane source inventory.

At a more local scale, Hutyra and colleagues developed methods for detecting and attributing methane leaks from urban natural gas pipelines. Partially on the basis of the results and of numerous meetings between the researchers and policy makers, both the city of Boston and the state of Massachusetts

revised their rules for gas leak repairs. Boston also incorporated results from separate CMS-funded research on vehicle emissions into its transportation plan for 2030.

The successes show how CMS has made carbon measurement science policy relevant, Hutyra said. "We've demonstrated it can be done, we've quantified the uncertainties, and it's moving toward becoming operational by nonuniversity scientists."

Political Science

CMS's stop and start underscore the divisions around climate science that have become the norm in Washington. Trump administration budget requests have also targeted NASA's Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE) satellite mission and the Orbiting Carbon Observatory 3 instrument.

But NASA and Congress are increasingly charting a separate course. Both Democrat and Republican lawmakers came to CMS's defense after the announcement that it would be shuttered. And at a House Subcommittee on Commerce, Justice, Science, and Related Agencies hearing in February, committee members on both sides of the aisle agreed that the climate is clearly changing and asked the National Oceanic and Atmospheric Administration and NASA experts for guidance. Michael Freilich, the outgoing head of NASA's Earth Science Division, confirmed the scientific consensus, saying, "the changing climate has profound impacts and opportunities for us and for our adversaries."

"We're Back!"

A week after the program was funded in February, NASA released a solicitation for new CMS proposals. Although the program's overall focus remains unchanged, the agency will place more emphasis on carbon in aquatic environments such as oceans and wetlands in the new funding round, said Kenneth Jucks, a program manager at NASA's headquarters in Washington, D.C.

Even after being told to wind down the program, NASA did not cancel any already-funded grants. But the administration's attempt to kill the program meant a year's delay for all new projects; new funding decisions won't be announced until sometime this summer.

"I think we lost some momentum," Hurtt said. But, he added, "to me, it's a happy story. Because we're back!"

By **Gabriel Popkin** (gpopkin@gmail.com; @gabrielpopkin), Freelance Science Journalist

EOS CENTENNIAL COLLECTION
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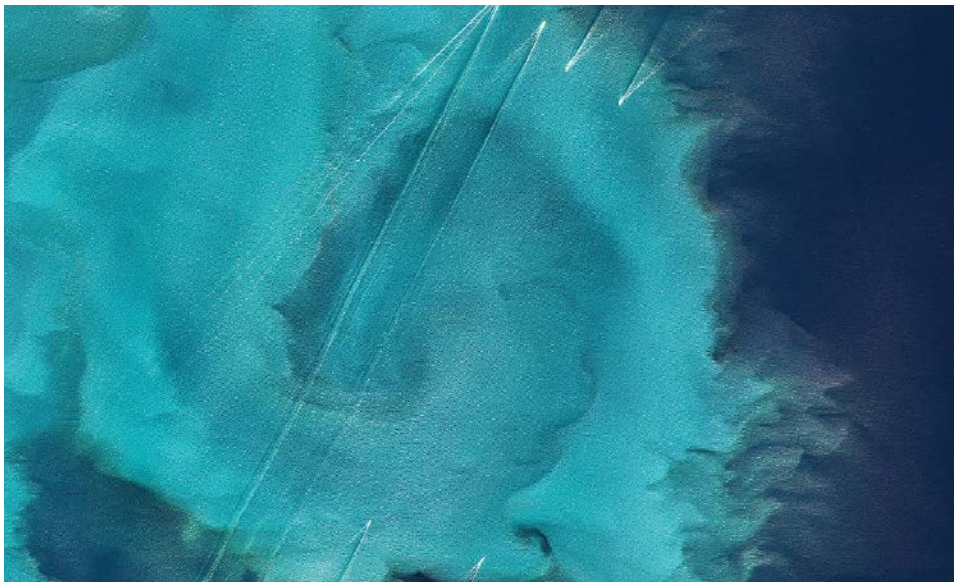
The Deep Blue Sea Is Getting Bluer



Ships sail across a phytoplankton bloom in the North Sea on 14 May 2018. Credit: Ocean Biology Processing Group/ NASA Goddard Space Flight Center

The ocean's aquamarines and seafoam greens are shifting as climate change warms the planet. A study published in February in *Nature Communications* (bit .ly/ocean-color) predicts that the colors of the world's oceans will intensify by the end of this century as changes in phytoplankton patterns alter light reflection.

Water molecules absorb all visible light except for those at blue wavelengths, making the ocean appear blue. When phytoplankton float near the surface, they change how incoming light reflects. Typically, the greener the ocean water, the more phytoplankton occur there. Satellites can differentiate subtle changes in hues from hundreds of kilometers away.

Previous research has suggested that warming waters will alter phytoplankton distribution in the ocean, but pinpointing this trend in the data can be difficult because commonly used metrics fluctuate due to other factors like El Niño and La Niña. The latest study models ocean color using a metric that better resolves long-term trends.

> The study is the first to consider the impact of climate change on ocean color.

The results reveal that the color of 50% of the ocean will change by 2100 due to the shuffling of phytoplankton communities. Blue regions in the subtropics will grow bluer as fewer phytoplankton are able to survive in their waters. Green regions at the poles will turn greener as warming waters become more habitable for them. The color change won't be discernible to the human eye, the researchers write in the study, but satellites will be able to see an "unambiguous signal."

Models that include light reflectance and the complex physical, biogeochemical, and ecological processes in the ocean are rare. This study is the first to consider the impact of climate change on ocean color.

"It could be potentially quite serious," said lead author Stephanie Dutkiewicz in a press release. "If climate change shifts one community of phytoplankton to another, that will also change the types of food webs they can support."

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

EOS CENTENNIAL COLLECTION

The Economic Losses from "Nuisance Floods"

Scientists have put a price tag on the high-tide floods that plague the coastal community of Annapolis, Md. High-tide floods, also called nuisance or sunny day floods, are small-scale inundations that last a few hours and flood areas with tens of centimeters of water during high tides. Rising sea levels are making high-tide floods more common: The Annapolis district of City Dock had 44 high-tide floods in 2017 alone.

A study published February in *Science Advances* quantified the decrease in visits and the loss of revenue to downtown businesses due to 1 year of high-tide floods. Total parking lot visits to City Dock decreased by about 3,000 in 2017 because of the floods. Miyuki Hino, the lead author and a doctoral student at Stanford University, said in a media briefing that "high-tide flooding is already measurably disrupting the economic activity in this location."

The researchers also projected losses that rising seas could bring to the community. "With just 3 more inches of additional sea level rise," Hino noted, "loss of visits would double." The authors predict that this will happen in the next 2 decades at the present rate of sea level rise.

"High-tide flooding is already measurably disrupting the economic activity in this location."

Floods Scare Away Shoppers

Many towns around the United States may face challenges similar to those of Annapolis. A recent report found that more than 170 coastal communities will flood as frequently as 26 times per year by 2035. Small floods disrupt daily life by blocking streets, closing schools, and damaging vehicles.

The latest study calculated the impact of high-tide floods by tracking the dip in parking ticket sales in City Dock. The researchers created their own tally of high-tide floods using social media posts, police footage, and tidal gauges. The floods are often so ephemeral that no record was previously available.

"We found that high-tide flooding reduced visits to City Dock by about 2%," Hino explained. The decrease in visits lasted after the flood subsided, even up to 5 hours after the flood occurred. The lack of customers translated to "about a hundred thousand dollars in lost revenue across about 16 businesses" in 2017, Hino said.

The study's analysis does not take into account missed work days, delayed travel times, or damage to infrastructure. Although the authors note that the 2017 losses are small, their projections of future sea level rise suggest that City Dock could lose more than 37,000 visitors with just a 1-foot (0.3-meter) increase in sea level rise.

Local government officials in Annapolis are actively seeking grants to mitigate the issue, according to the study's authors. The funds would go to build pumps to siphon away water from downtown. As the city faces more extreme floods due to sea level rise, "there are a range of adaptation options," said coauthor Samanthe Tiver Belanger, a Stanford University business school graduate student.

"Some of them are as extreme as picking up the businesses and moving them entirely, whereas others are smaller," she added, such as building walls.

Not Simply a Nuisance

Benjamin Hamlington, a scientist in the Sea Level and Ice Group at NASA's Jet Propulsion Laboratory, told *Eos* that the latest study is "one of the first assessments of the effect of high-tide flooding on economic activity."

"One of the most important results is that high-tide flooding is already having a measurable impact on coastal populations, beyond simply being a nuisance," Hamlington noted. "With increasing sea levels, it no longer takes a hurricane or strong storm to cause coastal flooding."

Thomas Wahl, an assistant professor of coastal engineering at the University of Central Florida, told *Eos* that coastal planning often focuses on extreme events like hurricanes but misses the "cumulative effects" of small repeated floods. The paper raises a "very important emerging issue," Wahl noted.

For study coauthor Chris Field, director of the Stanford Woods Institute for the Environment in Stanford, Calif., the latest findings are an example of how humans' relationship to the coast is shifting.

"Many coastal areas in the U.S. are built as close to sea level as possible to facilitate the interaction between humans and the ocean," Field said. "But as the sea has risen, that closeness to the ocean has transitioned from being an asset to being potentially a liability."

Flood waters rise onto the sidewalk and around statues of the Kunta Kinte–Alex Haley Memorial at City Dock in downtown Annapolis, Md., in 2012. Credit: With permission from Amy McGovern

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

Glacial Census Reveals Ice Thicknesses Around the World

The Mendenhall Glacier in southeastern Alaska. Credit: iStock.com/chaolik

There are hundreds of thousands of glaciers worldwide, and many are a major source of fresh water for agriculture. But estimates of both freshwater resources and sea level rise, a by-product of glacial melting, critically hinge on knowing individual glaciers' thicknesses, data that have been largely lacking. Now researchers have calculated the thicknesses of all of Earth's nonpolar glaciers on the basis of ice flow dynamics inferred from satellite imagery. They found that glaciers in southern and central Asia contain, in total, about 50% less ice than previously estimated. That's an unsettling result given the importance of glacial runoff for agriculture in this region, the scientists concluded.

215,000 Glaciers

The thickness of a glacier can be measured using ground-penetrating radar, but this method is laborious and must be applied to individual glaciers. To conduct a census of a large number of glaciers—each of the roughly 215,000 in the Randolph Glacier Inventory—Daniel Farinotti and his colleagues clearly needed a more efficient technique. The researchers turned to existing models that predicted ice thickness on the basis of satellite-derived glacial topography and ice dynamics: Thicker glaciers tend to flow faster. Farinotti, a glaciologist at Eidgenössische Technische Hochschule Zürich in Switzerland and the Swiss Federal Institute for Forest, Snow and Landscape Research, and his collaborators applied up to five different models to each glacier and averaged the results, weighted according to their performance, to reduce the uncertainties associated with relying on just one model.

The researchers also calculated an ice volume for each glacier by multiplying its area by its thickness. Nonpolar glaciers worldwide have a total ice volume of about 158,000 cubic kilometers, they estimated. That's enough ice to bury the entire state of California in a layer 400 meters deep.

Less Ice in High Mountain Asia

When the scientists compared their data with previously published values for glaciers in 19 geographical regions, they found striking differences. The largest discrepancy was in High Mountain Asia, a term that encompasses both southern and central Asia and includes countries adjoining the Tibetan Plateau. Farinotti and his colleagues recovered a total ice volume in High Mountain Asia that was 46% lower than the average of previous studies. They attributed this significant difference to advances in satellite imagery, which made it possible to better resolve individual glaciers. "There's better satellite data," said Farinotti.

The implications of a smaller total ice volume in High Mountain Asia will be felt in the coming decades, the researchers suggest. Glacier evolution modeling with these new results suggests that 50% of the glacial area in High Mountain Asia will be gone by the mid-2060s rather than the late 2070s, as predicted by previous estimates. And simulations of glacial discharge with the new data are similarly worrying: Summertime runoff rates near the end of the 21st century will be roughly 6 billion cubic meters lower per month. "In light of the importance of glacier melt for the regional water supply, these differences are unsettling," the authors concluded in their study, which was published in February in *Nature Geoscience* (bit.ly/glacial-ice-thickness).

These new results are important for a variety of calculations ranging from estimates of local and regional water availability to global mean sea level rise, said Georg Kaser, a glaciologist at the University of Innsbruck in Austria not involved in the research. "Knowing the mass of ice stored in glaciers is crucial for projecting any future development of glaciers."

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

Changing Name for Earth's Changing Poles

Every now and then (on a scale of hundreds of thousands of years), Earth's magnetic field does a flip-flop: Magnetic north becomes magnetic south, and vice versa. In between these major realignments, the magnetic poles wander over shorter distances, throwing models of Earth's magnetic field off kilter. A record of these polar wanderings, the paleomagnetic timescale, is preserved in successive layers of volcanic and sedimentary rocks. Scientists take great pains to ensure that they interpret this record accurately. Unfortunately, they have not been as careful with their spelling.

Occasional shorter polarity reversals or large perturbations of the magnetic field are called excursions, events, or microchrons [*Laj and Channell,* 2007; *Roberts,* 2008]. The first evidence of such a geomagnetic excursion was identified by *Bonhommet and Babkine* [1967] in lava and volcanic features from the Chaîne des Puys, a volcanic chain near the village of Laschamps in the Auvergne region of central France.

Signs of this reversal have since been observed in volcanic and sedimentary rocks in many places around the world, and the event, logically, has been incorporated into paleomagnetic timescales as the *Laschamp* excursion. The most recent—and we hope the most accurate—dating by *Guillou et al.* [2004] indicated that the excursion occurred about 40,000 years ago; its duration was probably less than 2,000 years [*Laj and Channell,* 2007; *Roberts,* 2008].

The first evidence of a geomagnetic excursion was identified in lava and volcanic features from the Chaîne des Puys, a volcanic chain near the village of Laschamps.

During the event, the virtual geomagnetic pole traveled a clockwise loop around Earth.

A sign near the north entrance to the village of Laschamps shows the correct spelling of the name. Unfortunately, the final s *is missing in many scientific publications. To the north, the Puy-de-Dôme volcano dominates the plain of Laschamps. Credit: Jacques Kornprobst*

When it was oriented southward, the magnetic field was at its minimum, about one fifth to one sixth of the present magnetic field [*Roperch et al.,* 1988; *Chauvin et al.,* 1989; *Laj et al.,* 2004]. This minimum is well correlated with an increase in the beryllium isotope ratio $^{10}Be/^{9}Be$ in oceanic sediments [*Laj and Channell,* 2007; *Ménabréaz et al.,* 2012]. This relative increase in ^{10}Be isotope levels reveals a general decrease in the magnetic shielding of Earth from cosmic rays during the excursion (which might have been one cause for the extinction of the Neanderthals [*Valet and Valladas,* 2010]).

It is, however, unfortunate that such an important event in Earth's history is misspelled in all scientific documents. The correct name is *Laschamps,* instead of *Laschamp*. We would like to explain the origin of the correct spelling.

How Laschamps Got Its *s*

Most cartographers since *Cassinis* (in 1777) have curiously forgotten the final *s* of Laschamps, except for Michelin's road map number 32 (1909–1929). Current signage and the local ancestral use attest to the correct spelling *Laschamps,* and it appeared in this form in the Puy-de-Dôme localities dictionaries [*Bouillet,* 1854; *Tardieu,* 1877]. The Gordon Bennett car race cup in 1905 has popularized this spelling internationally.

As for the etymology of the name of the village, Jean-Pierre Chambon, a specialist in Roman topology, gave a formal explanation in a personal communication:

> Laschamps *consists of the definite feminine plural article* las *associated with the substantive* chalm *(plateau or moor) in the plural; the substantive was altered to* champ, *a very frequent evolution in toponymy. The* Laschamps *current form is the direct legacy of the era (14th or 15th century) during which the French language borrowed its toponymy from the medieval Occitan.*

Thus, it would be desirable for paleomagneticians to get into the habit of restoring the final *s* to the name of such a significant geomagnetic excursion.

Acknowledgments

We owe many thanks to Jean-Pierre Chambon for invaluable information about the medieval Occitan language. The authors are also very grateful to two anonymous reviewers for their constructive remarks.

Detail of the monument currently erected on the church square of the village. The full inscription reads, "Remembrance of the fire of 1865, September 17th, to Mr. Franc Chauvassaigne, mayor of the municipality of St Genès Champanelle, the grateful inhabitants of Laschamps." Credit: Jacques Kornprobst

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It's Time to Shift Emphasis Away from Code Sharing

Have you ever watched a student struggle to perform a seemingly straightforward analytical procedure? It may be a routine preprocessing step, like detrending a time series or removing a seasonal cycle, but somehow the simple operations can stymie a student for weeks. It's tempting to assume that young people with their short attention spans are unwilling or unable to think through the task at hand, but a closer look suggests that students may have little choice but to blindly tinker with code until things seem to work.

In Earth science, students typically enter graduate school without much coding experience, they are often new to the analytical principles of their subdiscipline, and they have not yet developed a guiding intuition for the geophysical processes at the center of their work. They are thrust into research and asked to implement methods they've never seen before, and in contrast to other fields of study, they find very few opportunities to check their work.

Where classical physics textbooks and online forums abound with derivations of the wave equation, in the Earth sciences it can be difficult to verify that even common climate indices like the El Niño–Southern Oscillation have been calculated correctly. Without a way to be sure the elementary steps are being performed properly and without the sure footing of a common framework in which to perform these steps, how can we expect students to make headway on the bigger, multidisciplinary problems?

As a community of Earth scientists, we need to develop holistically designed numerical toolboxes to ensure accuracy, transparency, and replicability. Credit: Adam S. Nelsen

A Global Problem

The issues here affect not just students. Every established researcher in the Earth sciences has certainly devoted an afternoon or a week or a month to writing low-level code to perform a common task and has then found no clear means of validating the code. What a terribly inefficient path toward progress this is, as highly skilled scientists spend a great deal of time writing code that has been written before, rather than moving forward. But worse than simply wasting time, our way of doing business has ensured that scripting typos inevitably go undetected, leading to publication of incorrect findings that at best get caught by follow-on studies or at worst go unidentified and perpetually misguide science.

We Need Better Toolboxes

For efficiency, accuracy, and transparency in Earth science, we need to develop and adopt standard sets of well-tested tools for all our analyses. This will require investing in the development of comprehensive toolboxes that the community can use for a wide range of problems.

The toolboxes we need must be holistically designed—not just stand-alone scripts for performing specific analyses, but entire toolboxes of functions designed to work together in streamlined, repeatable workflows. Toolbox documentation should describe the steps of analysis in a pedagogical, narrative fashion, with example data that users can load to follow along with and understand the documentation. If we design our toolboxes holistically, they will naturally become starting points for students to learn and will serve as vehicles for collaboration among established scientists, providing consistent, reliable, trusted results that are easy to cite in scientific journals.

For example, a common method of obtaining the El Niño–Southern Oscillation index requires spatially averaging sea surface temperatures within a given geographic region, calculating anomalies by removing the seasonal cycle and the mean of the resulting time series, and then smoothing the remaining anomalies with a 5-month moving average. At first glance, each of these steps may seem trivial, yet their implementation can quickly become unwieldy. For example, a spatial average of sea surface temperatures requires accounting for the variable grid cell size in a regularly spaced geographic grid; calculating a seasonal cycle requires detrending the time series before assessing the mean anomaly for each day or month of the year; and calculating a 5-month

moving average can prove difficult, particularly if the data are not available at regular temporal intervals.

A well-designed Earth science toolbox would address this problem with three simple functions designed to work together: one function to properly compute spatial averages from a georeferenced grid, another to remove seasonal cycles, and a third to calculate moving averages. Each function would be fully documented on its own, with its methods described alongside explanations of when to use the function and how to interpret its results. With the proper tools in hand, calculating the El Niño–Southern Oscillation index would then become a three-step endeavor in which the focus is fully on the physics rather than on the coding. But for this kind of solution to manifest, we will need buy-in from the community and from funding institutions.

Code-Sharing Requirements Aren't Working

Until now, attempts to address the issues of transparency and replicability in science have been broadly aimed at encouraging scientists to share their code, but that approach has come up short. Putting the onus on individuals to share scripts developed for specific research projects has created a landscape of piecemeal, untested, poorly documented code and has ignored the underlying structural problem at hand.

Without standard toolboxes of well-trusted, generalized functions for common types of data analysis, it is unreasonable to expect everyone to voluntarily develop, validate, share, and effectively communicate all of their code. So rather than continuing the quixotic insistence that scripts must be uploaded with every publication, we should focus on developing standard, citable toolboxes that the community can come to know and trust.

A More Effective Way to Encourage Code Sharing

Although it may feel too easy to let scientists' responsibility end at citing which toolboxes were used in an analysis, we must not conflate effort with efficacy. We must instead recognize that only by providing standardized frameworks for clear and streamlined analyses can we expect individuals to become more willing to place their code in the public eye.

Thus, by shifting the focus away from simply requiring that authors make statements about code availability to addressing the underlying issues that currently stand in the way of code sharing, we may find that code becomes more reliable and gets shared more frequently.

In Earth science and in the hot-button field of climate science in particular, we need transparency, replicability, and tools that will enable any interested party to see and understand how we come to our findings. For efficiency in science, we need standardized tools that we can all use to move forward rather than repeatedly wasting time reinventing the wheel. And for students who are still developing their skills on many fronts, we need holistically designed toolboxes to let them focus on learning, rather than just tinkering with code until things seem to work.

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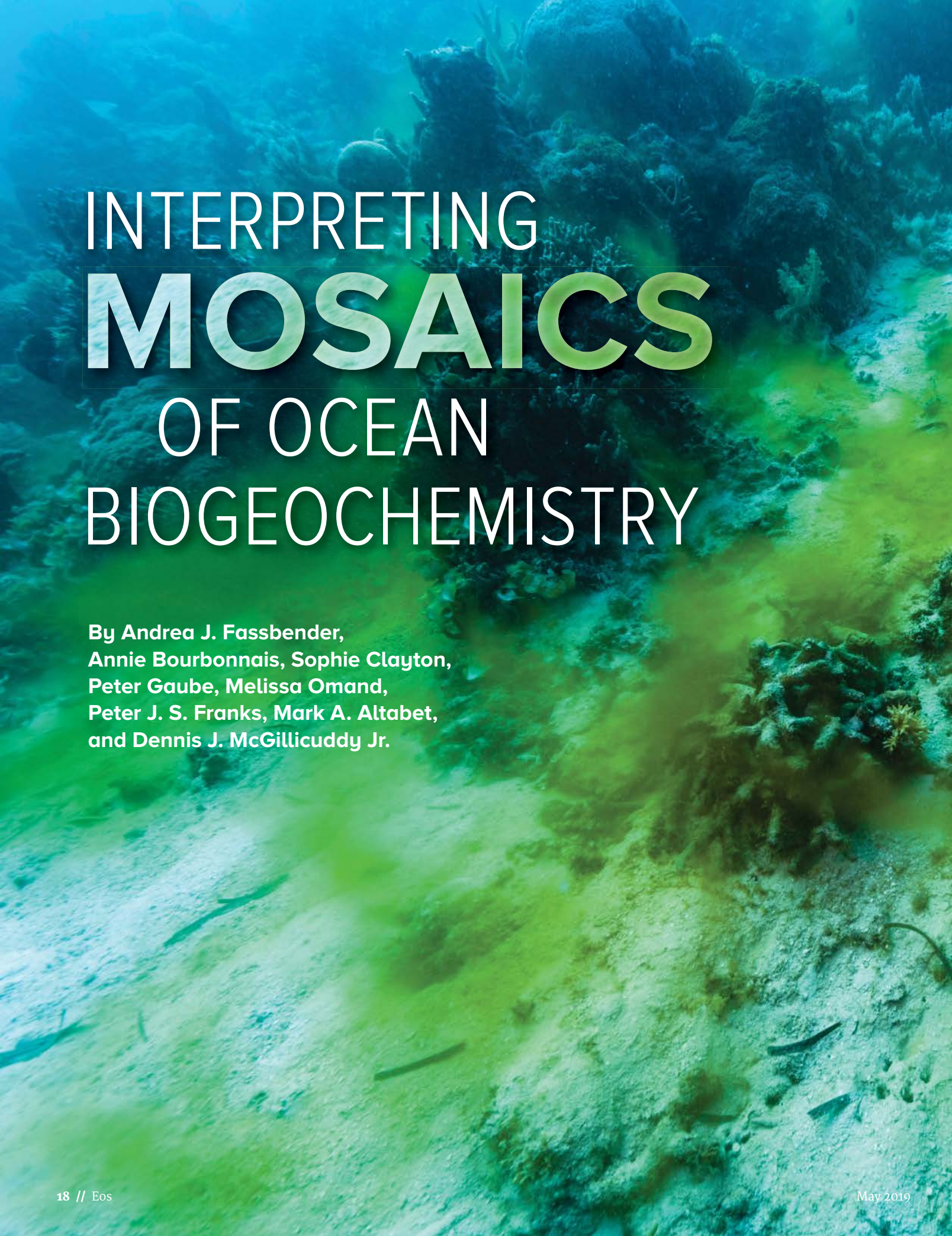


INTERPRETING MOSAICS OF OCEAN BIOGEOCHEMISTRY

By Andrea J. Fassbender, Annie Bourbonnais, Sophie Clayton, Peter Gaube, Melissa Omand, Peter J. S. Franks, Mark A. Altabet, and Dennis J. McGillicuddy Jr.

Sea level rise, heat transport, ocean acidification: These ocean processes, well known in the public sphere, play out on regional to global scales. But less well known are more localized processes that bring some ecological niches together, keep others separated, and help sustain ocean life by circulating nutrients.

Physical processes in the ocean that take place over intermediate and small scales of space and time play a key role in vertical seawater exchange. They also have significant effects on chemical, biological, and ecological processes in the upper ocean.

In the past, it proved difficult to quantify the role of small-scale features in the movements of ocean chemicals and materials because of their unpredictability. Compounding that

A phytoplankton algae bloom descends down the slope of a tropical reef.
Credit: National Geographic Image Collection/Alamy Stock Photo

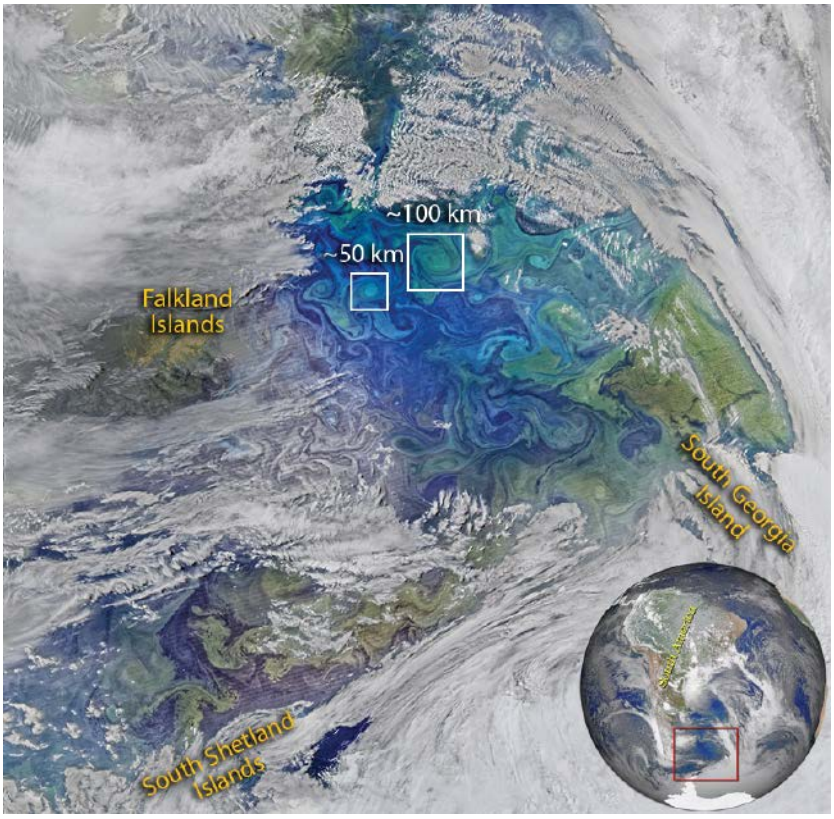


Fig. 1. Phytoplankton bloom between the Falkland Islands and South Georgia Island captured by the NASA-NOAA Suomi National Polar-orbiting Partnership (NPP) satellite on 16 November 2015. White patches are clouds. The overlaid white boxes and text provide approximate length scales for two of the mesoscale eddies pictured. Credit: Ocean Biology Processing Group, NASA Goddard Space Flight Center

difficulty, technological limits hindered scientists' ability to observe and model these processes.

All of this is now changing: Ocean-observing tools, models, and theories have evolved significantly within the past 2 decades. Strong links between physics, biology, and chemistry at the small and medium scales reflect exciting opportunities for interdisciplinary research. With new tools and improved understanding of these features, the oceanographic community is now overcoming historical roadblocks to evaluating the physical mechanisms responsible for and implications of widely observed mosaics of ocean biogeochemistry.

From the Medium to the Small

The term "meso," from the Greek word for middle, is often used to describe intermediate-scale processes (spanning some 10–100 kilometers, over a period of months). Physical oceanographers have been studying these mesoscale features and their contribution to the larger, ocean basin–scale distribution of chemicals and organisms since the 1970s.

Common mesoscale features, called eddies, are rotating columns of water that extend downward hundreds of meters from the sea surface, span diameters of 50–200 kilometers, and can last for months. These vortices generally form as a result of various instability processes, and they can move cool water upward to the surface or push warm water to depth, depending on what direction they rotate and whether they are in the Northern or Southern Hemisphere. The spin direction is dictated by Earth's rotation, which is accounted for in the study of fluid dynamics by what is called the Coriolis force. This force deflects water moving along a line to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. Therefore, a clockwise-rotating eddy in the Northern Hemisphere would pile water up in the eddy center, resulting in warm surface water being pushed deeper into the ocean interior. In the Southern Hemisphere, this same eddy would deflect water away from the eddy center, pulling deeper water up toward the sea surface.

These dynamic mesoscale vortices generate mounds and depressions in the surface of the ocean itself—topographical ocean features observable in satellite records of altimetry and temperature. Such observations paved the way for rapid scientific advances at the dawn of satellite oceanography.

The study of submesoscale features represents a newer scale of ocean inquiry into ephemeral processes. These small-scale processes take place over lengths of about 1–10 kilometers, and they occur over several days. The features these processes create often evolve from the stirring, straining, and density contrasts that occur near the boundaries of mesoscale ocean features that bring unique water masses into contact, tightly linking the physical dynamics of the two scales.

Within the past 2 decades, our ability to observe and measure ocean phenomena at medium and small scales has advanced significantly. Autonomous sensors and high-resolution numerical models are now revealing the ubiquity of mesoscale and submesoscale ocean features [*Mahadevan,* 2016; *McGillicuddy,* 2016] and their interactions, stimulating new hypotheses about how ocean physics shapes ocean chemistry and ecology (Figure 1).

Stirring Up Marine Ecosystems

Physical-biogeochemical ocean interactions are complex because of the fluid dynamics at play and the vast spectrum of biochemical pathways used by competing marine organisms. Phytoplankton form the base of the oceanic food chain. These organisms span a wide range of biological classifications and functions, and they play a key role in the Earth system by mediating elemental cycles, that is,

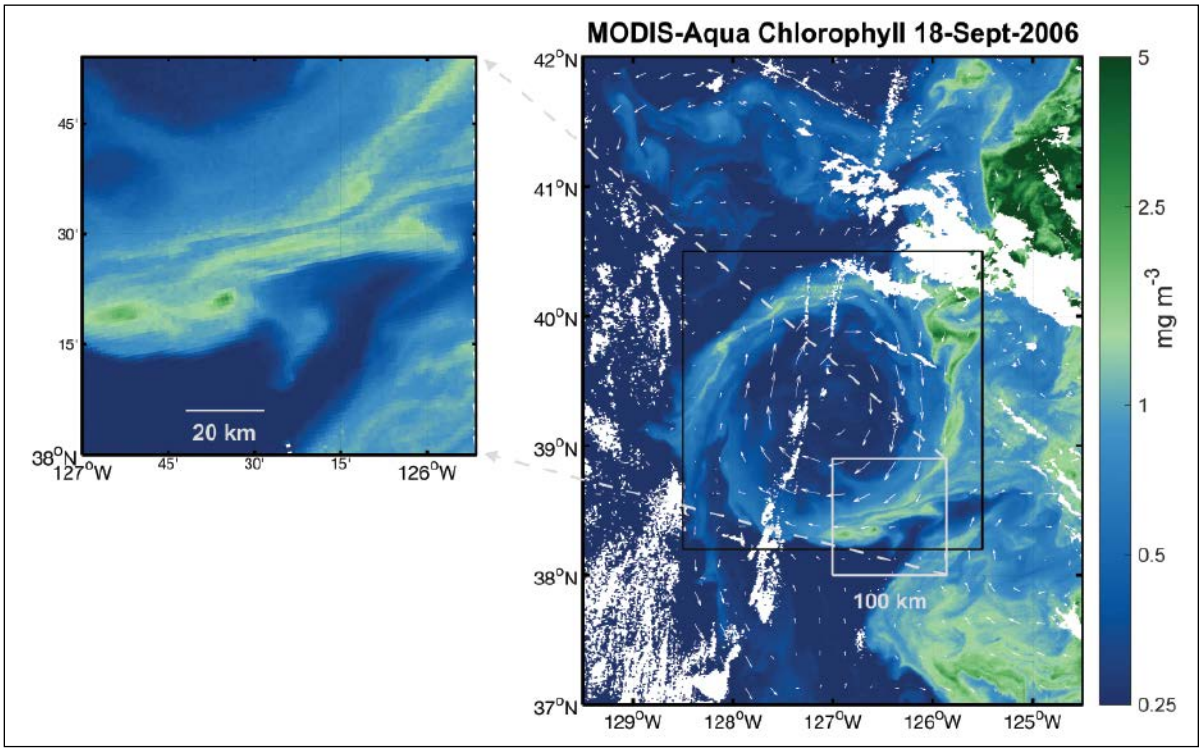


Fig. 2. Chlorophyll a concentrations in a mesoscale eddy offshore of central California on 18 September 2006, as observed by NASA's MODIS instrument on the Aqua satellite. Close-up of submesoscale features (detail on left) associated with the eddy (white box in the right panel). The anticyclonic mesoscale eddy (black box) shows elevated chlorophyll a levels around the perimeter (right). White arrows represent vectors of the mesoscale geostrophic current (generated from a balance between pressure gradients and Coriolis forces) estimated from sea level anomaly data. White patches indicate clouds. The logarithmic color scale represents chlorophyll a concentrations in milligrams per cubic meter.

the circulation of chemical elements through an ecosystem.

The physical ocean environment is punctuated by mesoscale and submesoscale features that act not only to mix and disperse phytoplankton populations but also to modify the local environment and interactions therein. Understanding and quantifying the ways that these interactions contribute to global biogeochemical cycles remain priorities for the oceanographic community.

Mesoscale eddies, for example, are ubiquitous features colloquially referred to as "the weather of the ocean" and often produce anomalies in sea surface height that are observable from space. Automated mesoscale eddy identification and tracking programs have made it possible for scientists to use satellite data to evaluate their influence on near-surface chlorophyll concentrations, which are an indicator of phytoplankton activity [*Chelton et al.,* 2011; *Siegel et al.,* 2011; *Gaube et al.,* 2014]. Eddies modulate near-surface chlorophyll primarily by stirring chlorophyll gradients near the intersections of water masses with distinct characteristics (Figure 2).

These eddies can also induce biological activity by lifting layers of water that contain nutrients into the sunlit region, where organisms that rely on photosynthesis live. In areas of intense mesoscale activity, such as boundary currents, eddies also entrain and subsequently trap large parcels of water, transporting entire ecosystems hundreds to thousands of kilometers, redistributing sharp gradients in chemical and biological properties into dynamic mosaics [*Gaube et al.,* 2014].

What's Stirring Up the Plankton Communities?

Mesoscale processes can generate or influence the structuring of submesoscale ocean features, which are often responsible for small-scale biogeochemical heterogeneity (Figure 2). It can therefore be challenging to determine whether heterogeneity in biogeochemical signatures reflects an active response to submesoscale physical forcing or the deformation of an existing biogeochemical gradient by mesoscale processes.

To evaluate this question, *d'Ovidio et al.* [2010] used satellite observations to investigate the organization of phytoplankton communities. These researchers showed that submesoscale filaments of chlorophyll and phytoplankton community structure were formed by simply stirring existing mesoscale (and larger) patches. This effect is particularly apparent near sharp ocean gradients. Stirring can stretch and deform distant ecosystems—usually separated by hundreds of kilometers—into swirling filaments that end up being separated by a few kilometers or less (Figure 2 and signature A in Figure 3).

Yet submesoscale processes that drive strong vertical exchanges near fronts may also cause in situ biological

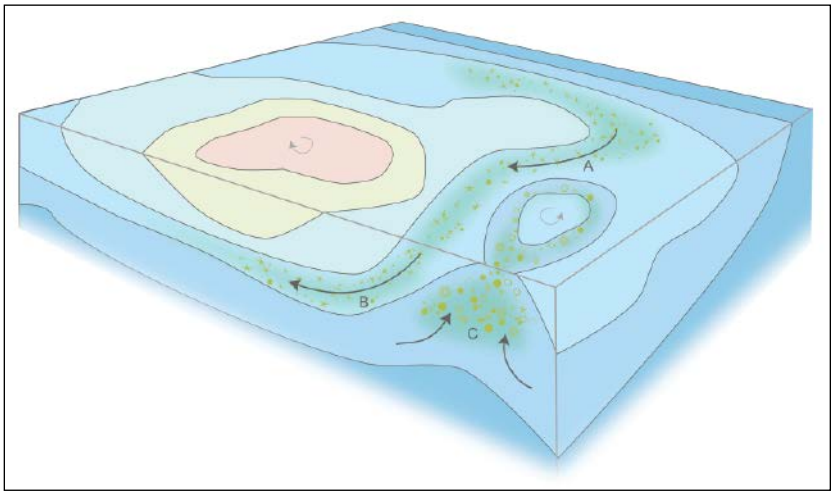


Fig. 3. Mesoscale eddies and the submesoscale filaments at their peripheries can give rise to complex chemical and biological signatures, such as lateral transport of nutrient- and particle-rich water (labeled A), interleaving of water masses and variations along density surfaces (solid contours; labeled B), and nutrient enrichment and phytoplankton growth as a result of an eddy raising a density surface into the sunlit zone (labeled C). The mixing and stirring processes that are often enhanced in these regions can result in diversification of phytoplankton communities. Here a surface intensified filament near the anticyclonic eddy edge brings one community of phytoplankton into proximity with another community of phytoplankton within a nearby cyclonic eddy.

responses by enhancing the nutrient supply to the surface mixed layer [*Lévy et al.*, 2012]. Accurately attributing the causes of a given process will thus require researchers to deploy novel sampling platforms, such as profiling drifters, autonomous underwater vehicles, and undulating towed vehicles, to constrain three-dimensional, time-evolving biogeochemistry associated with submesoscale features.

Chemical Signatures of Small and Medium Scales

Separating stirring from other processes is also a challenge when interpreting chemical signatures at mesoscales and submesoscales. Complex patterns of seawater chemistry can develop from a suite of processes occurring over small spatial and temporal scales. Such processes include offshore transport of particle- and nutrient-rich coastal waters [*Barth et al.*, 2002]; the development of chemical variations along density surfaces caused by the interleaving of water layers near fronts [*Nagai and Clayton*, 2017]; and biological activity that occurs as an eddy raises denser, nutrient-rich water into the sunlit zone (Figure 3, signature C) [*Benitez-Nelson et al.*, 2007; *Ascani et al.*, 2013].

Not all biochemical perturbations associated with mesoscale and submesoscale dynamics produce effects at the sea surface. These subsurface processes are difficult to detect using remote sensing, which challenges our ability to quantify how these perturbations increase ocean primary production (the conversion of inorganic carbon compounds into organic compounds [*Chenillat et al.*, 2015]).

Some ocean regions exhibit consistent mesoscale and submesoscale activity that facilitates consistent chemical transport. For example, *Woosley et al.* [2016] discovered multiple eddies along 10°S latitude in the Atlantic Ocean that contained ~20% more anthropogenic carbon than surrounding waters. Relatedly, a recent modeling study by *Yamamoto et al.* [2018] found that most of the nutrients supplied to the upper layer of the Northern Hemisphere subtropical gyres originate from eddy-induced lateral transport across the Gulf Stream and Kuroshio currents.

Effects on the Bigger Picture

Ongoing changes in ocean chemistry (e.g., acidification and deoxygenation) have generated a need to evaluate how eddy transport and the associated submesoscale processes may influence large-scale distributions and gradients of chemicals, now and in the future.

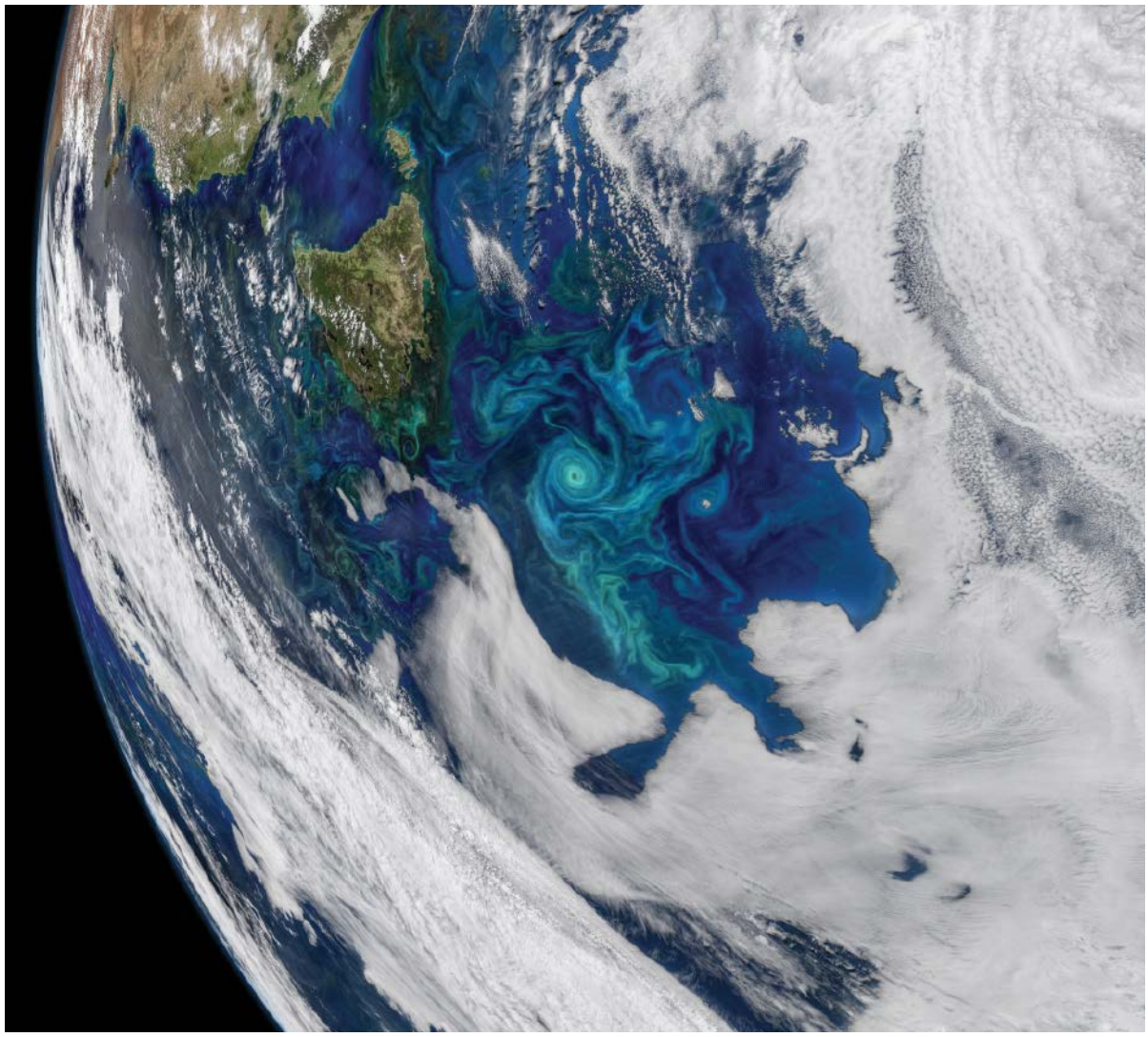
But in addition to heterogeneity and transport, mesoscale and submesoscale processes can facilitate unusual chemical conditions. Multiple recent field campaigns in an oxygen-deficient zone near the coast of Peru identified intensified subsurface nitrogen loss in mesoscale eddies originating from coastal waters [*Bourbonnais et al.*, 2015; *Callbeck et al.*, 2017]. Producing these chemical signatures, which are uncommon in the water column, requires water parcel isolation. Similar findings of unlikely water chemistries within eddies have been reported in other regions, which suggests that mesoscale eddies play an important role in facilitating chemical conditions that are otherwise improbable.

The broader implications for interpreting chemical tracers, budgets, and fluxes provide new opportunities for ocean chemists, who are now applying autonomous biogeochemical sensors and platforms to study these features [e.g., *Johnson et al.*, 2009; *Inoue et al.*, 2016].

Phytoplankton Diversity

Mesoscale eddies act as natural enclaves—mesocosms—in which populations are enclosed, transported, and subject to successional dynamics (a sequence of ecological changes after a disturbance) over weeks or months. This isolation from the surroundings may result in reduced biodiversity as less-fit species are excluded. On the other hand, submesoscale gradients and filaments can also mix populations together, enhancing local biodiversity over short timescales.

“Mesoscale eddies play an important role in facilitating chemical conditions that are otherwise improbable.”



Phytoplankton bloom in the Tasman Sea captured by the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the Aqua satellite on 21 November 2017. White patches are clouds. Advances in remote and in situ sensing, as well as methods for modeling and simulation, are driving an era of progress in ocean biogeochemistry research. Credit: Ocean Biology Processing Group, NASA Goddard Space Flight Center

Because of the technical challenges involved in gathering phytoplankton data that are taxonomically resolved and at the required spatial resolution, modeling studies are currently our best tool for understanding the dynamic effects of mesoscale and submesoscale processes on phytoplankton community structure. Ecological models have shown that mesoscale eddies enhance regional and annual mean biodiversity by creating more local niches for different phytoplankton species and by mixing populations together [*Clayton et al.*, 2013].

Models have also revealed the range of local impacts that eddies and fronts can impose on phytoplankton community dynamics and diversity [*Lévy et al.*, 2015]. Observational evidence that supports these models has been seen in the mingling of coastal and oceanic ecotypes of the phytoplankton species *Ostreococcus* at the Kuroshio Extension Front east of Japan [*Clayton et al.*, 2017]. Advances in automated cytometric, imaging, and sample collection technologies are starting to generate data sets that can be used to explore these questions in the field.

Carbon Export

A fundamental goal in oceanography is to quantify and understand how carbon produced by photosynthetic organisms in the surface ocean is transported to the deep sea, where it is sequestered from the atmosphere. This process of carbon export has played an important role in regulating Earth's climate over the past million years [*Sigman and Boyle*, 2000] and represents a moderately constrained (~50% uncertainty [*Siegel et al.*, 2016]) component of the modern global carbon budget.

This export of particulate organic carbon (POC) from the surface to the deep sea traditionally was thought to be

driven primarily by sinking particles. Indeed, glider-based observations from the 2008 North Atlantic Bloom study showed a fast sinking plume of particles resulting from the demise of a diatom bloom [*Briggs et al.*, 2011].

However, the observations also showed evidence of POC that would normally remain buoyant (nonsinking POC) in subsurface features coincident with elevated oxygen and chlorophyll. These features formed when POC-rich surface water was pulled beneath the surface, carrying the nonsinking POC with it (signature B in Figure 3) [*Omand et al.*, 2015].

Modeling tools helped to demonstrate that this process often coincides with enhanced downward fluxes associated with strong vertical velocities that are extremely challenging to characterize in situ. Combining observations with modeling was essential for visualizing and understanding these dynamics and may be a useful method for evaluating additional tracers and mechanisms that are presently difficult to observe at these challenging scales.

Understanding the Mosaics

The combination of existing research tools and the development of new tools is driving progress in understanding biogeochemical ocean mosaics. The integration of satellite and in situ observations continues to deliver insights, whereas high-resolution data-assimilating models present exciting opportunities to study mechanisms that help us interpret in situ and satellite observations.

These efforts are guiding the ways that the research community applies novel techniques to observe and study ocean processes from the submesoscale to the basin scale. Creative applications of small, low-power ocean sensing technologies, such as sensors that can be affixed to marine mammals, are informing new ways to study ocean features of interest [*Block et al.*, 2011].

In addition, burgeoning disciplines that link the chemicals found in seawater to specific marine organisms are moving us closer to relating biochemical pathways to plankton diversity for more rigorous interpretation of bulk chemical transformations. Thus, the simultaneous application of physical, biological, and chemical tools and tracers with models is rapidly accelerating our progress in unraveling the ocean's mesoscales and submesoscales.

Acknowledgments

We thank the Ocean Carbon and Biogeochemistry Program (supported by the National Science Foundation) for providing a forum to discuss this topic at the 2017 Summer Workshop. Author research informing this document was supported by the National Science Foundation, NASA, the National Oceanic and Atmospheric Administration (NOAA), the Moore Foundation, the Sloan Foundation, and the Washington Research Foundation. The authors thank Nina V. Buzby and Kelly Lance for their contributions to Figure 3.

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WHY IS THE GULF OF MAINE WARMING FASTER THAN 99% OF THE OCEAN?

By Laura Poppick

Late last October, four endangered sea turtles washed ashore on northern Cape Cod, marking an early onset to what has now become a yearly event: the sea turtle stranding season.

These turtles—in this case, Kemp's ridley sea turtles—venture into the Gulf of Maine during warm months, but they can become hypothermic and slow moving when colder winter waters abruptly arrive, making it hard for them to escape.

"They are enjoying the warm water, and then all of a sudden the cold comes, and they can't get out fast enough," said Andrew Pershing, an oceanographer at the Gulf of Maine Research Institute in Portland, Maine.

Thanks to record-breaking summer water temperatures that quickly transition to cooler conditions, an expanded sea turtle stranding season is just one facet of a new normal

Kemp's ridley sea turtles inhabit warm waters—such as this one here, on the shore of the Gulf of Mexico in Texas—and were almost never seen farther north than the coast of New Jersey until the Gulf of Maine waters began rapidly warming. Credit: NPS Photo/ Alamy Stock Photo

A lobsterman throws a trap off the coast of Maine. As the Gulf of Maine warms, fisheries, including lobster fisheries, are expected to shift in range, potentially disrupting an industry that has historically defined this region's economy. Credit: Associated Press

for the Gulf of Maine, Pershing explained. And this new normal is a striking contrast to prior conditions.

In 2018, the Gulf of Maine has experienced 250 days with what have been considered heat wave temperatures. Such persistent warmth, scientists warn, can set off a series of other cascading effects on the marine life and fisheries that have historically defined the culture and economy of this region's coastline.

But what, exactly, makes this region such an acute hot spot for ocean warming? Pershing and others now think they know the answer. They're using that knowledge to try to predict the impact of future heat waves on marine life in the gulf.

A Hot Spot for Warming

While flying to a conference in 2014, Pershing had an idea. He had been mulling over data showing the Gulf of Maine's rate of warming over the past decade. That rate seemed high to him, but he wanted to know how it compared with warming in the rest of the ocean.

So, midflight, he pulled together global satellite data. What he found surprised him: This region was warming faster than 99% of the rest of the ocean.

"The Gulf of Maine is way out on the curve," said Pershing, who published these findings in the journal *Science* in 2015 (bit.ly/gulf-of-maine). Since then, the warming trend has continued. Over the past 15 years, this region has warmed an alarming 7 times faster than the rest of the ocean, according to his research.

The source of the Gulf of Maine's rapid warming lies in the "heartbeat" of the Atlantic Ocean.

The trick now was to tease out just how warm the gulf may become and over what time period.

A Weakening "Heartbeat"

The source of the Gulf of Maine's rapid warming lies in the "heartbeat of the Atlantic Ocean," explained Hillary Scannell, an oceanographer at the University of Washington in Seattle who studied with Pershing as a master's student.

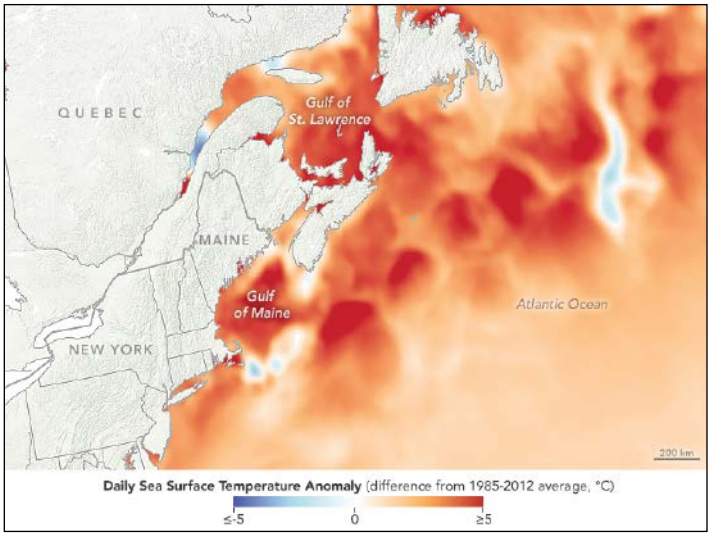
The heartbeat she refers to centers around the east coast of Greenland, where a large mass of cold water sinks and pulses southward along the east coast of North America, eventually winding its way into the Gulf of Maine. To

A tagged loggerhead sea turtle paddles off the coast of Cape Cod after spending 6 months rehabilitating at the New England Aquarium in Boston. The turtle became stranded last winter when abnormally warm summer waters abruptly turned cold. It was released in July. The cycle of stranding and rehabilitation happens yearly. Credit: Erin Clark/The Boston Globe/Getty Images

occupy the space left by this southward traveling Labrador Current, a northward traveling Gulf Stream flows from the equatorial Atlantic to the Arctic, in a circulation system reminiscent of arteries leaving and veins entering a heart.

These two opposing currents brush paths along the Gulf of Maine; that encounter is what makes this region so susceptible to rapid change, Scannell said.

Under "normal" conditions, the Labrador Current easily surges into the gulf, keeping Maine waters cool and the related cold-water ecosystem healthy. But as climate change melts Arctic ice around Greenland, the water in the north freshens. Because fresh water doesn't sink as readily as denser saline water does, the Labrador Current loses its vigor. This allows the Gulf Stream to nudge its way more prominently into the Gulf of Maine.



Compiled satellite and computer model data showing the anomalous heat of 8 August 2018, the second-warmest day ever recorded in the Gulf of Maine. Credit: NASA Earth Observatory/Lauren Dauphin/Coral Reef Watch

Stuck in a Bathtub

Aside from this weakening Labrador Current, bursts of warm water have other ways of pooling up in this region, Scannell noted. The Gulf of Maine's C shape and the broad underwater plateau of Georges Bank keep water blocked in place longer than it would be in more free-flowing systems.

Add to that its fairly shallow depth, and the gulf behaves like a bathtub, Scannell said. "If you're turning down the cold spigot, you're going to feel more of an effect from that warm water," she added.

All of these factors set the Gulf of Maine up to be especially susceptible to marine heat waves. And by heat waves, Scannell and other international researchers mean something specific. They defined the term in a 2016 study in the journal *Progress in Oceanography* as a warming period that "lasts for five or more days, with temperatures warmer than the 90th percentile based on a 30-year historical baseline period" (bit.ly/marine-heat-waves).

Sunrise over the Gulf of Maine, in Portland. Last summer, the Gulf of Maine experienced its second-warmest day on record, with water temperatures reaching 20.52°C (68.93°F) on 8 August 2018—just a fraction of a degree lower than the warmest-ever day recorded in 2012. Credit: Laura Poppick

Other regions also susceptible to long-lasting marine heat waves include the fringes of the Arctic Ocean, especially around the Barents Sea north of Norway, where the Gulf Stream ends. Another region lies off the coast of Japan, where the warm Kuroshio Current, similar to the Gulf Stream, flows northward.

Despite this susceptibility, no other large-scale region is warming quite as fast as the Gulf of Maine, Pershing said. The 1% of the ocean warming faster is just "pixels here and there," he explained.

Ecosystems in Flux

Scientists don't know what long-lasting impacts this warming will have on marine because since their understanding of such impacts "has only been opportunistically gained following a few recent events," said Thomas Frölicher, an oceanographer who studies marine heat waves at the University of Bern in Switzerland.

One such well-studied event off the coast of Western Australia in 2011 demonstrated that heat wave effects can have immediate and long-lasting impacts. In this case, a 10-week heat wave caused habitat-forming seaweed to die, fundamentally changing the temperate reef ecosystem. "Since then, the whole ecosystem hasn't really recovered," Frölicher said, explaining that more tropical fish have moved into the system. "It was kind of a tipping point."

Warming also changes the chemistry of water, including its ability to hold dissolved oxygen, Frölicher pointed out. Warm water can't hold as much oxygen as cold water can, so heat waves in places that are already oxygen depleted will produce a compounding effect that "probably has a much bigger impact than just one single extreme event," he said.

The risk of disease also seems to increase in warmer oceans. The infamous Blob—a mass of warm water that amassed along the western coast of North America in 2013 and continued to spread through 2015—triggered a large-scale toxic algal bloom that researchers linked to mass strandings of sea lions during that time.

Lynda Doughty, executive director of the group Marine Mammals of Maine, holds a seal pup she treated in 2018. Her organization responds to stranded animals along the southern half of Maine's coastline. Last year, more than 1,000 seals have washed up dead in the northeast, in what the National Oceanic and Atmospheric Administration has declared an unusual mortality event. Credit: Laura Poppick

Seals are also facing threats: More than 1,800 have washed up injured or dead between July 2018 and March 2019 along the Gulf of Maine. This unusual mortality event seems to be caused by viral infection, although it's unclear whether the ongoing heat wave has caused or exacerbated the strandings.

With water warming as fast as it is in the Gulf of Maine, Pershing said, marine heat waves warrant serious consideration as a cause of any unusual shift in marine life.

"The burden of proof is almost flipped to the other side; you probably should be proving that the temperature isn't what's causing this unusual thing to happen," Pershing said.

The burden of proof is almost flipped to the other side; you probably should be proving that the temperature isn't what's causing this unusual thing to happen.

Shifting Baselines

The turtles that were found stranded last October were brought to the New England Aquarium in Boston for rehabilitation.

As the region warms, other unusual things have started happening in the Gulf of Maine. For example, a lobsterman found two seahorses in traps he set offshore of the coastal town of Boothbay last summer, an event Pershing called "really remarkable." These seahorses are typically found only as far north as Cape Cod. Butterfish, another species associated with warmer waters, are also making their way into the Gulf of Maine.

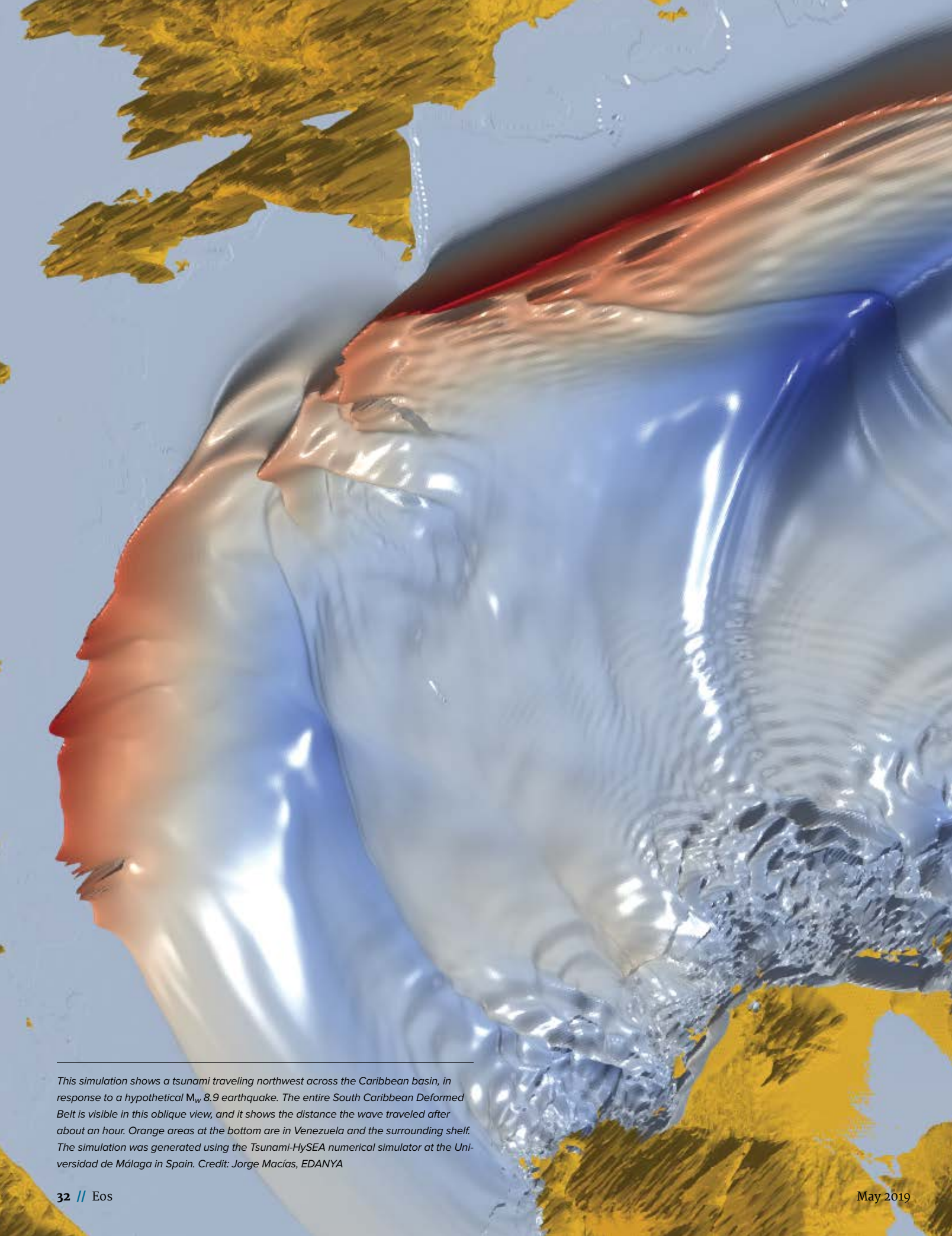
Such shifts in species pose problems for native animals that aren't accustomed to these newcomers. For example, adult Atlantic puffins have been seen foraging for butterfish to feed their chicks, but butterfish are often too wide for the chicks to swallow, "so it can create real challenges for the puffin colonies," Pershing said.

Scannell hopes that studying marine heat wave patterns will improve her ability to predict these events. With these predictions, scientists could give those in the fishing industry a sense of what to expect in a coming month or a coming season. But, she noted, such predictions may become more difficult as the days in which the Gulf of Maine is not experiencing a heat wave in a given year dwindle.

Thus, researchers will need to shift their baseline to more accurately describe the current conditions, "or else everything will be a heat wave, and we will have no idea what is extreme for this period," Scannell said.

Author Information

Laura Poppick, Freelance Science Journalist



This simulation shows a tsunami traveling northwest across the Caribbean basin, in response to a hypothetical M_w 8.9 earthquake. The entire South Caribbean Deformed Belt is visible in this oblique view, and it shows the distance the wave traveled after about an hour. Orange areas at the bottom are in Venezuela and the surrounding shelf. The simulation was generated using the Tsunami-HySEA numerical simulator at the Universidad de Málaga in Spain. Credit: Jorge Macías, EDANYA

NATIONS WORK TOGETHER TO SIZE UP CARIBBEAN TSUNAMI HAZARDS

By A. M. López-Venegas, S. E. Chacón-Barrantes, N. Zamora, and J. Macías

The Caribbean is known for its tropical beaches and surfing resorts, but it is not exempt from earthquakes and tsunamis. Over the past 500 years, this region may have been exposed to approximately 100 tsunamis, of which 20 are confirmed to have caused significant damage *[National Centers for Environmental Information,* 2017].

This relatively high frequency—once every 25 years—is noteworthy because the Caribbean region is home to about 40 million people, with a growing coastal infrastructure, tourism industry, and population. Of particular concern is how the enclosed nature of the Caribbean basin means that tsunami waves can reach the coastlines in as little as a few

International Ocean Discovery Program

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Application deadline: 1 August 2019

South Atlantic Transect 1

Expedition 390 – 5 October to 5 December 2020

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South Atlantic Transect Expeditions 390 and 393 (based on IODP Proposals 853-Full2 and 853-Add) are a multidisciplinary and joint scientific ocean drilling project that aims to recover complete sedimentary sections and ~200 m of oceanic crust along a crustal age transect at ~31°S across the South Atlantic Ocean to (1) investigate the history of low-temperature hydrothermal interactions between the aging ocean crust and the evolving South Atlantic Ocean; (2) quantify past hydrothermal contributions to global geochemical cycles; (3) investigate sediment and basement-hosted microbial community variation with substrate composition and age in the low energy South Atlantic Gyre subseafloor biosphere; and (4) investigate the responses of Atlantic Ocean circulation patterns and the Earth's climate system to rapid climate change, including elevated CO_2 during the Cenozoic.

The South Atlantic Transect expeditions will target six primary sites on 7, 15, 31, 48, and 63 Ma ocean crust. The proposed transect, which follows a Mid-Atlantic Ridge crustal flow-line, will fill critical gaps in our sampling of intact in-situ ocean crust with regards to crustal age, spreading rate, and sediment thickness. The transect traverses the previously unexplored sediment- and basalt-hosted deep biosphere beneath the South Atlantic gyre, samples of which are essential to refine global biomass estimates and investigate microbial ecosystems' responses to variable conditions in a low energy gyre and aging ocean crust. The transect is located near World Ocean Circulation Experiment (WOCE) line A10, providing access to records of carbonate chemistry and deep-water mass properties across the western South Atlantic through key Cenozoic intervals of elevated atmospheric CO_2 and rapid climate change. Reconstruction of the history of the deep western boundary current and deep-water formation in the Atlantic basins will yield crucial data to test hypotheses regarding the role of evolving thermohaline circulation patterns in climate change, and the effects of tectonic gateways and climate on ocean acidification.

For more information about the expedition science objectives and the *JOIDES Resolution* Expedition Schedule see http://iodp.tamu.edu/scienceops/ - this site includes links to individual expedition web pages with the original IODP proposal and expedition planning information.

APPLICATION DEADLINE: 1 August 2019

WHO SHOULD APPLY: Opportunities exist for researchers (including graduate students) in all shipboard specialtiesm, including but not limited to sedimentologists, petrologists, micropaleontologists, paleomagnetists, petrophysicists, geophysicists, inorganic and organic geochemists, and microbiologists.

WHERE TO APPLY: Applications for participation must be submitted to the appropriate IODP Program Member Office. For contact info, see http://iodp.tamu.edu/participants/applytosail.html

The working group has now defined worst-case tectonic scenarios for several Caribbean subregions.

minutes to 3–4 hours, in contrast to the 15–20 hours it can take a tsunami to cross the Pacific basin.

Recent catastrophic experiences, such as the 2010 earthquake and tsunami in Haiti, have demonstrated how critical the need is for earthquake and tsunami preparedness in the Caribbean region. Moreover, the region shares similarities in population, tourism, development, and tectonic setting with those of the Indian Ocean, where a massive, catastrophic tsunami in 2004 resulted in a quarter of a million deaths.

Thus, the Caribbean has become a focus of interest to scientists working to quantify the possible effects and threats of significant tsunamis. What's more, the potential for massive damage has provided the necessary catalyst to get decision makers to launch risk reduction programs.

In light of this interest and potential, scientists and policy makers across the region spearheaded an international collaboration through the United Nations Educational, Scientific and Cultural Organization (UNESCO). This collaboration quickly established a permanent working group specifically focused on hazard assessment. The working group has now passed some key milestones: It has defined worst-case tectonic scenarios for several Caribbean subregions.

Sustaining Collective Memory

While an average of one tsunami every 25 years is frequent over geological eras, it is not frequent over a typical lifespan, so it can be challenging to raise awareness of their catastrophic potential. Experiences stemming from these phenomena tend not to last very long—maybe a couple of generations—in collective memory. This collective memory also tends to be localized in the community or island affected by a past tsunami rather than spanning the region.

The UNESCO collaboration, formed in 2005 following the structure of its Pacific counterpart, is called the Intergovernmental Coordination Group (ICG) for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG/CARIBE-EWS). It includes 47 countries and territories: all locations with coasts along the Caribbean Sea and the Gulf of Mexico, as well as locations with coasts farther afield, such as the Bahamas, Bermuda, Brazil, Canada, French Guyana, Guyana, and Suriname.

To help keep tsunami awareness alive, ICG/CARIBE-EWS quickly established a permanent working group (WG2) specifically focused on hazard assessment. As members of WG2, our task is to take stock of the potential impacts of tsunamis across Caribbean communities so that emer-

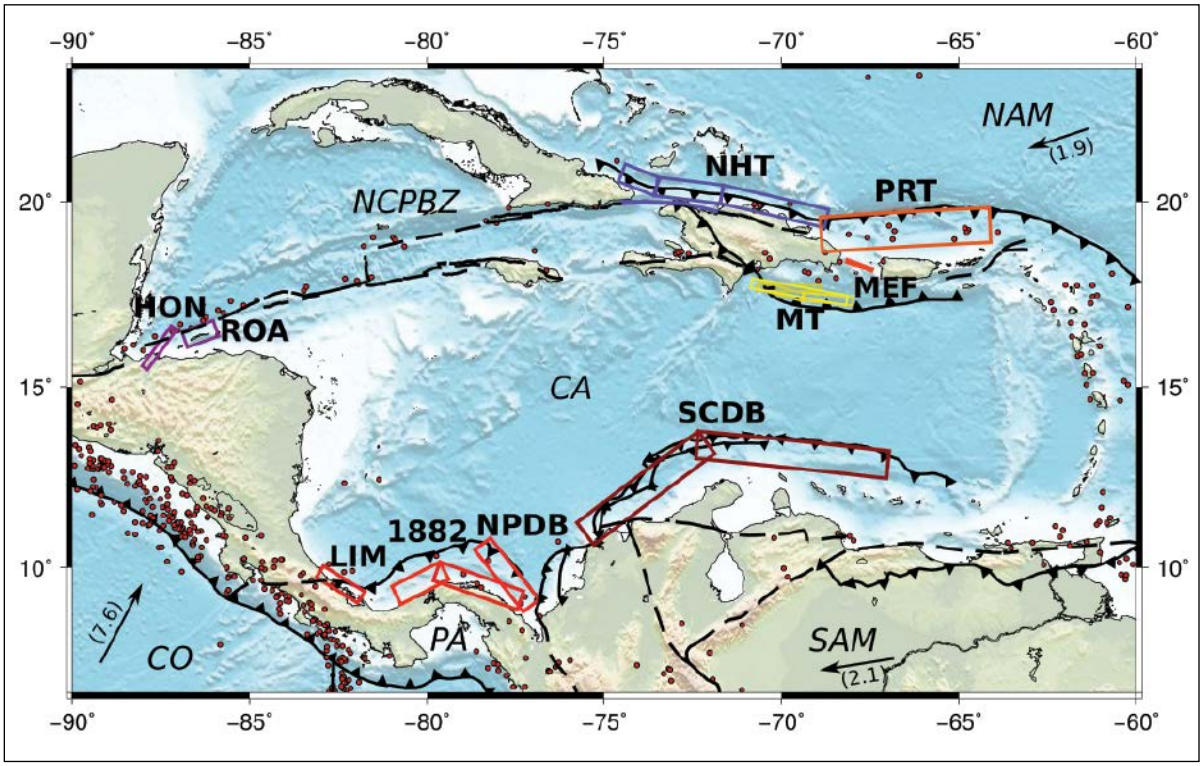

Fig. 1. Our project addresses tsunamis that arise from fault planes (colored rectangular boxes). Abbreviations in bold are modeled scenarios by subregions: (1) northeast: NHT, Northern Hispaniola Thrust (three scenarios); MEF, Mona Passage; MT, Muertos Trough (four scenarios); PRT, Puerto Rico Trench; (2) south: SCDB, South Caribbean Deformed Belt including two scenarios, only the western segment and both segments (full); (3) southwest: LIM, Limón; 1882, repeat of Panama 1882 earthquake; NPDB, North Panama Deformed Belt; and (4) northwest: HON, Honduras; ROA, Roatán. Abbreviations in italic are tectonic features: NCPBZ, Northern Caribbean Plate Boundary Zone; CO, Cocos plate; CA, Caribbean plate; NAM, North American plate; PA, Panama microplate; SAM, South American plate. Red circles are earthquakes $M_w > 5.5$ from 1976 to 2017 from the global centroid moment tensor (CMT) catalog.

gency planners can pursue risk mitigation and preparedness. More information on WG2 can be found on its website (bit.ly/tsunami-programme).

Scope, Scenarios, and Sources

For our first assessment, we took a multidisciplinary approach in which experts determined the tsunami potential of selected regions.

The first step was to define credible worst-case tsunami scenarios. During a series of meetings, held under the auspices of UNESCO's ICG, geologists, seismologists, oceanographers, computer programmers, modelers, and engineers from within and outside the Caribbean region gathered to define and refine potential seismic sources.

Models of the identified scenarios showed that regardless of the source location in the Caribbean basin, these seismically induced tsunamis are not capable of affecting the whole Caribbean basin, but they can affect a significant portion of the region. Thus, it is important that communities across the region realize their vulnerabilities and prepare for tsunamis. If they don't, the assessment concludes, their populations and industries face heightened risks. These simulations also provide useful data to develop tsunami evacuation maps and plans to help mitigate tsunami effects across the Caribbean region.

This project builds upon existing reports that have focused on Caribbean tsunami sources. However, our studies so far have focused on tsunamis caused by simple slip earthquakes and have not taken into consideration more complex structures or slow-slip events such as the 1992 Nicaragua earthquake and tsunami. For this reason, the project envisions future studies that elaborate seismic sources with more complex or variable slip distribution as well as those that augment the list of sources to include submarine landslides and volcanic eruptions.

Possible Caribbean Tectonic Sources

So far, our meetings have identified seismic sources affecting northern Hispaniola, Honduras, the southern Dominican Republic, and Central America. The experts attending these meetings mocked up 17 tsunami scenarios using a deterministic approach (Figure 1) [*Chacón-Barrantes et al.*, 2016].

Although some scenarios yield a low probability of occurrence, we still took them into consideration for preparedness purposes. We determined fault parameters by consensus during the respective meetings by considering available data on historical events, seismic density, and the latest geodetic and tectonic studies of the Caribbean.

These simulations also provide useful data to develop tsunami evacuation maps and plans to help mitigate tsunami effects across the Caribbean region.

Whenever possible, we used the largest observed earthquakes to estimate the largest probable magnitude where a full rupture can develop.

For each tectonic source we discussed and agreed on tsunami source parameters to compute a maximum likely moment magnitude (M_w) following the *Wells and Coppersmith* [1994] relationship between rupture size and earthquake magnitude.

To better categorize the 17 tsunami sources modeled for the Caribbean, the group identified four main subregions: (1) northeast, (2) south, (3) southwest, and (4) northwest. Significant historical events have been documented, and recent damaging events have been recorded in some of these subregions.

Subregion 1 has suffered great devastation from at least three major earthquakes. In 1787, the Boricua earthquake originated in the Puerto Rico Trench. The M_w 7.3 San Fermín earthquake in 1918 originated between the islands of Puerto Rico and the Dominican Republic. In 1946, the M_w 8.1 Hispaniola earthquake struck the northern Dominican Republic.

In subregion 2, the Caribbean and South American plates collide along the South Caribbean Deformed Belt. Current scientific consensus in this region cannot confirm whether this feature is capable of a megathrust earthquake, and there are no historical records in this subregion. However, recent geodetic data have been used to suggest active compression, which implies an increased tsunami risk for the region.

The North Panama Deformed Belt in subregion 3 has the largest number of tsunami records within the Caribbean. They include the devastating event of 1882 in eastern Panama; three strong earthquakes and tsunamis with similar characteristics that originated at the border between Costa Rica and Panama in 1798, 1822 (M_w 7.6), and 1991 (M_w 7.6); a small tsunami in 1916 in western Panama; and an earthquake in 1904 that caused the uplift of coral reefs in Costa Rica with no associated tsunami records.

The largest run-up (the highest point that a tsunami reached) along the Caribbean coast of Central America occurred in subregion 4 following an earthquake in 1539. More recently, an M_w 7.6 strike-slip earthquake caused a small tsunami in this region in early 2018.

A comprehensive list of events affecting the entire Caribbean region can be found in the Global Historical Earthquake Archive from the Global Earthquake Model and in the database of the National Centers for Environmental Information and its colocated World Data Service for Geophysics. Sources along the Lesser Antilles Arc, where tsunamis affect near-field islands, were recently added after a meeting of experts was held in Martinique in March 2019.

Tsunami Simulations for Local Hazard Assessment

Our group performed tsunami numerical simulations of the 17 sources using the numerical model Tsunami-HySEA

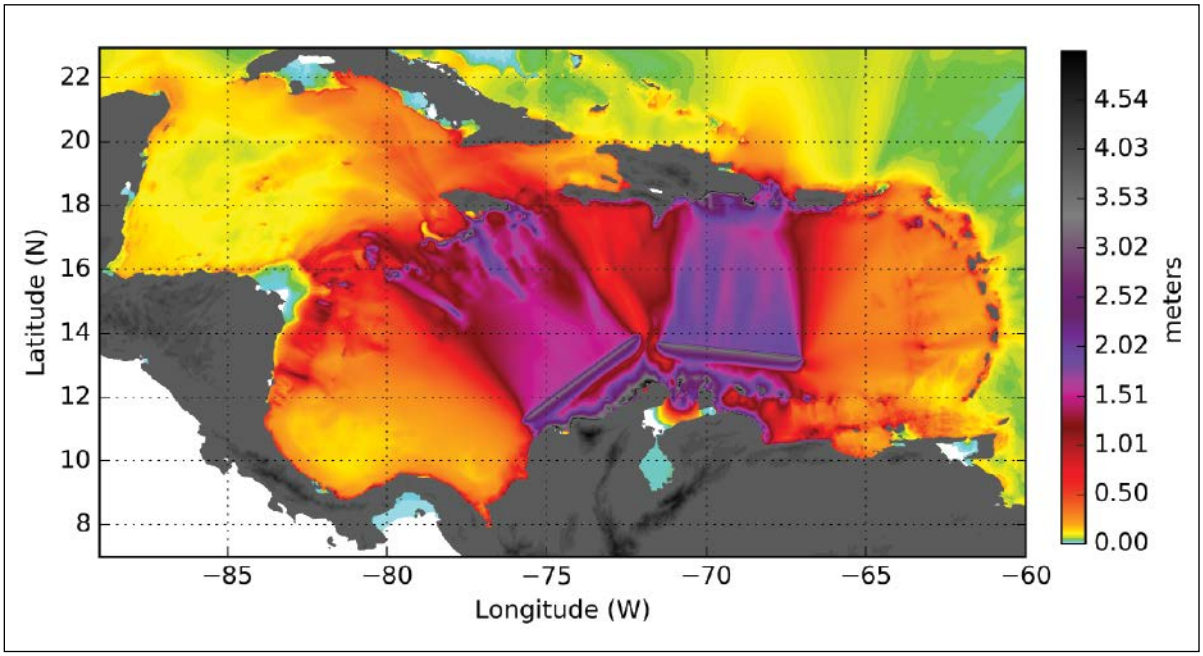

Fig. 2. This map illustrates the regions at risk and the maximum wave height (color scale) for the largest possible event in the list of scenarios in this study: a source consisting of a hypothetical M_w 8.9 earthquake that simultaneously ruptures two faults, each 500 kilometers long, near the coast of South America at the South Caribbean Deformed Belt. Current understanding deems it unlikely that the eastern segment would rupture without the western segment failing too.

[*Macías et al.,* 2017] with a 60–arc second resolution. In all cases, we simulated only tsunami propagation [*Chacón-Barrantes et al.,* 2016]. Our simulations indicate that geomorphology and bathymetry features have a strong effect on the wave propagation. When these features are combined with the type of tsunami source, none of the resulting tsunamis affects the entire Caribbean basin. Figure 2 shows one such example of a large simulated event that affects a large portion of the basin without covering it entirely. However, any future earthquake still has a high chance of affecting a significant portion of it.

An added value of the modeling results is that ICG/CARIBE-EWS member states can apply these results to assess their tsunami hazard and develop mitigation plans. During its annual assembly in 2017, ICG/CARIBE-EWS declared that creating tsunami evacuation maps is a priority for the region, and it encouraged member states to use these modeling results to develop their own tsunami evacuation maps.

Challenges in the Future

The most significant hurdle WG2 has faced in supporting detailed inundation modeling for specific locations in the Caribbean has been acquiring high-resolution bathymetric data of nearshore regions. Collecting coastal bathymetric data is expensive, and because of possible security concerns, some countries do not provide access to these data. To overcome this, WG2 has worked toward capacity building in the Caribbean, where local governments or agencies might perform their own simulations once they get the proper bathymetric data, favoring the development of their own inundation and evacuation maps.

Although our study illustrates the potential effects of tsunamis that have a seismic source trigger within the region, teletsunamis and tsunamis from other nonseismic sources such as landslides and volcanic eruptions have yet to be considered. The Caribbean basin shows evidence of these sources in past events. Quantifying these additional sources would supplement the existing assessment and provide a more thorough understanding of all tsunami risks for the Caribbean region.

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Leading Societies Come Together to Address Harassment in STEMM

Freeograph/Depositphotos

Building on the idea that professional societies—such as AGU—are standard setters for the science, technology, engineering, mathematics, and medicine (STEMM) fields and that in this role they have a unique responsibility for combating such issues as sexual and gender harassment, an important new partnership was launched in February: the Societies Consortium on Sexual Harassment in STEMM.

The consortium was established by AGU, the American Association for the Advancement of Science (AAAS), and the Association of American Medical Colleges (AAMC), but its reach is much broader. With an executive committee that comprises AGU, AAAS, AAMC, the American Chemical Society, the American Educational Research Association, the American Psychological Association, the American Physical Society, the American Society for Cell Biology, the Entomological Society of America, and the Institute of Electrical and Electronics Engineers; policy and law consultation from the EducationCounsel; and more than 50 member societies to date, the consortium is already positioned to be a transformative voice in STEMM.

"While AGU and many others have been working independently to make a difference in areas of harassment, bias, and discrimination, this consortium will allow us to collectively use our voice, as leaders of the international science community, to truly transform the workplace culture in ways that allow all to thrive," said Billy Williams, vice president for ethics, diversity, and inclusion at AGU. "This work will have an immeasurable impact not just on science, but on its ability to drive the next 100 years of innovations, discoveries, and solutions. We enrich discovery and innovation and strengthen our science when a diverse set of voices feel encouraged and supported in sharing their perspectives and ideas."

"This consortium will allow us to collectively use our voice, as leaders of the international science community, to truly transform the workplace culture in ways that allow all to thrive."

"This consortium provides both leadership for a broad diversity of our societies' collective voices and actions to advance ethics, equity, inclusion, and excellence in STEMM research, education, and practice," said Shirley Malcom, senior adviser at AAAS.

"Combating sexual harassment in academic medicine and across the STEMM fields requires a multipronged, ongoing, and sustained approach," said David Acosta, M.D., chief diversity and inclusion officer at AAMC. "The Societies Consortium will help our organizations—and in, turn, our respective member institutions—see across the landscape of STEMM as we work together to develop the strategy and tools needed to foster a more inclusive learning and workplace environment."

"Consortium members are saying loudly and clearly that we need the best scientific output of all talent in STEMM, if these fields are to maximize their potential to drive innovation, economic strength, and security, benefiting society across the nation and around the world," said Jamie Lewis Keith, a partner at EducationCounsel. "And, they stress, that success depends on fully inclusive settings in which all professionals and students are treated with respect."

Initially, the group will focus on the societies' honors and awards operations. Given the important role these programs play in everything from professional development to public outreach, the consortium will work to develop model policies and procedures that can help to improve diversity and inclusion and ensure professional and ethical conduct. Ultimately, the group hopes to provide practical research- and evidence-based resources that are informed by social and behavioral science and are applicable to the consortium's member societies' own operations.

The consortium is the latest addition to a growing list of efforts AGU is undertaking to build a diverse, inclusive, welcoming, and supportive workforce and workplace—all of which has particular resonance during our Centennial. On 12 February 2019, AGU launched the Ethics and Equity Center. A new hub for comprehensive resources and tools designed to support our community across a range of topics linked to ethics and workplace excellence, the center provides resources to individual researchers, students, department heads, and institutional leaders to promote leading practices on issues ranging from building inclusive environments, to scientific publications and data management, to combating harassment, to example codes of conduct. The center is an outgrowth of the update of AGU's Scientific Integrity and Professional Ethics Policy in September 2017. In the wake of high-profile cases alleging sexual harassment in the sciences, the updated policy was one of the first steps AGU took to address ongoing issues within the Earth and space science community that have a profound impact in the workplace and on scientists' individual lives and careers.

By **Joshua Speiser** (jspeiser@agu.org), Manager, Strategic Communications, AGU

Grassroots Group Commended by Virginia House for Work on Flooding

For 2 years, Virginia Wasserberg and Bob Jennings have been working tirelessly to stop the recurrent flooding in their town of Virginia Beach. On 20 February, the Virginia legislature recognized the work of the organization they founded, Stop the Flooding NOW, with House Resolution 292. The resolution also recognized their partners, coastal resources scientist Michelle Covi of Old Dominion University in Norfolk and AGU's Thriving Earth Exchange.

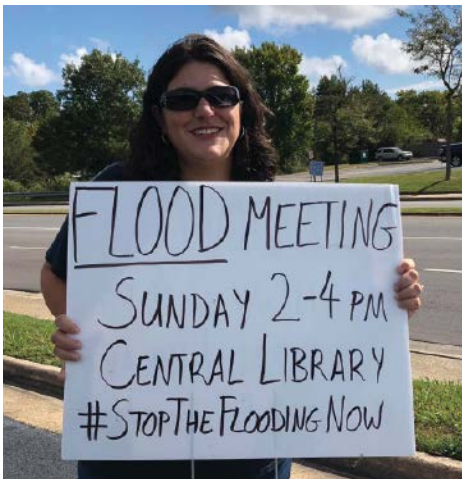
The resolution reads, in part, "Stop the Flooding NOW has worked with other groups concerned with flooding throughout the country, including churches, civic organizations, Flood Forum USA, and Thriving Earth Exchange and its Community Science Connect program sponsored by the American Geophysical Union."

The resolution "solidifies the work we've been doing as volunteers in Virginia Beach," says Wasserberg. "And it brings a sense of accomplishment to our community. It really means a lot to me to have the community recognized in such a way."

Wasserberg and Jennings organized Stop the Flooding NOW after Hurricane Matthew hit in late September 2016. Over 24 centimeters of rain fell in some areas of Virginia Beach, overwhelming the municipal stormwater system. Nearly 2,000 homes in the central part of the city were flooded. Wasserberg and Jennings saw an opportunity to draw together a group of concerned citizens to work on behalf of all residents who were experiencing chronic flooding. They quickly realized that they needed to understand the science behind flooding and began asking around about how to recruit a scientist with the expertise that could help them.

It brings a sense of accomplishment to our community and means a great deal to be recognized in such a way.

Thriving Earth Exchange, AGU's program that helps scientists and community leaders work together to tackle local issues, connected Wasserberg and Jennings with Covi, an assistant professor of ocean, Earth, and atmospheric sciences. Together, they began to analyze the flooding and share what they were learning with residents and lawmakers.



Virginia Wasserberg holds a sign inviting Virginia Beach residents to a meeting she organized to discuss flood prevention. Credit: Virginia Wasserberg

In April 2018, Wasserberg, Jennings, and Covi hosted a community event that attracted over 70 people to learn about the effects of sea level rise, flooding, and climate change in the region. Neighbors attended to express their concerns and become more informed about the consequences of their changing environment.

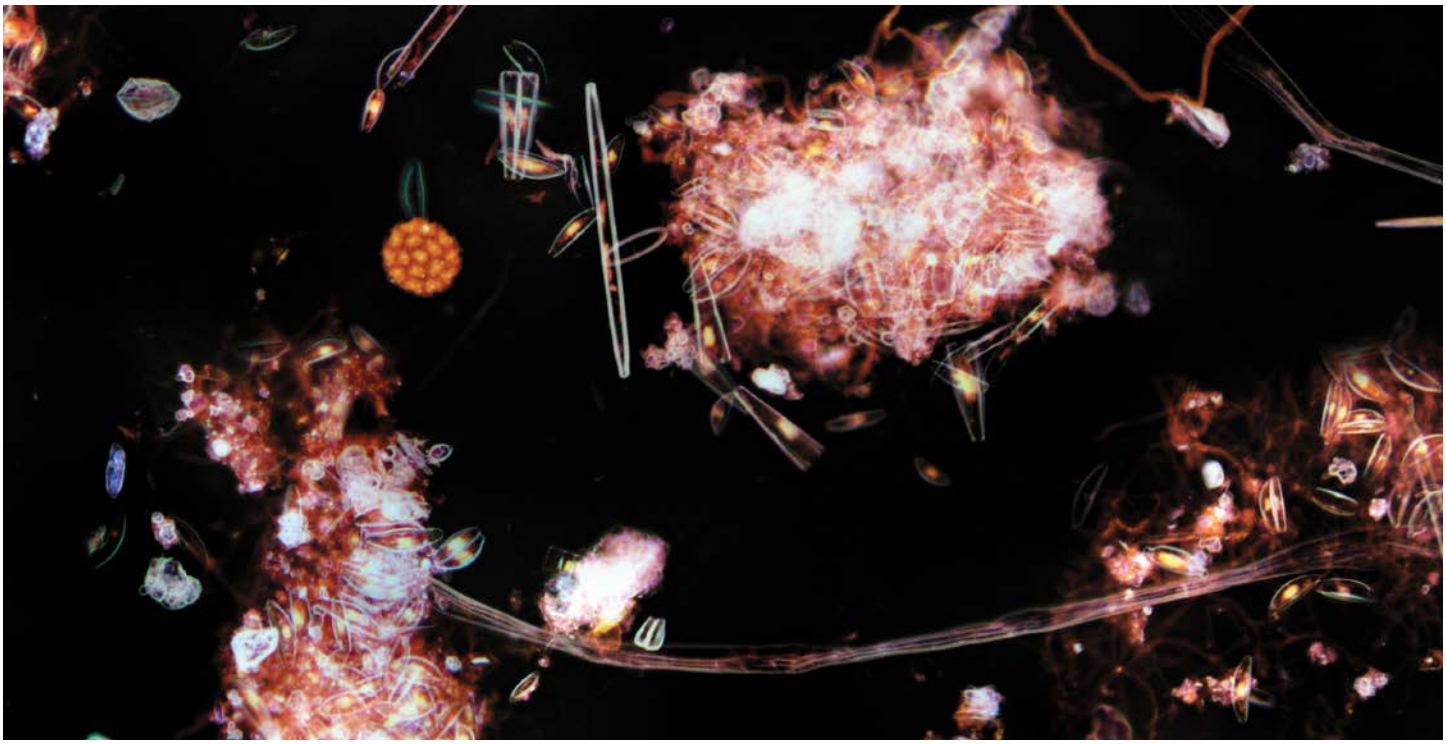
Since then, the group has had great success connecting with state lawmakers. In the past 2 years, Wasserberg and Jennings have incorporated the science they learned with Covi into dozens of speeches and presentations at city council meetings. They've also held rallies to advocate for their rights, as citizens, to apply scientific results to protect their homes and businesses and promote flooding solutions.

"Stop the Flooding NOW is the community of Virginia Beach," said Wasserberg. "These are people who work together to educate themselves on flooding [and] climate change and make a difference in their neighborhoods and backyards."

*Norfolk, Va., residents contend with flooding in the aftermath of a storm on 4 September 2016. Credit: Vicki Cronis-Nohe/*The Virginian-Pilot *via AP*

By **Sarah Wilkins** (swilkins@agu.org), Project Manager, Thriving Earth Exchange, AGU

Oceanic "Pump" Sends Small Carbon Particles to Twilight Zone



New research uses underwater gliders to track how carbon from the atmosphere reaches the deep ocean, influencing ecosystems and organisms like these diatoms. Credit: iStock .com/BeholdingEye

The ocean is a major carbon sink that has absorbed about a quarter of all carbon dioxide emissions since the Industrial Revolution. It is generally understood that atmospheric carbon dioxide dissolves in surface waters, where photosynthesis converts it to organic carbon. As it sinks or progresses through the food chain, much of this carbon ends up sequestered in the deep ocean.

Most of the organic carbon in surface waters descends first to the twilight zone, which extends from about 100 to 1,000 meters deep and harbors myriad life forms, such as bioluminescent fish and sea jellies. Scientists traditionally believed that twilight zone denizens got all their carbon from large, fast sinking organic carbon particles, as well as from frequent feeding trips to shallower waters. However, these mechanisms appear to be insufficient to meet the ecosystem's needs.

New research by *Bol et al.* challenges traditional ideas of how organic carbon descends from surface waters and adds to a growing body of evidence that small, slow sinking particles—as opposed to larger, fast sinking ones—play a bigger role than previously thought.

To examine the potential role of small-particle organic carbon, the team analyzed data collected by autonomous underwater Seagliders in the twilight zone above the Porcupine Abyssal Plain, southwest of Ireland. Five Seagliders crisscrossed the region for 1 year, taking daily measurements with sensors that detect light scattered by carbon particles, thereby revealing their concentration.

The analysis showed that a significant amount of small-particle organic carbon does indeed descend to the twilight zone. With at least 2–4 grams of particulate organic carbon flowing through a 1-square-meter area of water per year, the researchers calculated that these small particles account for at least 5%–25% of the annual carbon flow from surface waters to the twilight zone in the region.

They found that the greatest flux of small-particle organic carbon to the twilight zone occurred in winter and spring. These data add new support to earlier evidence that a mechanism known as the mixed-layer pump drives transport of these small particles.

The mixed-layer pump arises from changes in the depth of the ocean's uppermost layer, where winds and waves mix surface waters to form a mass of uniform temperature and salinity. Over the Porcupine Abyssal Plain, strong storms cause this mixed layer to extend deeper into the ocean in winter and spring, whereas in the summer it remains shallow. This variation in depth appears to drive net transport of small-particle organic carbon into the twilight zone.

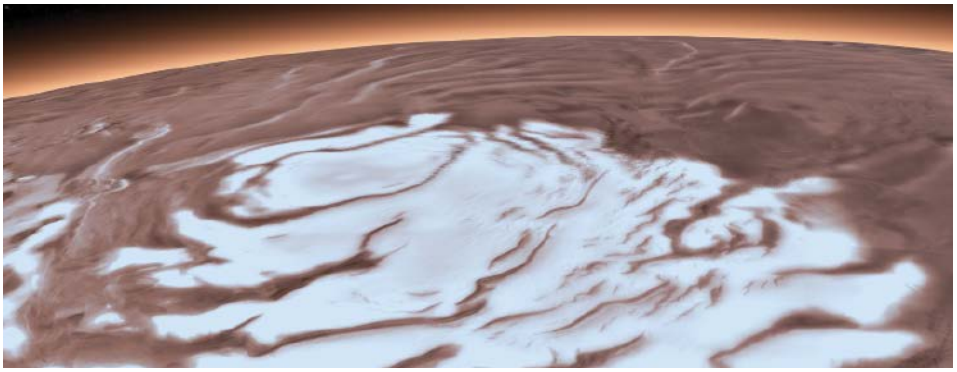
This study marks the first use of daily particulate organic carbon measurements taken over a full year. The findings suggest that future research could make further use of optical sensors on autonomous gliders to help clarify organic carbon transport and the role of the mixed-layer pump around the world. For example, such efforts could address the fate of small-particle organic carbon that reaches the twilight zone and reveal how much it actually contributes to carbon sequestration, especially in the context of global climate change. (*Global Biogeochemical Cycles*, https://doi.org/10.1029/2018GB005963, 2018) **—Sarah Stanley, Freelance Writer**

Local Heat Source Needed to Form Liquid Water Lake on Mars

Liquid water appears to be a fundamental requirement for life, which is why a recently published article reporting evidence of a 20-kilometer-wide lake located at the bottom of Mars's south polar ice cap, 1,500 meters below the icy surface, has stimulated considerable scientific interest. The article's authors proposed that concentrated salts, which lower the freezing point of ice, could account for the lake's presence, but the study did not consider the conditions needed to melt ice in this location or whether they are physically plausible.

Sori and Bramson have taken this step to better constrain the circumstances under which subglacial water could form on Mars today. Using a series of one-dimensional thermal models, the team evaluated whether several key parameters, including subsurface heat flow and the concentrations of different salts, could induce melting at the base of the south polar ice cap.

The results indicate that no amount of salt would suffice to melt the basal ice under typical Martian conditions. Instead, the researchers calculate that a local source of heat with a flux of at least 72 milliwatts per square meter would be necessary to raise subsurface temperatures high enough to melt the ice.



Perspective view of Mars's south polar ice cap. Credit: Michael Sori, NASA Solar System Treks/Viking Global Color Mosaic

The authors argue that a subsurface magma chamber is the most plausible local heat source. According to their calculations, a chamber with a diameter of at least 5 kilometers, located about 8 kilometers below the ice and appearing within the past few hundred thousand years, could generate enough heat to create a lake 20 kilometers wide. Because of the spotty nature of magmatism, this explanation implies that liquid water is not likely to be widespread along the ice cap's base. Although the authors caution that the presence of this liquid water on Mars must still be confirmed, if it does exist, their findings imply that the Red Planet has experienced volcanism much more recently than other lines of evidence have indicated. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL080985, 2019) **—Terri Cook, Freelance Writer**

What Do People Drink When They Think Their Tap Water Isn't Safe?

Despite extensive evidence indicating that bottled water in the United States is generally no better or safer than what's available from the faucet, many households still regularly purchase it. Previous research has suggested that some people do so because they believe that their tap water is unsafe, but few studies have focused on Americans' perceptions of drinking water on a nationwide basis or have examined these households' choices of alternative sources of water for drinking and cooking.

To help bridge this gap, *Javidi and Pierce* present an analysis of publicly available data from the U.S. Census Bureau's 2015 American Housing Survey, which collected socioeconomic, ethnic, and housing information from people occupying more than 94,000 dwellings nationwide. All respondents were asked whether they believed that their tap water was safe, and a subset of those answering no was also asked to identify their primary source of drinking water.

To assess which variables most closely affected the respondents' perceptions of water safety and their choice of alternative sources, the researchers used a two-stage statistical regression analysis. The results indicate that minority households are much more likely to believe that their tap water is not safe, and they also reveal statistically significant differences between different ethnic groups. For example, although the team found the perception of unsafe tap water was twice as common in Hispanic households (16.4%) compared with African American households (8.48%) and more than 3 times as frequent when compared with that of non-Hispanic whites (5.07%), African American households were much more likely to buy bottled water as a substitute.

The team estimates that the expenditures for buying bottled water to replace what is perceived to be unsafe tap water total at least $5.65 billion per year in the United States. The results clearly illustrate the substantial economic cost of avoiding tap water, and because this burden is disproportionately borne by minority groups, these findings highlight issues of social inequity and emphasize the need for targeted policy and education interventions. (*Water Resources Research,* https://doi.org/10.1029/2017WR022186, 2018) **—Terri Cook, Freelance Writer**

Identifying Uncertainties in Climate Models

A view of Hurricanes Jose, Irma, and Katia swirling across Earth's Northern Hemisphere in September 2017. Scientists are working to unravel just how the spatial patterns of climate change vary from the equator to the poles. Credit: NASA

The enduring consensus among scientists is that Earth's climate is warming because of human activity. But exactly how climate change will manifest at regional scales remains a topic of discussion; in particular, scientists are interested in unraveling how the spatial patterns of climate change vary from the equator to the poles. These "meridional" patterns (moving north–south) are important in understanding the future of our planet, but climate models often do not agree on the exact magnitude of warming at each latitude. Future warming in the Arctic and Antarctic, for instance, is particularly uncertain.

Bonan et al. aim to investigate out why climate models disagree on these warming patterns. To start, the researchers used a simplified model known as a moist energy balance model (MEBM) to simulate how energy is transported through the atmosphere from the warm tropics to the cold poles. In a scenario in which carbon dioxide (CO_2) was abruptly quadrupled relative to preindustrial levels, they found that this simple model could explain 90% of the variance in local surface warming seen in more complex global climate models.

Once satisfied that the MEBM could capture the uncertainty in warming predictions made by global climate models, the researchers began to identify the variables that contributed most to the spread in warming patterns. They focused on three variables that regulate the balance between energy absorbed from the Sun and energy reflected back into space: radiative feedbacks, ocean heat uptake, and top-of-the-atmosphere radiative forcing from CO_2. Their analysis showed that radiative feedbacks account for 70% of the total uncertainty in the meridional pattern of warming.

Next, the researchers broke down the feedbacks into individual components, specifically, how surface albedo, combined lapse rate and water vapor, and net cloud feedbacks influence warming uncertainty. They concluded that among these subcategories, cloud feedbacks are the main driving factor behind uncertainty in the pattern of warming. Because clouds are some of the hardest processes to represent in global climate models, each model has a completely different pattern of cloud feedbacks that can result in either positive or negative values at different latitudes.

Despite the challenges that cloud feedbacks present, the researchers assert that understanding these processes better is vital to understanding the pattern of climate change on Earth. Their work here shows that uncertainty surrounding how clouds change in the tropics leads to warming uncertainty at all latitudes through changes in poleward energy transport but that uncertainty in polar processes results in warming uncertainty that is confined to the poles. This fact, the researchers say, makes the polar regions of the planet, which are important determinants of global climate, particularly uncertain because they aggregate uncertainty from distant feedbacks in the tropics and from strong local feedbacks.

The team concludes that studies like this will become more important as global climate models continue to become increasingly complex and their sources of uncertainty become increasingly obfuscated. (*Geophysical Research Letters*, https://doi.org/10.1029/2018GL079429, 2018) **—David Shultz, Freelance Writer**

Unraveling the Origin of Slow Earthquakes

Unlike conventional plate boundary earthquakes, which violently release pent-up energy for seconds or minutes at a time, slow earthquakes do not release seismic waves and can endure for many months. Although previous research suggests that these slow-slip events occur in the region between an upper, brittle seismogenic zone and the more pliable underlying material, the physical mechanisms that generate slow earthquakes remain unclear.

To better understand these puzzling aseismic events, *Kano et al.* scrutinized geodetic records from beneath the Yaeyama Islands, which sit along southwestern Japan's Ryuku subduction zone. Using specially filtered Global Navigation Satellite System (GNSS) data from the GNSS Earth Observation Network System (GEONET) and Kyoto University networks, the researchers detected and analyzed the evolution of five slow-slip events between July 2010 and February 2013.

Yaeyama Islands in Okinawa, Japan. Researchers examined geodetic records from beneath the islands to better understand the mechanics behind slow earthquakes. Credit: iStock.com/Takosan

Their results indicate that although all five slow earthquakes occurred within the same portion of the fault and had nearly the same magnitudes, they evolved quite differently over time. In particular, the style of nucleation varied considerably between events. In three of the five records, the slow earthquakes reached their maximum rate of slip within a few days, whereas the nucleation occurred much more slowly during the other two, which sputtered along for 25 and 45 days before rapidly accelerating. The total durations of the slow earthquakes also differed substantially, from about 30 to 95 days; their maximum slip rate varied from 0.4 to 1.2 meters per year.

The differences between the five recorded events suggest that the fault's physical properties, such as friction and the distribution of fluid pressure, may vary over time or that the stress state prior to slow-slip nucleation can differ between events. Additional studies describing the temporal and spatial evolution of slow earthquakes should help researchers constrain the physical properties of these plate interfaces and ultimately clarify how slow-slip events are generated. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1029/2018JB016072, 2018) **—Terri Cook, Freelance Writer**

The Meteorological Culprits Behind Strange and Deadly Floods

On 14 June 1903, a massive swell of water overwhelmed the small town of Heppner, Ore., killing more than 250 people. Floods are ordinarily reported in probabilistic terms: A 10-year flood, for example, describes streamflow conditions that have a 10% chance of occurring within any given year. But the Heppner Flood was so extreme that it defied standard descriptions. At its peak, the flood was more than 200 times larger than the discharge of a 10-year flood.

"Strange" is not an adjective commonly applied to floods and other natural disasters, but *Smith et al.* argue that it may be the most appropriate descriptor for extreme and unusual flooding. The Heppner Flood, they argue, may have been one of the strangest floods on record. It was triggered by an intense hailstorm in June of that year, in a region where spring snowmelt typically drives peak annual streamflow. These conditions are characteristic of strange floods, which the authors define as extreme events triggered by circumstances that contrast with the common flood-generating mechanisms in a region.

The researchers examined extreme floods across several decades in the conterminous United States, using annual flood peak observations from more than 8,000 U.S. Geological Survey stream gauging stations. They developed a statistical framework they call the upper tail ratio, in reference to the upper tail of a statistical distribution, where rare events reside. The upper tail ratio is defined as the peak discharge for a flood of record divided by the stream's 10-year flood magnitude. The 1903 Heppner Flood registered an upper tail ratio of 200, topped only by the 1976 flood caused by the bursting of the Teton Dam in Utah.

The team discovered that record floods share many traits. In the western United States, severe flooding is linked to mountainous terrain and intense thunderstorms; in the east, it occurs in coastal regions susceptible to tropical cyclones. Major floods also have a different seasonal distribution than annual peak flow events: Annual flood peaks across the United States tend to have winter or spring maxima, whereas the strange floods in the upper tail nearly always occur in the warm season.

In addition to the analysis of floods across the United States, the authors provide a case study of the Blue Mountains, the setting for the Heppner Flood and other strange floods in the 1950s and 1960s. In the case study, they examined the hydrology, hydrometeorology, and hydroclimatology of the extreme floods in the region.

Strange floods are the least expected and most damaging floods, but their infrequency can make them difficult to study. The analysis offers insight into extreme floods and provides a platform for comparing floods around the world with those in the United States. (*Water Resources Research,* https://doi.org/10.1029/2018WR022539, 2018) **—Aaron Sidder, Freelance Writer**

The Urban Dry Island Effect

Urban sprawl in Shanghai, which a new study suggests could influence the flow of water from the ground to the atmosphere. Visit bit.ly/Shanghai-urbanization to see a side-by-side comparison of urbanization between 1984 and 2017. Credit: NASA Earth Observatory

Heat generated by people, vehicles, and the Sun is easily trapped by the materials used to build houses, industrial buildings, sidewalks, and parking lots. This heat often makes cities significantly warmer than surrounding rural areas, a phenomenon known as the urban heat island effect. A new study of the highly developed Yangtze River Delta in southern China examines a less studied but related impact of city building: the desiccation of the local atmosphere.

Spanning more than 210,700 square kilometers, the Yangtze River Delta region contains the largest concentration of metropolitan areas in the world, including such megacities as Shanghai. It is urbanizing at a breakneck pace: Between 2000 and 2010, for example, the proportion of land covered by cities and suburbs increased by 75%, replacing flooded paddy fields, cropland, and forests.

Hao et al. hypothesize that in addition to increasing local temperatures in urban areas, this rapid development has altered the flow of water between the ground and the atmosphere, making built-up regions drier. To test that hypothesis, they obtained data from the Global Land Surface Satellite (GLASS), products derived from multiple satellite imageries. They also obtained more than 50 years of climate data from 33 weather stations spanning the delta and data from Chinese government records on urbanization and the amount of land being used to grow paddy rice.

The researchers performed a correlation analysis—a statistical test used to study the strength of a relationship between two variables—to analyze the relationship between urbanization and relative humidity (a measure of moisture in the air) between 2001 and 2014. They found that urbanizing regions of the Yangtze River Delta grew dramatically drier as wetlands, rice paddies, and forest were replaced by cities. These findings indicate that as they design growing cities, urban planners need to account not only for the urban heat island effect but also for a related "urban dry island" effect, the team argues. (*Water Resources Research,* https://doi.org/10.1029/2018WR023002, 2018)

—Emily Underwood, Freelance Writer

Ocean Science

Biological Oceanography Assistant or Associate Professor

The Division of Marine Science in the School of Ocean Science and Engineering (SOSE) at The University of Southern Mississippi (USM) invites qualified applicants for a full-time, nine-month, tenure-track position in Biological Oceanography at the Assistant or Associate Professor level to begin in Fall 2019. SOSE includes two academic divisions, Marine Science, and Coastal Sciences, and several R&D centers including: Hydrographic Science Research Center, Center for Fisheries Research and Development, and Thad Cochran Marine Aquaculture Center. The Division of Marine Science is based at the NASA Stennis Space Center where Marine Science faculty benefit from close working relationships with a number of on-site federal agencies, including the Naval Research Laboratory–Stennis Space Center, the Naval Oceanographic Office, the Naval Meteorology and Oceanography Command, the USGS and NOAA, including the National Data Buoy Center.

Marine Science graduate and undergraduate programs extend across traditional marine science emphasis areas in biological, physical, chemical and geological oceanography, as well as hydrographic science and ocean engineering. Marine Science faculty and graduate programs are housed at Stennis Space Center, where the M.S. and Ph.D. degrees in Marine Science and the M.S. degree in Hydrographic Science are delivered. The Marine Science and Ocean Engineering B.S. degree programs are delivered at the USM Gulf Coast Campus in Long Beach, MS as well as at USM's main campus in Hattiesburg, MS. The Long Beach campus is in close proximity to the Port of Gulfport, which is the home port for USM's R/V Point Sur and the recently opened USM Marine Research Center, that features a state-of-the-art fabrication lab, testing tank, and laboratory space.

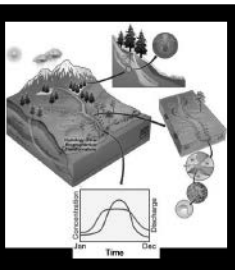
Applicants must hold a Ph.D. in oceanography, biological oceanography, or a related field. Preference will be given to candidates with post-doctoral experience, and a demonstrated record of scholarship, service, grant development, communication, and commitment to diversity. For appointment at the Associate level, candidates should also have demonstrated a national or international reputation for excellence in their discipline. The successful candidates areexpected to develop and deliver courses in their field of specialization. The successful candidate should demonstrate the potential to contribute across disciplines and promote the continued interdisciplinary growth of the academic and research programs

Hydrologist

The Earth and Environmental Sciences (EESA.lbl.gov) of Berkeley Lab is advancing and integrating diverse expertise to accelerate scientific discoveries and their translation into scalable solutions that simultaneously sustain the Earth's environment and the growing need for energy and water resources.

We seek an outstanding Earth Scientist with a record of innovative research in hydrology. Aligned with EESA's 'Future Water' and possibly 'Sustainable Earth' strategic directions, we particularly encourage applicants who develop and utilize novel field methods and experiments with theory to advance understanding of multi-scale, multi-phase behavior of hydrological systems. Topics of interest include, but are not limited to: watershed response to extreme events and climate change; critical zone ecohydrology and hydrogeochemistry; aquifer storage and recovery; and bedrock flow and reactions relevant to subsurface energy strategies.

The position is open at the Research and Staff Scientist levels. The incumbent is expected to take advantage of world-class experimental facilities at Berkeley Lab and develop active collaboration with UC Berkeley. The incumbent may also be considered for leadership roles within EESA.



Berkeley Lab, located next to UC Berkeley, is part of the stimulating San Francisco Bay Area innovation ecosystem. The region is also recognized for offering a high quality of life, having both abundant natural beauty and exciting urban surrounds.

To apply online at **http://jobs.lbl.gov**, please select "Search Jobs", enter 86204 in the keyword search field, and follow the online instructions to complete the application process.

LBNL is an Equal Opportunity/Affirmative Action Employer.

within SOSE. Applicants should submit a letter of interest outlining their qualifications for the position, including a research plan, teaching philosophy with a curricular plan, a curriculum vitae, and names and contact information of at least four references. Salary packages will be nationally competitive and commensurate with experience. Applications must be submitted online at https://usm.csod.com/ats/careersite/jobdetails.aspx?site=1&c=usm&id=624. For inquiries about the position, contact Donald G. Redalje, Chair of the Search Committee, at 1-228-688-1174 or Donald.Redalje@usm.edu. Review of applications begins 1 March 2019 and continues until the position is filled, with an anticipated start date of August 2019.

EOE/F/M/VET/DISABILITY

Postdoctoral and Assistant Research Scientists Positions at Texas A&M University

Overview: The Qingdao National Laboratory for Marine Science and Technology (QNLM), Texas A&M University (TAMU), and the U.S. National Center for Atmospheric Research (NCAR) have establish the International Laboratory for High-Resolution Earth System Prediction (iHESP). This laboratory will play a fundamental role in advancing Earth System science by combining the expertise of these three renowned research institutions to pursue transformational efforts in the development and application of high-resolution Earth System models for predicting climate variability at subseasonal-to-decadal time scales. We are currently conducting a cluster-hire for up to five positions with research interests that intersect with one or more scientists within iHESP: two to three (2–3) positions for postdoctoral researcher, one (1) position for an assistant research scientist in Earth system modeling and analysis and one (1) position for an assistant research scientist specializing in software engineering and high-performance computing.

The postdoctoral researchers will be supported and managed through the iHESP main office at TAMU, College Station, Texas, but can be mentored by scientists in the partner institutions of iHESP. The research scientists will be on the research staff of the Department of Oceanography at Texas A&M University, but are expected to work closely with scientists at NCAR and QNLM.

Area of research: We seek candidates with strong background and training in physical oceanography, atmospheric and climate dynamics, and/or high-performance scientific computing. Special areas of expertise include but not limited to:

- Modeling and understanding ocean dynamical processes, including oceanic fronts, eddies, waves and mixing, and their interactions with the atmosphere
- Subseasonal-to-decadal climate prediction and predictability studies
- Weather and climate extreme simulations and analyses
- High-performance scientific computing and data science with application to Earth system modeling and prediction

Appointment: The postdoc positions each will be supported for two (2) years, and the assistant research scientist positions will be supported for five (5) years. All positions are contingent upon funding availability and satisfactory performance.

Application Instructions: Applications must include the following:

1. A cover letter containing a statement of interest in a specific position. A curriculum vitae. Three references with complete contact information.

Review of applications will begin immediately and the advertisement will remain open until the positions are filled.

More detailed information about the required and preferred education and experience for the postdoctoral and assistant research scientist positions along with the electronic applications submission information can be found:

Postdoctoral positions:

https://tamus.wd1.myworkdayjobs.com/en-US/TAMU_External/job/College-Station-TAMU/Postdoctoral-Research-Associate-1_R-017421-1

https://tamus.wd1.myworkdayjobs.com/en-US/TAMU_External/job/College-Station-TAMU/Postdoctoral-Research-Associate-2_R-017419-1

https://tamus.wd1.myworkdayjobs.com/en-US/TAMU_External/job/College-Station-TAMU/Postdoctoral-Research-Associate-1_R-017421-1

Assistant research scientist in Earth system modeling and analysis:

https://tamus.wd1.myworkdayjobs.com/en-US/TAMU_External/job/College-Station-TAMU/Assistant-Research-Scientist---1_R-017652-1

Assistant research scientist specializing in software engineering and high-performance computing:

https://tamus.wd1.myworkdayjobs.com/en-US/TAMU_External/job/College-Station-TAMU/Assistant-Research-Scientist---2_R-017654

Information on applying for a position is also available at: http://ocean.tamu.edu/about

Texas A&M is located in College Station, Texas, The Department of Oceanography is part of an alliance of Ocean Sciences at Texas A&M University that spans the Marine Biology and Marine Sciences Departments at TAMU Galveston, the Geochemical and Environmental Research Group, the International Ocean Discovery Program, and Texas Sea Grant. This alliance of Ocean Sciences represents a unique concen-

tration of educational and research resources. The capacity is greatly enhanced by close ties to the College of Geosciences Departments of Atmospheric Sciences, Geography, and Geology & Geophysics, as well as the Berg Hughes Center, the Texas Center for Climate Studies and the International Laboratory for High-Resolution Earth System Prediction. The Department web site http://ocean.tamu.edu contains a full description of our program.

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

Space Physics

Development of a New Ground-to-Space Atmospheric Prediction Model, The Space Science Division of the US Naval Research Laboratory (NRL)

The Space Science Division of the US Naval Research Laboratory (NRL) in Washington, DC seeks a highly motivated individual to join a cross-disciplinary research team, tasked with rapidly developing and validating a new state-of-the-art global numerical model of the neutral atmosphere extending from the ground to 500 km altitude, for future high-resolution forecasting of the deep atmosphere for space-weather applications. The successful candidate will join a strong team of research scientists already in place at NRL for this new project that builds upon NRL's institutional expertise in high-altitude atmospheric model development for new and improved operational environmental prediction capabilities for the globally deployed Navy.

The new atmospheric model will be based on an emerging Navy dynamical core that solves the deep-atmosphere nonhydrostatic equations on the sphere using spectral element (SE) methods. The candidate will work primarily with a group at NRL DC developing new upper-atmospheric (mesospheric and thermospheric) components of the model, including dynamics and physical parameterizations. As model development proceeds, the candidate will conduct high-resolution model experiments on massively parallel high-performance computers to test and refine new features that help the team achieve specific project goals and milestones. In the process, the candidate may also collaborate with other project research teams located at NRL DC and elsewhere, focusing on the model's lower altitudes, high-altitude data assimilation capabilities, and physical coupling to ionospheric models.

We seek a self-motivated candidate eager to study upper-atmospheric dynamics and physics relevant to short-term prediction, to develop efficient algorithms of these processes, and then to integrate them as new computer code within the evolving infrastructure of the new model. A Ph.D. in atmospheric science, computational fluid dynamics, physics, or a related discipline, is therefore preferred, but not essential. Ability and willingness to work in the environment of a large, diverse and geographically distributed team, to achieve collective team goals, are essential. Strong programming skills will also be required in working with a complex modern highly-scalable Fortran code using up to 1 million processors per run. Thus, candidates with interests in learning and applying modern coding practices on new and emerging supercomputing architectures are encouraged to apply.

All applicants for federal positions must be US citizens. To apply, send your resume, a cover letter addressing placement factors for the position, and current transcripts via the AMRDEC Safe Access File Exchange found at https://safe.amrdec.army.mil/safe/Welcome.aspx, to the attention of Steve Eckermann (email address stephen.eckermann@nrl.navy.mil). Please contact Dr. Eckermann directly with any questions about the position prior to applying. Applications will be accepted until 30 April 2019 or until the position is filled. NRL is an equal opportunity employer.

DEAN OF THE SCHOOL OF ENVIRONMENTAL SCIENCE AND ENGINEERING

The Southern University of Science and Technology (SUSTech) invites applications and nominations for the position of **Dean of the School of Environmental Science and Engineering**, currently a division within the Faculty of Engineering at SUSTech. The compensation package is globally competitive (including US and Hong Kong) and commensurate with experience and qualifications.

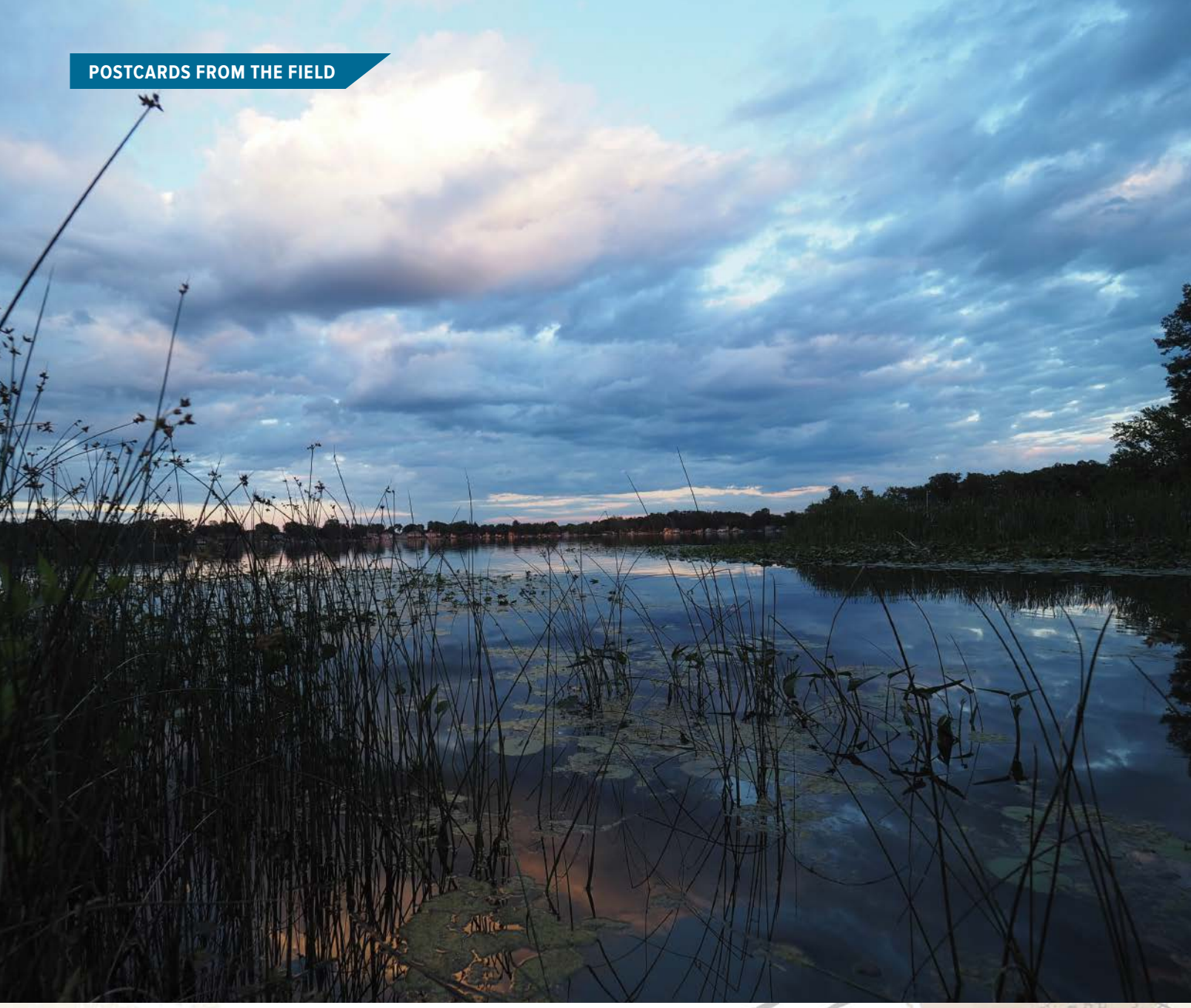
SUSTech (**http://www.sustc.edu.cn/en**) was founded in 2011 with public funding from the Municipal Government of Shenzhen. A thriving metropolis of over 20 million people bordering Hong Kong, Shenzhen has often been referred to as the "Silicon Valley of China" with strong telecommunication, biotechnology and pharmaceutical sectors. Widely regarded as a pioneer of higher-education reform in China, SUSTech aims to become a top-tier international university that excels in interdisciplinary research, talent development and knowledge discovery. In the latest Times Higher Education (THE) World Universities Rankings 2019, SUSTech was included for the first time and ranked as the 8th among the mainland China universities.

Internationalization is a hallmark of SUSTech where English is a primary instructional language.

The SUSTech | School of Environmental Science and Engineering (ESE) (**http://ese.sustc.edu.cn/en/**) was established in May 2015. The mission of ESE is to become: an innovative training ground for cultivating top talent in environmental fields; an international center of excellence for environmental research; a leading platform for innovation and industrialization of advanced environmental protection technologies; and an influential think-tank for environmental sustainability. Currently, ESE has over 50 full-time faculty and research staff, including the recipients of numerous national and international awards and honors. ESE is organized into three broadly-defined groups (programs): Environmental Science/Engineering/Health; Hydrology and Water Resources Engineering; Global Environmental Change and Management. Major areas of research represented by the existing faculty include: watershed hydrology and biogeochemistry, soil and groundwater contamination and remediation, environmental health risk assessment and interventions, environmental microbiology and biotechnology, atmospheric chemistry and air pollution control, solid waste recycling and management, remote sensing of the environment, macroecology and biodiversity, global change and environmental sustainability. ESE is planning to fill additional two dozen tenure-track/tenured positions over the next 3-4 years to enhance and expand existing faculty and research strengths. The school is home to the State Environmental Protection Key Laboratory of Integrated Surface Water-Groundwater Pollution Control as well as the Shenzhen Institute of Sustainable Development.

The ideal candidate will provide vision and strategic and intellectual leadership for ESE while promoting excellence and collegial work environment within the ESE and across the university. The dean will advance and accelerate research, innovation and education in the school and facilitate collaboration across the campus as well as nationally and internationally. Qualified candidates must have an earned doctorate in environmental science/engineering, geoscience, or a related discipline; a distinguished record of scholarly achievements that meet the standards for a tenured appointment at the full professor level in ESE; a record of sound leadership and administrative accomplishment; and a familiarity with both international and Chinese higher education systems.

All inquiries, nominations, and applications are invited. Applicants should e-mail a comprehensive curriculum vitae and detailed letter of interest along with the contact information of five references to ESE Dean Search Committee Chair, **iese@sustc.edu.cn**. The position will remain open until filled, but for fullest consideration, applicant materials should be received as soon as possible and no later than **May 1, 2019**.



Hello, AGU!

Just back from a long day in the field. We've been running a seismic survey of Pretty Lake in Indiana for a summer research project to complement some continuing paleolimnological analyses. The field crew managed to get the gear broken down and packed back into the trailers just as the Sun was setting. Now it is time to go rehydrate. Wish you were here!

—Jeffery Stone, Department of Earth and Environmental Systems, Indiana State University, Terre Haute

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"The **more** opportunities there are to get **students involved**, the more you will **encourage** previously unreached and **unrepresented groups** to join the Earth and Space science community."

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