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EOS

Earth & Space Science News

100 YEARS

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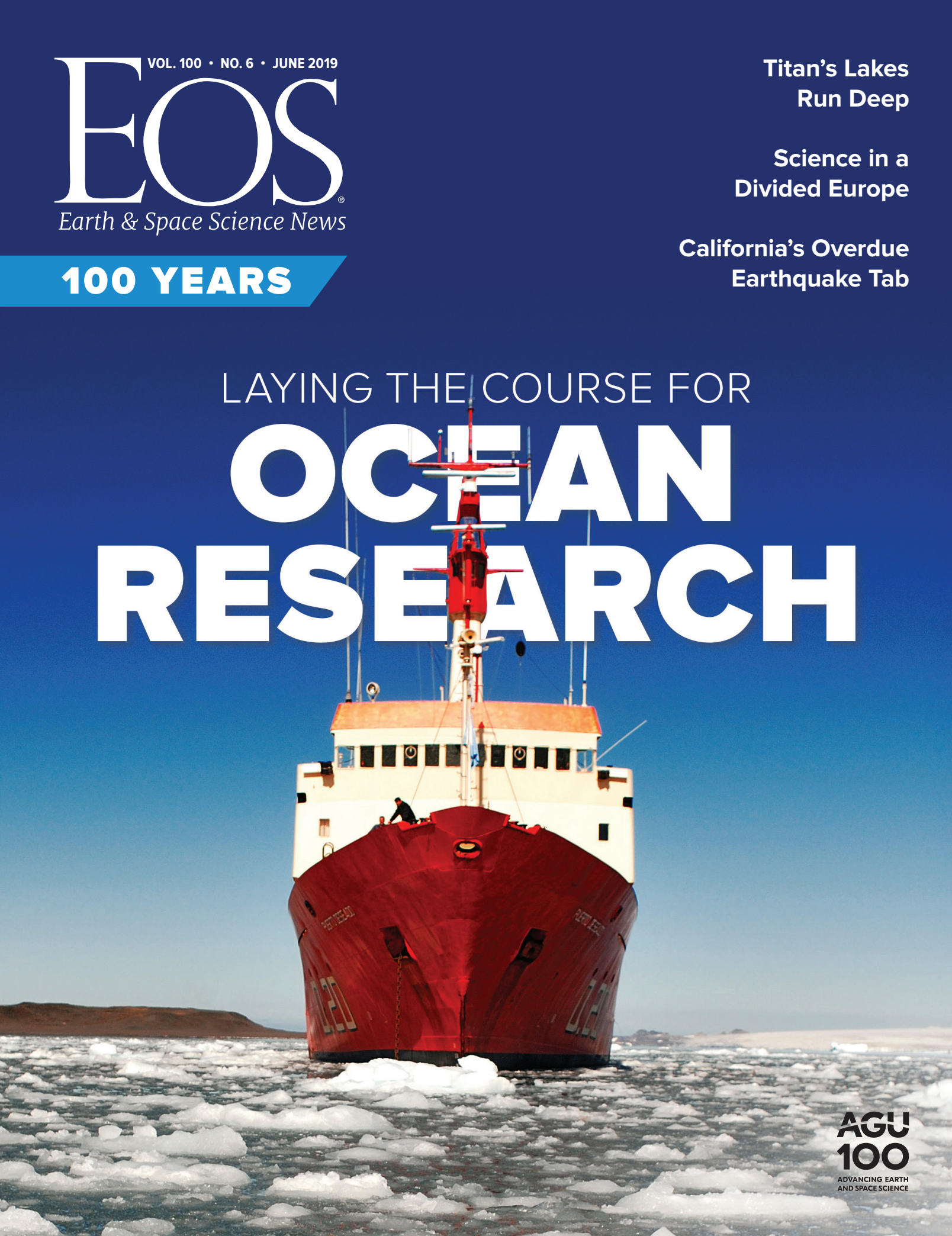

AGU 100

ADVANCING EARTH AND SPACE SCIENCE

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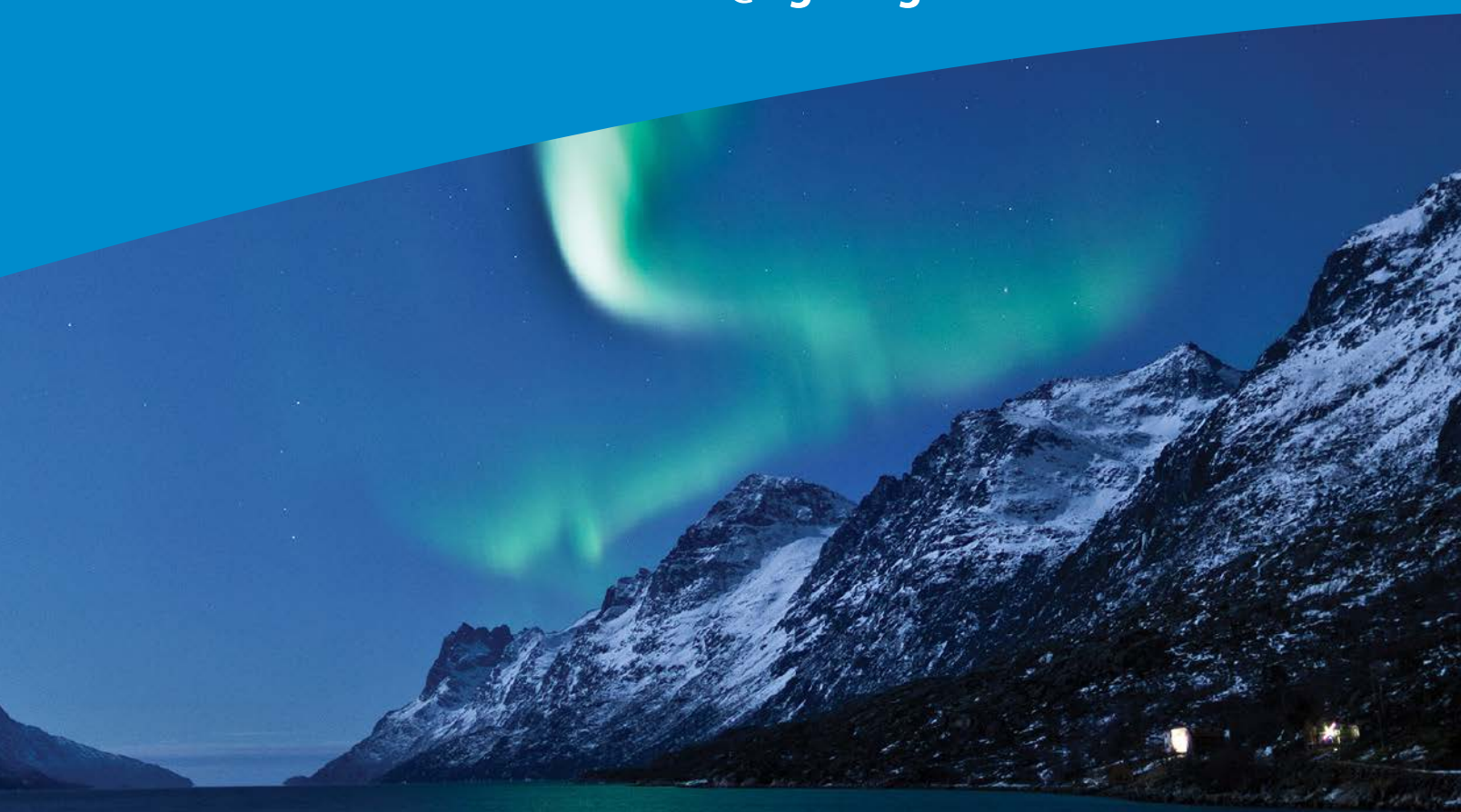

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Science in the Deep

Maurice Ewing was blowing things up in the name of science. With a little dynamite, the Lehigh University physics professor spent all the time he could find developing field experiments—specifically, ones using seismic waves to study subsurface geology. In 1934, he was approached by a couple of geologists who urged him to use his techniques to study the seafloor. Eager for any opportunity to probe Earth, Ewing and his explosions pioneered an entirely new way to study the oceans.

Ewing went on to have a distinguished career, including 25 years as director of the Lamont-Doherty Earth Observatory, where he lifted up the entire field of oceanography with his insight into instrument development. Ewing served as AGU's president in the late 1950s, and since 1976, AGU has awarded a medal in his honor, recognizing significant original contributions to ocean science. This month, as we continue to celebrate our Centennial, *Eos* is recognizing the ongoing contributions by those who study Earth's massive, interconnected ocean systems.

Scientists in Australia are building on nearly a century of seafloor mapping progress that began with Ewing, using modern techniques to create an entirely novel marine habitat map. On page 22, read about how the team at Seamap Australia is using high-resolution bathymetric data to extract information about seafloor geomorphology and using it to visualize which reefs, sea grasses, and other habitats need the most protection. This isn't just about doing the science; it's about the heavy lifting of coordinating efforts across a continent to collect the data and develop a scalable, usable tool. That tool is already helping, the team writes, to "inform policies for a well-functioning ocean, one of the two major goals of the United Nations Decade of Ocean Science for Sustainable Development, which supports the 2030 Agenda for Sustainable Development."

Studying our vast oceans demands innovation. When oceanographers needed a way to study deep-sea currents, they had to stray from techniques such as using satellites and surface floats. In the 1970s, scientists developed a way to track acoustic floats over long ranges, enabling them to make long-term observations under the surface. Today fleets of these acoustic floats are anchored underwater and ballasted to drift at a certain pressure or density within a region for years before being released to the surface to send their data to a satellite for collection. These float studies have revealed a wealth of information about the complexity of deep-sea currents around the world—that archive of information has been collected into a new database, which you can read about on page 34.

Getting these instruments out into remote areas of the ocean is a major challenge to surmount before the science can even start. In our cover story, on page 28, a group of oceanographers reports on their recommendations to make everyone's lives a bit easier when planning research cruises. They offer new protocols for navigating the increasingly complex coordination of large and diverse teams of scientists with governments around the world—on top of the typical challenges of sourcing a vessel, crew, and funding. As the authors write, "Collaboration continues to be a hallmark of U.S. oceanographic research," and building on those skills to streamline access to research cruises will lay the course for the future of the field.

This month we look closer at the scientists whose creativity (and, in Ewing's case, explosive innovation) has allowed us to know the oceans much more intimately than a glimpse from the shoreline. Our observations into space so far have shown us just how rare and special our oceans are. Every day, oceanographers look into the deep to show us again.

Heather Goss, Editor in Chief

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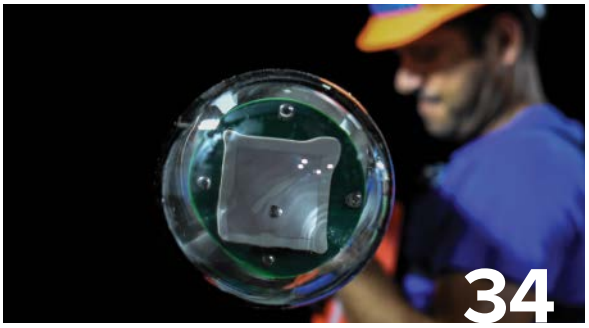

Cover Story

On the Cover

Argentina's oceanographic ship ARA *Puerto Deseado* near the South Shetland Islands in Antarctica

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Global Tree Cover Loss Continues but Is Down from Peak Highs

The World Resources Institute's Global Forest Watch released new data on 25 April about global tree cover loss. Pictured are agricultural fires in Sumatra, Indonesia. The image was acquired on 10 September 2015 and is made available through a partnership between Global Forest Watch Fires and DigitalGlobe. Credit: World Resources Institute

The world lost 12 million hectares of tropical tree forest cover in 2018. That's a loss the size of Nicaragua and a rate of 30 football fields every minute, according to data announced in April by the World Resources Institute's (WRI) Global Forest Watch.

Among the tree cover lost were 3.64 million hectares of primary rain forest, which had not been cleared or regrown in recent history. That's an area the size of Belgium.

The losses of tropical tree cover are sharply down from 2016 and 2017, when forest fires swept through Brazil, but still represent a gradual increase since record keeping began in 2001. The loss of tropical primary forest also is sharply down from 2016 and 2017 and is almost unchanged since 2001.

"It's really tempting to celebrate a second year of decline since peak tree cover loss in 2016, but if you look back over the last 18 years, it's clear that the overall trend is still upward," according to Frances Seymour, a senior fellow at WRI, a Washington, D.C.–based global research organization. Seymour, an authority on forest and governance issues, was among the experts who announced the new data at a briefing.

"We are nowhere near winning this battle" to halt forest loss, despite some progress in forest monitoring and protection efforts in Indonesia, Brazil, and other countries, Seymour said. "The world's forests are now in the emergency room. Even though they are recovering from extensive burns suffered in recent fires, the patient is also bleeding profusely from fresh wounds. It's death by a thousand cuts."

> "We are nowhere near winning this battle."

The data derive from the University of Maryland's annual tree cover loss data set, which measures the complete removal of tree cover canopy in 30- × 30-meter pixels, according to WRI. That measurement does not differentiate between permanent and temporary land cover change or between natural and human causes of the loss.

> "Continued tropical forest loss pulls the rug out from under efforts to stabilize the global climate."

Why the Forest Loss Matters

"Continued tropical forest loss pulls the rug out from under efforts to stabilize the global climate," Seymour said. She noted that forests store carbon in addition to providing habitat for numerous species and resources for people.

"For every area of forest loss, there is likely a species that's 1 inch closer to extinction," she said. "And for every area of forest loss, there is likely a family that has lost access to an important part of their daily income from hunting, gathering, and fishing."

Seymour added that forest loss also poses "an existential threat" to the cultures of indigenous people.

Countries with Big Forest Losses

The primary forest loss was less concentrated in 2018 than it had been in the past. In 2002, Brazil and Indonesia accounted for 71% of primary forest loss but made up just 46% of the loss in 2018. Instead, those two countries, along with the Democratic Republic of the Congo, Colombia, and Bolivia, accounted for more than two thirds of the loss in 2018.

In Colombia, the loss appears to be linked to land grabbing in the Amazon, as the peace process opened up lands previously occupied by the Revolutionary Armed Forces of Colombia (FARC) guerrilla movement, according to Global Forest Watch manager Mikaela Weisse. Forest losses in Bolivia are largely due to large-scale agriculture and pasture, and many of the losses in the Democratic Republic of the Congo are related to small-scale agriculture, Weisse said.

Brazil often is touted as a success story in reducing deforestation, with the country lowering the rate of deforestation by about 70% in

the early 2000s, Weisse noted. However, she said that although the country's primary forest loss of 1.3 million hectares in 2018 is less than the 2016–2017 fire-related spike, the losses otherwise are the highest for Brazil since 2006.

"It's too early to say whether this increase is related to Brazil's new administration," Weisse said. "Next year's data should give us a better idea." Brazilian president Jair Bolsonaro, who has indicated his support for expanded development in the Amazon, took office on 1 January 2019.

Other countries of concern include Ghana, where primary forest loss in 2018 jumped 60% higher than in 2017. Madagascar lost 2% of its primary forest in 2018, the most by percentage of any tropical country.

> "We know what to do to stop forest loss, but we're not doing enough of it."

Some Cause for Cautious Optimism

One bright spot appears to be Indonesia. Although Indonesia lost 340,000 hectares of primary forest in 2018, it was that country's lowest rate of loss since 2003. Reasons for this improvement include recent government policies about forest and peatland management, according to Belinda Arunarwati Margono, director of forest resources inventory and monitoring for the Indonesian Ministry of Environment and Forestry.

"We can expect dryer, more fire prone conditions in the 2019 El Niño year, a true test of how successful these policies are," WRI documents state.

Other causes for optimism include increased monitoring, protection, and enforcement measures, along with heightened concern among people in tropical countries about forest loss.

"Clearly, at the end of the day, the decisions about whether to continue allowing tree cover loss to take place [are] going to take place in the forest countries themselves," Seymour said. "And increasingly, there is an appreciation within those countries of why preserving the forest is important domestically."

She added, "We know what to do to stop forest loss, but we're not doing enough of it."

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

Satellite Imagery Reveals Plastic Garbage in the Ocean

Discarded plastics such as water bottles, fishing nets, and grocery bags have been identified in the far reaches of the ocean, both on the surface and in places as deep as the Mariana Trench.

Most of this garbage has been found laboriously: Cameras towed underwater have snapped images, and humans have peered over the sides of boats—or even swum through the debris.

Now scientists have used satellite imagery to pinpoint aggregations of floating plastic debris off the coasts of Scotland and Canada, a technique that opens up wide swaths of the remote ocean for analysis, the researchers suggest. Their results were presented in April at the European Geosciences Union General Assembly in Vienna, Austria.

Ben Mierement, NOAA NOS (ret.)

A New Application

Lauren Biermann, a marine satellite scientist at Plymouth Marine Laboratory in Plymouth, U.K., and her colleagues used imagery from the Sentinel-2A and Sentinel-2B satellites, platforms intended to image Earth's landforms. These satellites, orbiting roughly 780 kilometers above Earth, were never designed for marine applications, Biermann said. But their frequent overpasses—the satellites image the same patch of Earth every few days—and high spatial resolution (10 meters) make them perfect for imaging discarded plastics near coastlines.

Using sightings of plastic debris reported in the literature and on Twitter, the researchers focused on two areas: Gabriola Island, British Columbia, Canada, and the eastern coast of Scotland near Edinburgh. They collected Sentinel images of these regions and compared them with reference measurements of how water, floating plants (e.g., *Sargassum* seaweed), and plastics reflect and absorb light.

Biermann and her collaborators then estimated the relative contributions of these different materials to each pixel. Plastics exhibit a spectral peak in the near infrared, and vegetation emits at certain wavelengths because of its photosynthetic activity, said Biermann.

"There are distinct differences that we can use to determine what is what."

A Promising Monitoring Tool

Biermann and her colleagues inferred that aggregations of plastics—probably water bottles, polystyrene, and packaging—were present off the coasts of Canada and Scotland.

It's critical to do follow-up fieldwork to validate these findings, however, Biermann said. That's because one possible source of confusion might be marine creatures: Some of the plastic debris measured near Scotland might have instead been northern gannets, large seabirds common along the shorelines of the Atlantic Ocean.

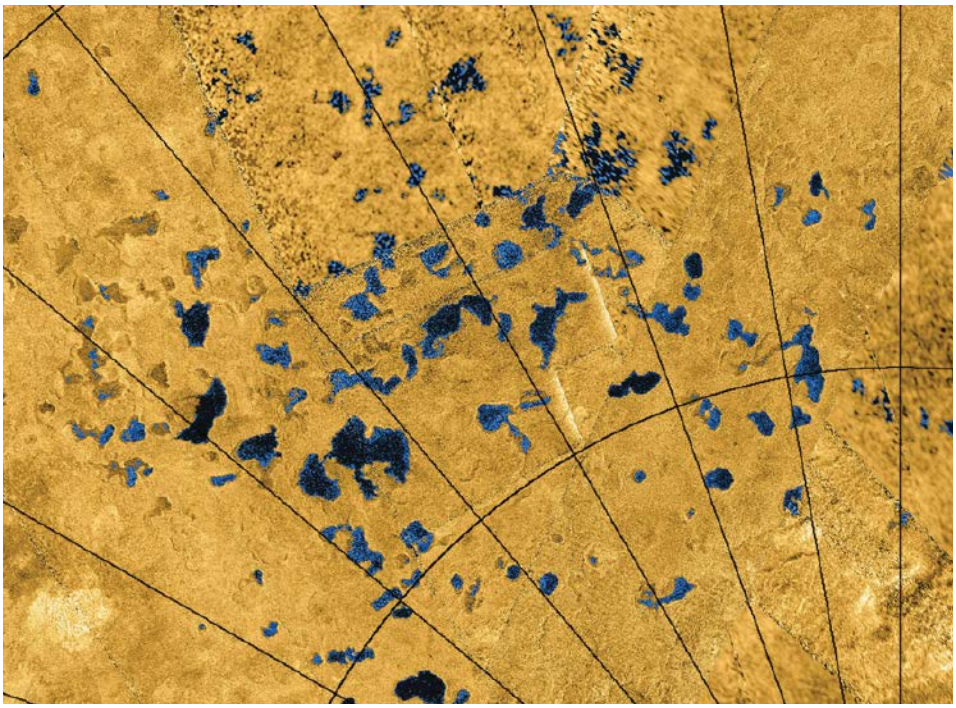
This work is promising, said Stefanie Rynders, an oceanographer at the National Oceanography Centre in the United Kingdom not involved in the research, but follow-on research is necessary. "Provided they can do the ground truthing, it will be a useful monitoring tool, for both natural ecosystems and man-made pollution."

In the future, Biermann and her colleagues hope to automate their analysis. Right now it takes half a day to manually process a single image, she said. By developing an algorithm to pinpoint pixels that likely contain plastics, this work could be expanded to encompass coastal regions around the world.

"What we'd like to do eventually is build a global hot spot map," said Biermann.

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

Titan's Northern Lake District Has Hidden Depths



A radar map of the lake district near Titan's northern pole. These data from NASA's Cassini spacecraft are falsely colored to highlight areas with liquid hydrocarbons on the surface (blue-black) and areas that are dry (tan) and are overlaid with a geographic grid (black lines). Credit: NASA/JPL-Caltech/ASI/USGS

Titan's north pole is home to the majority of its lakes and seas. Recent analysis of data collected by NASA's Cassini spacecraft revealed that these lakes rest high above sea level yet plunge deep, are filled with methane, and may change with the seasons.

"These new measurements help give an answer to a few key questions," Marco Mastrogiuseppe, a planetary scientist at the California Institute of Technology in Pasadena, said in a statement about the discovery. "We can actually now better understand the hydrology of Titan."

Mastrogiuseppe is the lead author of a 15 April paper in *Nature Astronomy* that discusses the lakes' elevation, depth, and composition (bit.ly/titan-lakes). Another paper, led by Shannon MacKenzie, in the same journal shows how a few northern lakes seemed to disappear as spring set in (bit.ly/seasonal-surface).

"One possibility is that these transient features could have been shallower bodies of liquid that over the course of the season evaporated and infiltrated into the subsurface," MacKenzie, a planetary scientist at the Johns Hopkins University Applied Physics Laboratory in Laurel, Md., said in a statement.

Sounding It Out

During its flybys of Saturn's largest moon, Cassini used its radar instrument to sound out how deep the northern hemisphere lakes are and determine their composition. Mastrogiuseppe's team confirmed for the first time that the northern lakes are primarily filled with liquid methane—about 70%—which had not been directly measured before.

This composition is starkly different from the composition of the only major lake in the southern hemisphere, Ontario Lacus, which is mostly filled with liquid ethane.

The radar data also revealed that Titan's lakes sit hundreds of meters above sea level and that some are more than 100 meters deep. With lake beds so high above sea level, these lakes must be replenished by rainfall, not subsurface liquid flow, the team argues.

"Every time we make discoveries on Titan," Mastrogiuseppe said, "Titan becomes more and more mysterious."

Phantom Lakes

Although some of Titan's northern lakes stretch deep below ground, others seemed to come and go.

MacKenzie and her team identified lakes seen in radar data collected during Titan's winter. Infrared data taken 7 Earth years later, after Titan's vernal equinox, showed that three of those were no longer consistent with having surface liquid.

The researchers suggested that these "phantom lakes" were merely shallow ponds during winter. As Titan warmed into spring, either the ponds quickly evaporated—maybe because the liquid was more purely methane—or the liquid drained into the ground.

Either scenario would help scientists paint a fuller picture of Titan's "hydrologic cycle," which affects the moon's subsurface geochemistry, seasonal weather, and climate evolution.

"MacKenzie et al. suggest lake shoreline changes probably due to subsurface flow, and so do Mastrogiuseppe et al.," Rajani Dhingra, a recent Ph.D. from the University of Idaho in Moscow, told *Eos*.

Dhingra, who has studied Titan's precipitation and was not involved with this work, said that both studies "suggest the importance of subsurface flows and infiltration. The sad part is, we still have not constrained the infiltration rates on Titan," which a follow-up mission to Titan might measure, she added.

This study "shows the value of extending the Cassini mission beyond its initial 4-year lifetime to cover a substantial range of Saturn's seasonal cycle," Bonnie Buratti, a planetary scientist at NASA's Jet Propulsion Laboratory in Pasadena, told *Eos*. Buratti was not involved with this research.

One thing is clear, MacKenzie's team wrote: The phantom lakes don't last for long, so they probably have few nutrients and are unlikely to support life.

"The lakes may not be as habitable as thought," Buratti said. "If they dry up, there isn't time for organics to accumulate there."

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

Looking for Climate Solutions Down in the Dirt

Soil: It helps feed the world, but could it also help our efforts to keep it cool?

Soil is a store for carbon and moisture, and changing the way it is managed could help mitigate or even counteract global warming, according to two studies presented in April at the European Geosciences Union General Assembly in Vienna, Austria.

No-Till Farming

Hannah Cooper of the University of Nottingham in the United Kingdom is investigating the effect of no-till farming on the amount of carbon that is captured by the soil. No-till farming is currently used on about 10% of arable land worldwide.

Cooper took cores from 80 conventionally farmed fields in the United Kingdom's East Midlands region and from no-till fields right next to those. Some hadn't been under the plow for a few years; others hadn't been plowed for up to 15 years.

Cooper found that the nontilled soil after 1–5 years was less porous than tilled soil, and carbon content was about the same.

She found that water and roots after 5 years had an easier time penetrating nontilled soil, and it contained more carbon. The carbon was also increasingly bound in organic compounds, such as ethers and aromatics, which are less readily released into the atmosphere as carbon dioxide.

Combining these data with the release by the soil of nitrous oxide, another greenhouse gas, Cooper concluded that the emissions from no-till soil had a global warming potential that was almost 6 times lower than that of tilled soil.

Her results were met with a bit of skepticism by Dani Or, a soil scientist and environmental physicist at the Swiss Federal Institute of Technology in Zurich who was not involved with the study.

"I would say that no-till has tremendous ecological justification, and when it works, it is actually a good thing. The problem is that it is not a solution for all climates, or all soils, or all crops," Or told *Eos*. "I'm sure their work is very good. But the climate in the U.K. and the climate in the Sahel are quite different—there is a danger of generalization."

On the other hand, Or said, "People have been plowing their field to change the structure from the dawn of civilization. The tillage of arable land is probably the biggest civil engineering operation on the planet, year by year. And yet the scientific basis for why we do it and what benefit it derives is very vague."

Radical Climate Modeling Around Irrigation Practices

Whether soil is tilled or not tilled, the climate might benefit enormously by irrigating as much as possible, diverting all available water for that purpose, said Thomas Raddatz, a meteorologist at the Max Planck Institute for Meteorology in Hamburg, Germany.

Raddatz is not really proposing that, he reassured his listeners at the conference, but he did it in a computer model of the climate to see what effect irrigation may have on the climate now and in the future.

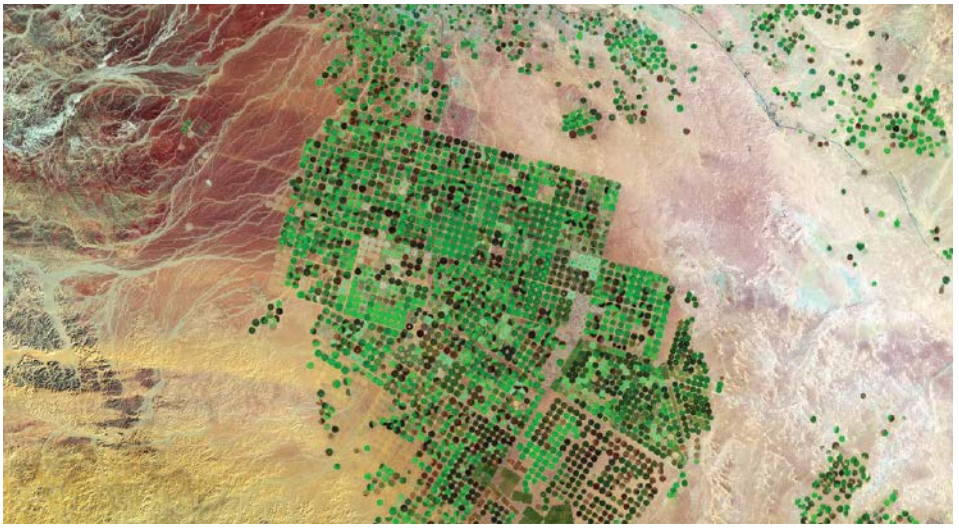
In Raddatz's experiment, in a model of the world not yet burdened by human-triggered greenhouse gas emissions, he diverted all available water on all landmasses to reservoirs, from which it was gradually released onto the local soil. To do all that, 41,000 cubic kilometers of water were needed each year, 50 times the amount used for irrigation today.

Surprisingly, Raddatz told *Eos*, diverting all that water didn't mean that rivers stopped flowing. "You bring the water to the surface of the land, this enhances infiltration, and after some time you have more drainage again, and you pump this water back to the reservoir. So you cycle it probably several times until it is evaporated to the atmosphere. And even then, for large parts of the Northern Hemisphere, you still keep it likely on the continent, because you also enhance precipitation."

The global effects of this radical piece of geoengineering would be impressive. The evaporating water takes heat from the surface, causing a 2.1°C cooling over land. Once in the air as vapor, the water acts as a greenhouse gas but also ends up in clouds that radiate energy into space as infrared radiation. On balance, there is a global cooling of 1.1°C and an increase of 2.5 million square kilometers in sea ice in the Arctic. Raddatz also notes a strengthening by 15% of the Meridional Overturning Circulation, the current in the North Atlantic that has a strong influence on Earth's climate and is thought to be vulnerable to global warming.

Raddatz said that attention must be paid to the climate-related consequences of policies that involve irrigation. This concern is motivated by runs of his model in which only some parts of the world were irrigated.

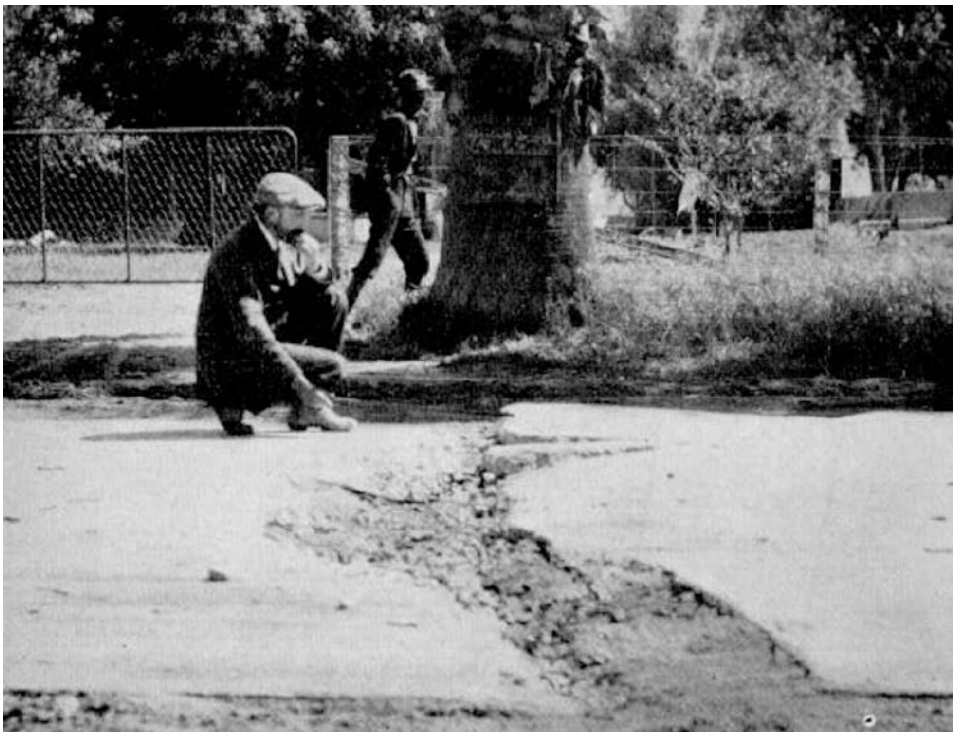
"If the [European Union (EU)] decides to have a massive irrigation program, to increase crop yields, to grow biofuels to reach carbon targets, to develop rural areas, they may conclude it is cost-effective. So over decades, you increase irrigation," Raddatz explains. "But it turns out this decreases the precipitation in the Sahel by 100–200 millimeters per year. Then we have a large catastrophe there. And all these 300 million people living there will try to come to the EU. So no one profits. We should care about this, before we do it."



Irrigation policies and methodologies may have already had an impact on climate. This satellite image focuses on irrigation-created "crop circles" in the Saudi Arabian desert. Credit: NASA Earth Observatory image created by Robert Simmon and Jesse Allen using Landsat data provided by the U.S. Geological Survey

By **Bas den Hond,** Freelance Journalist

Reassessing California's Overdue Earthquake Tab



A man examines concrete ruptured by a magnitude 6.7 earthquake on the San Jacinto Fault on 21 April 1918. Credit: Frank Rolfe

In 2018, California passed a portentous milestone: It had been 100 years since the last major earthquake struck one of the state's three most notorious faults. Now a study analyzing paleoseismic records along the San Andreas, San Jacinto, and Hayward Faults has shown that the 100-year earthquake hiatus is unprecedented in the past 10 centuries.

At a Seismological Society of America conference in 2014, University of California, Los Angeles geophysicist David Jackson presented a talk cleverly titled "Did Somebody Forget to Pay the Earthquake Bill?," which called attention to the lack of major seismic activity at paleoseismic sites around California. At the time, Jackson suggested that the gap could be a normal statistical occurrence if paleoseismologists had systematically overestimated the number of past earthquakes.

Paleoseismic records are gleaned by digging shallow trenches that expose scars from past earthquakes that have ruptured from the depths of a fault to the surface.

To determine the likelihood of a 100-year hiatus, Glenn Biasi and Katherine Scharer, both at the U.S. Geological Survey (USGS) in Pasadena, Calif., analyzed previously published paleoseismic records from 12 locations along the San Andreas, San Jacinto, and Hayward Faults. They found that the hiatus is highly unlikely, with a 0.3% chance of being a statistical fluke.

"Statistically speaking, this outcome is highly improbable," Biasi said. "It suggests that there must be some Earth system properties at work that we don't fully understand yet."

This study "suggests that there must be some Earth system properties at work that we don't fully understand yet."

The study, published in *Seismological Research Letters* in April (bit.ly/SRL-hiatus), does not attempt to explain the hiatus.

Biasi said that one possible explanation is that the eight major earthquakes that occurred between 1800 and 1918 may have relieved all the accumulated strain and set the faults up for a quiet century.

Another possible explanation is that faults throughout the state may be more interconnected than we realize. "Last century, all these faults ruptured together, and now they're all being quiet together," Biasi said.

Earthquake Forecasts

It's unlikely that the new study will affect current earthquake forecasts for the next century, said Ned Field, a geophysicist at the USGS Geologic Hazards Science Center in Golden, Colo., who was not involved in the study.

"I don't think anybody would say this overturns the practical implications of our latest model, but it does point out there might be something missing in our understanding of this system as a whole," Field said.

One possible impact could influence the Uniform California Earthquake Rupture Forecast, Version 3, developed by Field and used by the USGS to model hazard estimates for the state. The forecast does not take into account the relationships between parallel, adjacent faults, like the San Andreas and Hayward.

"If you have a big earthquake on the San Andreas, another fault that parallels it could be shut down in a way that the model doesn't presently acknowledge," Field said.

"Given what we know of the last 1,000 years of activity along these faults, it's likely that the next century is going to busier than this last century," Biasi said.

The long-term averages suggest that around three to four major ground-rupturing events should occur throughout the state each century. "These averages mean that the system has some catching up to do, but we don't know where or when that will happen," Biasi said.

"We've already lived through a 100-year hiatus," Field said. "Our models include the possibility that California could come out of it with a vengeance."

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

National Volcano Warning System Gains Steam

More than three of every four U.S. volcanoes that have erupted in the past 200 years are in Alaska (including Mount Redoubt, above). Credit: R. Clucas, USGS

Early in the morning on 17 May 2018, Hawaii's Kīlauea volcano unleashed a torrent of ash more than 3,000 meters into the sky. The explosion was just one noteworthy event in a months-long series of eruptions that destroyed more than 700 homes and caused $800 million in damage. Remarkably—thanks in large part to the relentless monitoring efforts of scientists at the Hawaiian Volcano Observatory (HVO)—no one died as a result of the destructive eruption sequence, which lasted into August.

Across the country in Washington, D.C., Senate lawmakers happened to meet that same day to vote on a topical piece of legislation: Senate bill 346 (S.346), the National Volcano Early Warning and Monitoring System Act. The Senate passed the bill by unanimous consent, marking a big step forward for a piece of legislation more than a decade in the making.

The bill seeks to strengthen existing volcano monitoring systems and unify them into a single system, called the National Volcano Early Warning System (NVEWS), to ensure that volcanoes nationwide are adequately monitored in a standardized way.

After ultimately lacking the floor time in the House necessary for a vote before the end of 2018, the bill was reintroduced as part of a larger package of natural resources–related bills at the start of the new Congress, which convened in January. The John D. Dingell, Jr. Conservation, Management, and Recreation Act (S.47) contained elements of more than 100 previously introduced bills related to public lands, natural resources, and water. This bill quickly breezed through Congress and was signed into law by President Donald J. Trump on 12 March; it's now Public Law No. 116-9.

Although the bipartisan effort and the bill's other contents, including an urgent reauthorization of the recently expired Land and Water Conservation Fund, captured the media's attention, Section 5001, National Volcano Early Warning and Monitoring System, will have lasting effects on the nation's volcano hazard awareness and preparation.

Volcano Observatories

Only five U.S. volcano observatories monitor the majority of U.S. volcanoes, with support from the U.S. Geological Survey's (USGS) Volcano Hazards Program and independent universities and institutions. These observatories are the Alaska Volcano Observatory in Fairbanks; the California Volcano Observatory in Menlo Park; the Cascades Volcano Observatory in Vancouver, Wash.; HVO; and the Yellowstone Volcano Observatory in Yellowstone National Park.

Volcanologists at these observatories monitor localized earthquakes, ground movement, gas emissions, rock and water chemistry, and remote satellite data to predict when and where volcanic eruptions will happen, ideally providing enough time to alert the local population to prepare accordingly.

The USGS has identified 161 geologically active volcanoes in 12 U.S. states as well as in American Samoa and the Northern Mariana Islands. More than one third of these active volcanoes are classified by the USGS as having either "very high" or "high" threat on the basis of their hazard potential and proximity to nearby people and property.

Many of these volcanoes have monitoring systems that are insufficient to provide reliable warnings of potential eruptive activity, whereas at others, the monitoring equipment is obsolete. A 2005 USGS assessment identified 58 volcanoes nationwide as being undermonitored.

"Unlike many other natural disasters…volcanic eruptions can be predicted well in advance of their occurrence if adequate in-ground instrumentation is in place that allows earliest detection of unrest, providing the time needed to mitigate the worst of their effects," said David Applegate, USGS associate director for natural hazards, in a statement before a House subcommittee hearing in November 2017.

During the 2018 Kīlauea eruption, HVO, the oldest of the five observatories, closely monitored the volcano and issued routine safety warnings. However, many volcanoes lack the monitoring equipment or attention given to Kīlauea. Of the 18 volcanoes identified in the USGS report as "very high threat," Kīlauea is one of only three classified as well monitored (the other two are Mount St. Helens in Washington and Long Valley Caldera in California).

Public Law No. 116-9 aims to change that. In addition to creating the NVEWS, the law authorizes the creation of a national volcano watch office that will operate 24 hours a day, 7 days a week. The legislation also establishes an external grant system within NVEWS to support research in volcano monitoring science and technology.

Volcanic Impacts

Since 1980, there have been 120 eruptions and 52 episodes of notable volcanic unrest at 44 U.S. volcanoes, according to the USGS Volcano Hazards Program. The cataclysmic eruption of Mount St. Helens in 1980 was the most destructive, killing 57 people and causing $1.1 billion in damage.

Although active volcanoes are concentrated in just a handful of U.S. states and territories, eruptions have the potential to pose significant security and economic threats across the nation. A 2017 report by the National Academies of Sciences, Engineering, and Medicine concluded that eruptions "can have devastating economic and social consequences, even at great distances from the volcano."

In 1989, for example, an eruption at Mount Redoubt in Alaska nearly caused a catastrophe. A plane en route from Amsterdam to Tokyo flew through a thick cloud of volcanic ash, causing all four engines to fail and forcing an emergency landing at Anchorage International Airport. More than 80,000 aircraft per year, carrying 30,000 passengers per day, fly over and downwind of Aleutian volcanoes on flights across the Pacific. The potential disruption to flight traffic as well as air quality issues from distant volcanoes pose serious health and economic risks for people across the United States.

"People think they only have to deal with the hazards in their backyard, but volcanoes will come to you," said Steve McNutt, a professor of volcano seismology at the University of South Florida in Tampa.

National Volcano Early Warning and Monitoring System Act

Passage of Public Law No. 116-9 authorizes funding for the implementation of the NVEWS. The bill recommends that Congress, during the annual appropriations process, appropriate $55 million to the USGS over fiscal years 2019–2023 to carry out the volcano monitoring duties prescribed in the bill.

The bill was introduced by Sen. Lisa Murkowski (R-Alaska), first elected in 2002 and consistently the most steadfast champion of NVEWS legislation. Her home state of Alaska contains the most geologically active volcanoes in the country, and more than three of every four U.S. volcanoes that have erupted in the past 200 years are in Alaska. Often in concert with Alaska's sole House representative, Don Young (R), Murkowski has introduced volcano monitoring legislation in nearly every congressional session since her election. Five bills over the past decade have stalled in committee without reaching the floor for a vote.

"Our hazards legislation has become a higher priority because we realize that monitoring systems and networks are crucial to ensuring that Americans are informed of the hazards that we face," Murkowski said in a speech at AGU's Fall Meeting 2018 in Washington, D.C., last December. "They help us prepare and are crucial to protecting lives and property."

By **Forrest Lewis,** Science Writer

A United Europe Benefits Global Science

Flags of European Union member states stand in front of the European Parliament building in Strasbourg, France. Credit: iStock.com/AdrianHancu

European geoscientists recently called for integration and cooperation between member states of the European Union (EU) to benefit global scientific research and progress.

At a 10 April session at the European Geosciences Union (EGU) General Assembly in Vienna, Austria, scientific and political leaders spoke about mounting threats to scientific progress and how a lack of European unity could damage research and researchers alike.

The looming specter of the United Kingdom's exit from the EU in October, the rise of populism in the United States and elsewhere, rampant proliferation of fake news, and growing attacks on scientific credibility could interrupt the EU's "virtuous circle" of economic growth and scientific discovery, according to former Italian prime minister Mario Monti. Monti also served as a European commissioner from 1995 to 2004.

"We may witness an undoing of the formerly virtuous circle into a potentially vicious circle, where the forces at play—followership, short-termism, personal interest, rejection of competence, fake news, fake history, and social media—may bring…authoritarian or slightly more demagogic organizations of power at the national level," Monti said during the session.

"The next victim, I'm afraid, is going to be you, that is, science," Monti said, "because there was once upon a time, and there still is, a very virtuous circle between Europe, European integration, and science."

Following the conference session, the EGU Council released a statement saying that "the EGU firmly believes that threats to a united Europe are threats to scientific research."

> "Populism and science are completely incompatible."

Decrying Populism

"Populism and science are completely incompatible," virologist Ilaria Capua said during the session. Capua was a member of the Italian Parliament from 2013 to 2016 and is a professor at the University of Florida in Gainesville. "Your decisions or opinions are more

linked to your emotions and not to facts. And we know that science doesn't work like this."

Populistic politics tries to appeal to average citizens who feel that their concerns are neglected in favor of those of elite groups. This, in and of itself, isn't bad, Monti said. "In most cases, [populists] point to really existing problems. I happen to believe that in 98% of the cases they come to wrong or impracticable or counterproductive solutions."

For example, Monti said that populism promotes closing national borders and restricting the outward flow of information as economic conditions worsen domestically. However, doing so also restricts the flow of scientific information, limits researchers' access to resources and equipment beyond their borders, and stymies scientific developments that might stimulate economic growth.

"To tackle the greatest challenges that we face such as antibiotic resistant bacteria, climate change, energy, [and] food and water security, the scientific community within Europe needs to work together, pooling complementary skills, expertise and infrastructure, and share data and information within an open and unified environment," according to the EGU statement.

Mario Monti speaking during a 2003 news conference in Brussels, Belgium, during his time as a European commissioner. Credit: danacreilly, CC BY 2.0 (bit.ly/ccby2-0)

Ilaria Capua is a virologist and former member of the Italian Parliament. Credit: Ilaria Capua

Fighting Attacks on Facts and Science

"As a virologist," Capua said, "I can tell you that I am very, very concerned of the next threat that is going to become viral. And this threat is the fake news threat for science."

Capua cited the antivaccination movement, protests against necessary animal trials, and misleading information campaigns about disease outbreaks as examples of fake news that directly hinders scientific progress and puts people's lives at risk.

"There is an industry out there, ready to make noise about whatever they dislike," she said. "And this industry has a very clear objective. And the objective is to change opinions and to make money."

"Despite communication being very easy today, so we have unprecedented opportunities to communicate, misconception and fake news have never been so high as well," said EGU president Alberto Montanari. "It's a contradictory setting."

Moreover, Monti and Capua explained, fake news catches on by using short and catchy—and also inaccurate—descriptions of scientific research, conclusions, or applications. Refuting those 5-second sound bites, Monti said, takes much longer and is not an effective method of defending the benefits of EU integration on science.

Capua has experience with how the fake news machine can personally affect researchers. In 2014, Capua learned that she was the target of a fake news conspiracy theory that accused her of deliberately causing international disease epidemics to profit from patented vaccines. Because of this attack, she faced invasive international investigation, damage to her scientific credibility, and the possibility of life imprisonment. She was cleared of all charges in 2016.

> "Thanks to the army of European scientists, the scientific advancements of Europe are one of the main products of European integration."

Her story, she said, is an extreme example of the attacks and gaslighting many climate scientists have faced for more than a decade.

"We were all brought together under one umbrella of European research," she said. "We need to prepare because attacks will come, and we need to develop strategies to maintain our credibility. And we need to find new ways to engage with the public."

"We cannot lose our credibility. We cannot. We must not," Capua urged.

Being Vocal Supporters of Integration

During the session, Günter Blöschl, a hydrologist at the Vienna University of Technology and a former EGU president, asked a question that is likely on many scientists' minds: "What can we as average researchers do to foster integration in our daily work?"

"It's very simple," Monti replied. "Be yourself and tell surrounding people who you are and how the EU relates to you and the aspects in your [research] activity."

Blöschl told *Eos* that after the session, Monti added that scientists should also be vocal about the benefits of an integrated Europe for their research. Blöschl said, "My reaction to this is that in simple answers there is often a lot of truth."

"I believe it is very important to promote Europe with the positives that Europe achieves," Monti said. "Thanks to the army of European scientists, the scientific advancements of Europe are one of the main products of European integration."

"And, of course," he added, "good education is of the essence because otherwise, electors will not make [informed] use of their electoral power, which may correspond to the political system delivering what they really care for."

What's at Stake

"The economic arguments are clear," the EGU Council stated. "For every euro invested in research and innovation, the return into the economy is multiplied by between a factor 6 to 8. Beyond the simple economic principles, it is also widely recognised that European Framework programmes provide a unique and critical mechanism for fostering and enabling trans-national collaboration on research and innovation."

Capua agrees. "What does European research do?" she asked. "It creates teams. It creates fantastic teams of people who worked together in the same place, or in another place in Europe, or in another place in the world."

"This is what European research does," she said. "It brings together an immense strength, love, and passion that we have in Europe for science. And it brings diversity. And this is what is empowered by our European research programs."

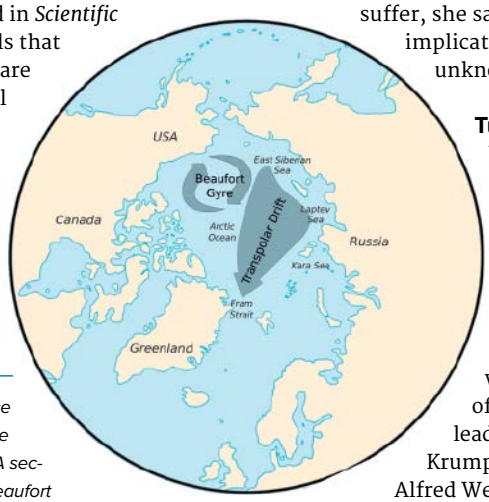
By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

The Ice Nurseries of the Arctic Are Melting

A crane lowers scientists from the icebreaker R/V Polarstern *to sample the surface of Arctic sea ice. The ice appears muddy in color because it was formed in shallow coastal waters. Credit: Alfred-Wegener-Institut/Rüdiger Stein*

Each winter, a cold, relentless wind blows over the northeastern coast of Russia toward the sea. The wind pushes sea ice away from land, opening up pockets for new ice to form. The process repeats endlessly, bringing fresh crops of sea ice out to the Arctic Ocean and feeding a slow migration of ice westward toward Greenland.

But a study published in *Scientific Reports* on 2 April reveals that warming temperatures are melting Russia's coastal "ice nurseries" faster than before (bit.ly/transpolar-drift). Some 80% of nursery ice melts before it joins the open ocean, compared with 50% before 2000.



The Transpolar Drift carries ice from the Russian shores to the Fram Strait near Greenland. A second major drift regime, the Beaufort Gyre, rotates near Canada and the United States. Credit: R. Botev, modified by T. Krumpen

Scientists worry that less nursery ice in the open Arctic Ocean could mean fewer nutrients for wildlife.

"Animals that rely on the food from sea ice will have trouble in the future," said coauthor Eva-Maria Nöthig, a scientist at the Alfred Wegener Institute in Germany. Polar cod is one example of a species that could suffer, she said, although the exact implications are still unknown.

Turbulent Seas

Don't be fooled by the name: Sea ice nurseries are chaotic places.

"In the Russian shelf seas, [ice formation] takes place over very shallow water, and there is lots of turbulent mixing," lead author Thomas Krumpen, a scientist at the Alfred Wegener Institute, told *Eos*. The mixing brings up sediment, dead organic matter, and pieces of tiny phytoplankton, all of which freeze inside the new sea ice.

The researchers wanted to know whether sea ice formed in nurseries was changing with thinning ice coverage in the Arctic, so they followed nursery ice movement over 20 years using satellite images. They also looked to see whether any nursery ice reached the Fram Strait, situated between Greenland and Svalbard at the end of the large Transpolar Drift, which sweeps ice across the Arctic.

The data showed that ice leaving the nursery had a 15% lower survival rate in open waters with each passing decade. Nursery ice that reached the Fram Strait, a journey that often takes 2 or 3 years, fell by 17% each decade.

But Krumpen warns against making assumptions about ice nurseries. "Some media stated that there's less ice being produced, but that's actually not the case," he noted.

Plenty of ice still freezes in the nurseries, but the sweltering summers melt the ice before it can travel far enough north to survive.

Eat Your Nutritious Sea Ice

The effects of fewer nutrients being transported offshore haven't been studied in detail yet, according to Nöthig.

"Who's winning and what this means for biodiversity, we don't know yet," she added.

> "Animals that rely on the food from sea ice will have trouble in the future."

Dorothea Bauch, a scientist at GEOMAR Helmholtz Centre for Ocean Research Kiel who was not involved in the study, said that less material transported by ice from the coastal regions could have "severe consequences" for biological systems. The latest study will allow researchers to "put a number to the projected changes," she told *Eos*.

The findings offer another piece of evidence for declining sea ice in the Arctic, a phenomenon Krumpen said he can see firsthand not only from his data but also from aerial flights over the Arctic.

"The Arctic Ocean is changing so rapidly, I can actually see it myself."

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

Let's Teach Scientists How to Withstand Attacks on Fact

iStock.com/IvelinRadkov

Science is always under pressure. Moderating the influence of personal, social, and political factors is pivotal for any scientific community to produce trustworthy knowledge from which society can benefit. Although the peer review technique is designed to rinse papers of such unwarranted influence, there are other forces posing a larger threat by exerting a more direct pressure on knowledge.

This threat is on full display whenever climate science is brought into the public sphere. For example, the production and the publication of the five Intergovernmental Panel on Climate Change reports have been accompanied by vitriolic attacks on climate science and individual scientists, underscoring that once scientific results interfere with any powerful group's interests, politicization is inevitable.

The late Stephen Schneider once asked whether the citizen scientist is an oxymoron [*Schneider,* 2000]. His central point was simple: Citizens are united by common values, and scientists are united by reasoning, which points toward common facts. Can a value-based entity share space with an entity devoted to fact if those values are at odds with fact?

Schneider argued convincingly that the term "citizen scientist" will become an oxymoron unless citizens differentiate between values and facts [see *Nature,* 2017]. With Donald J. Trump, Recep Tayyip Erdoğan, and Viktor Orbán in power, mentioning but three examples, Schneider's original question deserves a closer examination.

These three leaders came into office in part because of popular movements with values unmoored from fact. The leaders have, in turn, prioritized the reduction of scientific freedom, further fostering a culture in which reliance on fact is somehow considered unpatriotic. What now can people who identify as scientists and citizens do?

We contend that the answer involves rethinking how we educate future professionals. We need to imbue students with a central value: Adherence to the scientific method is, in itself, good citizenship.

The Trump Administration's Work to Make Facts Unpatriotic

The Trump administration's interference with how scientific synthesis and analysis are done is unprecedented [*Wagner et al.,* 2018]. Such attacks on the very nuts and bolts of science may even be a greater long-term threat than attempts to undermine science-based policy by implementing particular individual rules and policies [*Center for Science and Democracy,* 2017].

A recently proposed policy at the Environmental Protection Agency (EPA) is a case in point. The policy would effectively prevent the EPA from using most published medical research to inform decisions on rules aiming to protect human health from water, air, or chemical pollution. There are also unsettling examples of researchers receiving letters and subpoenas from members of the U.S. Congress attempting to intimidate scientists and politicize evidence-based science [*Halpern and Mann,* 2015; *Goldman et al.,* 2018].

In a survey carried out by the Union of Concerned Scientists, scientists at 16 federal agencies in the United States reported extensive political interference in their work [*Center for Science and Democracy,* 2018]. Responding scientists revealed that the term "climate change" is being censored at multiple agencies. At the National Park Service, where censorship of climate change was most likely, one respondent said they had been told to refrain from using the term "climate change" in internal project proposal and cooperative agreements.

Another report [*Carter et al.,* 2018] reveals chilling examples of attempts to suppress "politically inconvenient research" by censoring established climate science in press releases, preventing scientists from communicating their work, and ensuring that an appointee with a political rather than science background reviews scientific grants.

Not Just a U.S. Problem

In Europe, there are similar tendencies designed to undermine science's ability to distinguish values from facts. The recent eviction of the Central European University from Hungary [*Walker,* 2018], where it had resided since 1993, illustrates how critical science is threatened not by political extremists operating along the fringes of the political landscape but by extremists in power, in this case the prime minister of Hungary, Viktor Orbán.

In Turkey, students at Boğaziçi University in Istanbul were publicly denounced by the president himself, Recep Tayyip Erdoğan, for voicing critical opinions. Open attacks on academic freedom and what that entails send signals to students as well as professors that there are boundaries, and anyone crossing them runs the risk of being penalized. This was the case in 2016, when scholars were jailed and prosecuted in Turkey for signing a peace petition.

> Scientists revealed that the term "climate change" is being censored at multiple agencies.

Scientists Are Citizens Too

In these new political regimes, we must remind ourselves that scientists are also citi-

zens. The rapidly growing grassroots movements in science across the globe are seeking to do just that.

One example is AGU's Voices for Science, initiated in 2018, aiming to train scientists in the science policy process and to communicate science to the media and the public. Similarly, the European Geosciences Union has recently started a dedicated journal on geoscience communication. Although the latter is not focused on policy issues in particular or targeted exclusively to early-career scientists, it highlights that the scientific community increasingly recognizes the value of interaction with the public and policy makers.

Bateman and Mann [2016] claim that there is an urgency for scientists grabbing the reins themselves and showing leadership, but this requires both the scientist and the citizen to work in tandem. A group called 314 Action seeks to harness such partnerships; they're a grassroots initiative promoting evidence-based science, supporting science, technology, engineering, and mathematics (STEM) scientists interested in getting involved politically, and training researchers who want to communicate policy-relevant science more effectively.

The existence of these efforts suggests that an increasing number of scientists recognize the value and urgency of engaging with society on more than one level.

We find all these efforts encouraging, but more is needed if we are to successfully reclaim the idea that good citizens can engage in sound science.

We need a new frame of mind. We need to start equipping students with the tools they need to navigate the politicized terrain of their future scientific paths.

We need to start equipping students with the tools they need to navigate the politicized terrain of their future scientific paths.

Train Students to Be Prepared for Their Science to Get Politicized

With few exceptions, the emerging generation of scientists has not been trained in how to handle the direct and indirect pressure expertly exerted by stakeholders. Being trapped in a political power grip can be discouraging and potentially devastating for a young person in the starting blocks of a career. The worst-case scenario is that young and talented researchers bolt from potential careers in science because of such experiences.

Some effort has been made to bring into the classroom scientists who have sought more knowledge on the political process or who have themselves experienced the politicization of their work. But these examples so far are isolated off-campus initiatives found mostly in the United States rather than extensively implemented training opportunities for young scientists at universities worldwide.

Some coordinated efforts to bring these issues to university curricula do exist, and the Teaching GeoEthics Across the Geoscience Curriculum website provides a good starting point. However, the scale and severity of recent political interference call for action on a broader scale, going beyond the general ethics courses that many universities currently provide at the master's or Ph.D. level.

Without formal training, it is hard to safely navigate these increasingly politicized waters and to keep one's scientific integrity intact while interacting with society. As exemplified by the aforementioned surveys of U.S. federal scientists, such training is urgently needed for promising young professionals aiming at an academic career. Training in scientific integrity and how to handle political meddling is equally important for scientists heading to federal agencies, independent research institutes, and nongovernmental organizations and for those running for office themselves.

A New Platform

We foresee a visionary teaching platform addressing the challenges that come with scientific integrity in our new world. Such a platform, to our knowledge, has yet to materialize on a broader scale. One explanation is precisely the failure to recognize Schneider's oxymoron: It's only when we try to bridge the gap between science and society that we realize the pressure science is under, as well as its additional value.

An updated teaching platform for aspiring young scientists certainly aligns with the European Code of Conduct for Research Integrity [*All European Academies,* 2017], which states that research institutions and organizations should "develop appropriate and adequate training in ethics and research integ-

rity." Such training is desperately needed. In the United States, for example, at least 28 federal agencies have policies on scientific integrity in place to safeguard science from political interference and to protect scientists' rights. Federal scientists are generally well aware of these policies, yet only a minority of scientists would feel comfortable acting as a whistleblower should these policies be breached [*Center for Science and Democracy,* 2018].

Universities Should Rise to the Challenge

Last year we wrote "The Nordic Letter on Climate Action and Scientific Integrity" supporting American colleagues and urging the United States to comply with the Paris Agreement. Within weeks, nearly 500 scientists from all of the Nordic countries had signed the petition. Fortunately, many engaged climate scientists in the United States continue to enlighten a public served all kinds of preposterous allegations, but among colleagues there are also troubling signs that the new and hostile environment has quieted many.

Exactly how the next generation of scientists will handle a politically challenged environment remains to be seen. For this we cannot wait; universities need to equip tomorrow's leaders with the tools needed to excel in this new and daunting landscape.

Yet the challenge contains inherent pitfalls: University curricula define education and empower tomorrow's leaders, but universities are proud and old institutions that habitually are slow to change.

So let's use Schneider's oxymoron to our advantage. Our pride in our schools and in our fields unites us with common values. We know in our bones that universities have an obligation to prepare young scientists in how to guard their scientific integrity in all weathers. As citizens within a community of scientists, let's do what we can right now to protect future fact-based inquiry.

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Photo by Lija Treibergs; submitted by Adrianna Trusiak

Will the Desert Darken Your Door?

The desert has crept up on the town of Kolmanskop in Namibia. Credit: iStock.com/javarman3

Forests, while providing economic and recreational services, contribute to the climatic and hydrologic regulation of the landscape. Although fires are natural phenomena that contribute to the shaping of forest ecosystems, climate change exacerbates the threat of wildfires [*Westerling,* 2016]. A 2016 study reported that the burnt area in the northwestern United States expanded by almost 5,000% in the first decade of the 21st century relative to the years 1972–1983 [*Abatzoglou and Williams,* 2016].

Since records have existed, Earth's temperature has increased by more than 1° [*Intergovernmental Panel on Climate Change,* 2013]. However, temperature rise is just one of the many factors influencing wildfire risk. An add-on danger comes from extreme weather events, whether droughts or heat waves, earlier or later in the season in many regions of the world [*Stott,* 2016].

For example, in Spain, July temperatures in 2017 rose 3° above the average. Rains, when they arrive, are frequently late, sporadic, and torrential. Anomalous high temperatures, combined with recurrent and intense droughts, wreak havoc in the Mediterranean regions worldwide by extending the fire season to late autumn months.

Spain's drought, of course, triggered wildfires in the Iberian Peninsula. Similar droughts and wildfires have swept Mediterranean regions and burned unprecedented expanses of California, central Chile, South Africa, and elsewhere. In Iberia alone, the fires killed hundreds of people and displaced thousands of households in what Portugal's prime minister António Costa described as his country's "greatest human tragedy in the living memory."

Such linkages between drought and wildfires are well studied. But emerging research shows that there is more to that connection. The continuing and expanding cycle of wildfires may rapidly perpetuate arid conditions, transforming once lush landscapes into deserts before our very eyes.

Sound dramatic? It's happening right now, as you read.

Wildfire-Triggered Tipping Points

A discovery that has long intrigued ecologists is that ecosystems can quickly flip states of equilibrium [*Scheffer et al.,* 2001]. Wildfires are devastating environmental perturbations that can surpass evolutionary processes to keep pace with the rapidly changing conditions in the physicochemical and biological environment. And their effects can push ecosystems toward a critical tipping point of catastrophic loss of species and productivity.

The history of the Earth system indicates that abrupt environmental changes do occur. Just 5,500 years ago, giraffes, hippos, lions, and antelope roamed lands lush in vegetation and vast wetlands that today constitute the largest desert on Earth. However, the termination of this "green period" was abrupt, and within decades to centuries, the Sahara tipped to today's state of extreme aridity [*deMenocal et al.,* 2000].

Conceptual and empirical models of northern Africa support the existence of alternative stable ecosystem states [*Brovkin et al.,* 1998]. Right now, the ecosystem is in a "desert" system state with low precipitation and absent vegetation. But scientific evidence suggests that the region could maintain a "green" system state with moderate precipitation and permanent vegetation cover similar to what scientists know existed in the past. So how did northern Africa get to the state it is in today?

Although scientists attribute such transformations to natural climate change, the changes are most likely exacerbated by a terrestrial–atmospheric feedback loop of enhanced albedo and dust entrainment via excessive grazing and fire feedback mechanisms [*Wright,* 2017]. Such feedback mechanisms not only may reduce forest resilience but also can push the system closer to a point of irreversible damage [*Runyan et al.,* 2012]. And now the lone and level sands stretch far away.

Anthropocene's Collateral Damage

Mounting scientific evidence forecasts that environmental changes could be abrupt and, once certain limits are crossed, irrevocable. As in the history of the Sahara, the current massive destruction of forest and vegetation cover may well be the tipping point toward desertification and the deterioration in the quality of ecosystems and human life. Deforestation may lead to an increase in fire frequency, which in turn may inhibit the regrowth of forest vegetation [*Hoffman et al.,* 2003].

So how do we as a society realize that the costs of inaction on climate change are infinitely more expensive than those of prevention? It seems like an uphill battle: Throughout their brief history of life on Earth, humans have found that damaging the environment is far swifter than ecosystem recovery.

We live in the Anthropocene, when 7.5 billion humans have a common stake in the health of this planet. Hippocrates said that the greater the evils are, the more vigorous the remedy is. As this is our era, we should harness our numbers to fix it.

Some regions are doing just that, with ambitious projects to tackle desertification. India has shown the strength of cooperation as more than 1.5 million volunteers planted 66 million trees in just half a day, and similar planting efforts have been carried out in the Atlantic forest of Brazil and inner Mongolia [*Runyan and D'Odorico,* 2016].

We should take the spirit of those projects and amplify it to restore our historically degraded environments. The challenge of fires is shared across the landscape, so government plans should work in partnership with local organizations, private land managers, and stakeholders. Colleges, universities, agencies, and nonprofits should focus on restoring native forests and replacing fast growing invasive tree plantations that increase the risk and severity of wildfires [*Martinez-Harms et al.,* 2017].

It is no longer enough to appease our consciences by turning off the lights for 1 hour on World Environment Day or recycling or biking to work. We, collectively, must do more to actively repair the damage we have wrought.

Fight Catastrophe Fatigue

Today citizens may be weary of the catastrophic messages of scientists who predict ecological collapse. When faced with leaders who insist on believing that life is eternally resilient or become dazzled by globalized technology as the solution or simply flat out reject science, it's easy for the public to sink into indifference.

To fight this indifference, we as scientists need to show people the damage that's happening around them—not in some far-flung corner of the world or at an imperceptible molecular level in the atmosphere. We need to show them what's happening in their backyards, in their parks, around their schools. Landscapes are fundamentally altering as one wildfire season bleeds into the next.

California wildfires on 5 December 2017. Credit: MODIS on NASA's Terra satellite

Such alteration is something that people can see and touch and breathe [*Moritz,* 2012]. The tangible nature of this consequence of climate change may be vital to getting people to care. And once they care, perhaps they'll take action to recover our native forests, before the ash and desert dust darken future generations' doors too.

Acknowledgments

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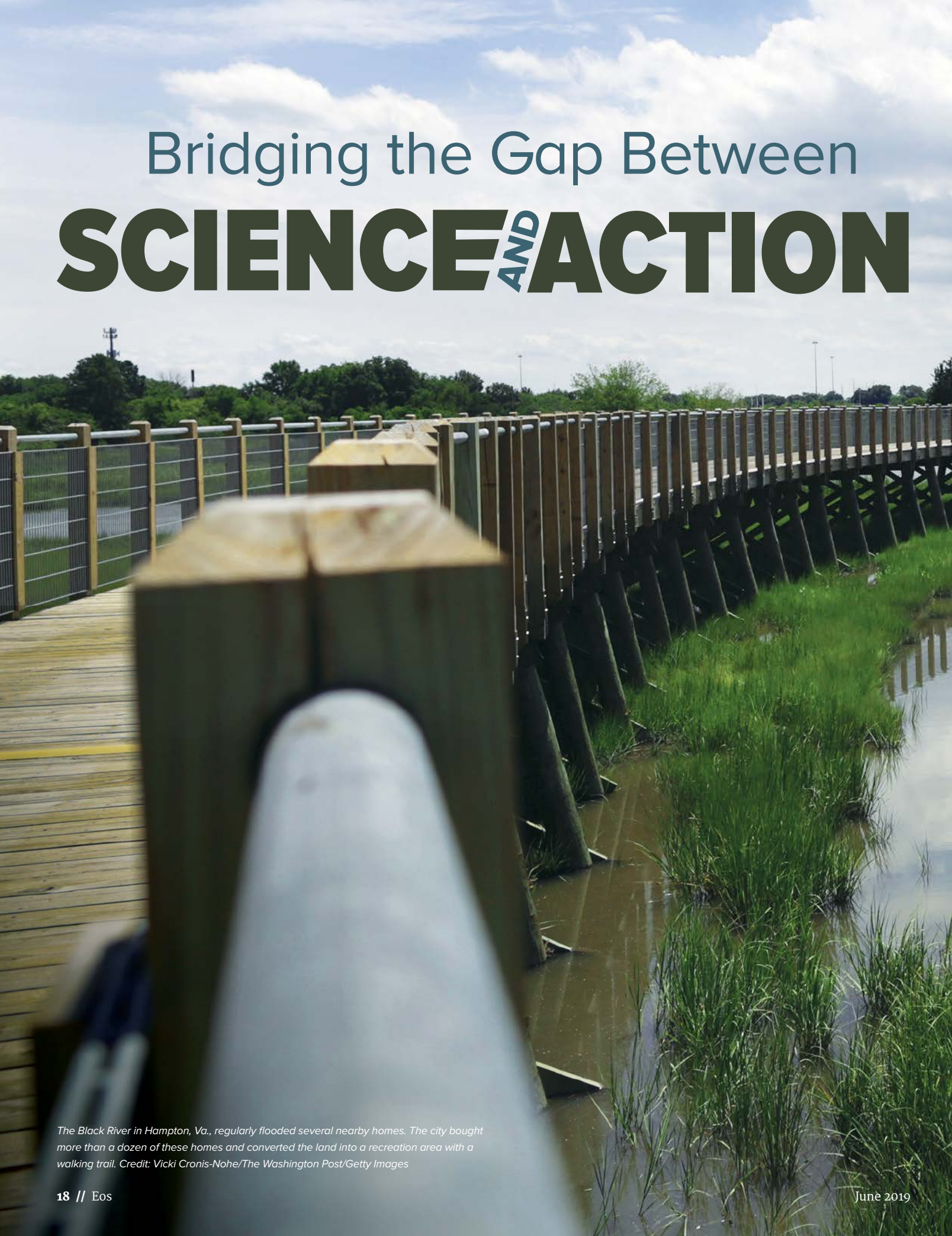
By **Manuel Villar-Argaiz** (mvillar@ugr.es), Departamento de Ecología, Facultad de Ciencias, Universidad de Granada, Granada, Spain

Bridging the Gap Between SCIENCE AND ACTION



The Black River in Hampton, Va., regularly flooded several nearby homes. The city bought more than a dozen of these homes and converted the land into a recreation area with a walking trail. Credit: Vicki Cronis-Nohe/The Washington Post/Getty Images

A new report identifies missing support that is slowing progress in limiting and adapting to climate change. The Science for Climate Action Network aims to provide it.

By Richard Moss, Bilal Ayyub, Mary Glackin, Alice Hill, Katharine L. Jacobs, Jerry Melillo, T. C. Richmond, Lynn Scarlett, and Dan Zarrilli

Evidence of the increasing pace and severity of the impacts of climate change is motivating local governments and communities to limit their carbon footprints and implement adaptation measures. In many locations, climate action plans are stalling, particularly in communities confronting such preexisting burdens as inadequate public health infrastructure and limited economic opportunity. New types of support are needed to accelerate progress, including technical guidance on how to use climate science to customize adaptation and mitigation strategies.

These are among the findings of a report released in April, Evaluating Knowledge to Support Climate Action. The report analyzes the types of support needed by communities and makes three main recommendations: (1) Establish a nonfederal network to assess how to apply science in making and implementing decisions, (2) focus these assessments on the common problems and challenges that climate risk managers face, and (3) use new methods such as artificial intelligence to support climate risk management. The report was prepared by the Independent Advisory Committee (IAC), a group of climate researchers; state, local, and tribal officials; and other experts. The group also included most of the members of a federal advisory committee that was dismissed by the Trump administration in 2017 and reconvened at the invitation of New York governor Andrew Cuomo, with support from Columbia University's Earth Institute, the New York State Energy Research and Development Authority, and the American Meteorological Society.

While the work of the IAC ended with the publication of the report, we—the authors of this *Eos*

article, including some members of the IAC—are taking immediate action on its recommendations by establishing the Science for Climate Action Network (SCAN). SCAN will coordinate preparation of applied climate assessments that evaluate the quality and usability of climate science to mitigate and manage climate threats. SCAN will serve as a backbone organization for groups that already are beginning to incorporate climate science in their work. It will facilitate collaborative learning, develop tested practices and authoritative data, and disseminate this information, with support, for user groups.

SCAN will build on the National Climate Assessments (NCAs) mandated by the Global Change Research Act passed by the U.S. Congress in 1990. Under the Act, the U.S. Global Change Research Program (USGCRP) has produced four NCAs, supplemental reports, and data that have clarified the economic, health, and environmental risks we face from climate change. The reports address such challenging topics as cascading impacts across interdependent infrastructure systems and provide increasingly high-resolution scenarios of climate parameters with more localized information. But the NCA reports stop short of delivering authoritative guidance on how to use that knowledge to address the risks they so clearly identify. SCAN can bridge this gap between knowledge and action by taking a sustained approach to interactions with stakeholders. But while SCAN can help, it is not a replacement for federal efforts, which remain of paramount importance and must be continued.

Need for Definitive Information

Local government and community leaders need information on how to integrate climate science into the decision-making, planning, and implementation processes they already use. For example, which of the many different data sets and methods used for projecting such hazards as droughts and floods, wildfires, and heat waves are useful in a community's unique locale? Is it scientifically advisable to use only a subset of models known to perform best for a specific region to increase certainty in projections? How should probabilities of extreme events and the effectiveness of preparedness plans be reflected in evaluation of financial risks?

Those tasked with managing climate risk can feel exposed and even fear legal vulnerability for decisions about the data and methods they use. Thus, they need guidance on what is authoritative and appropriate, given how they plan to use the information to frame problems and goals, design and calculate the benefits and costs of options, establish incentives, and monitor progress. But it can also be difficult for scientists to provide simple answers to these questions, because they don't have experience in implementing policy and won't know what information is useful or appropriate. They may lack understanding of the thresholds at which infrastructure systems are disrupted or which local groups are most vulnerable to climate risks.

The next frontier in actionable climate science involves bringing together these different types of expertise—scientific and applied—to evaluate what works and what doesn't and what science is robust but also usable. That is what we propose should be the focus of SCAN.

Bridging Science and Practice

The IAC's report is not the first to propose a sustained assessment process. In 2013, the federal advisory committee for the third NCA recommended that federal agencies adopt the concept of "sustained assessment" built on "enduring partnerships" of users and providers of climate science. While that report provided a number of specific recommendations, it did not delve into the details of how to structure these ongoing partnerships, which have proven difficult for federal agencies to sustain.

To address this challenge, the IAC's report recommends establishing a consortium of groups that have already started to bridge the worlds of science and practice. There are many worthy efforts and we cannot list them all, but we do offer a few examples. The American Society of Civil Engineers has developed a "manual of practice" on incorporating climate change data into infrastructure design. Credit rating firms such as Moody's are starting to incorporate risks and resilience measures when evaluating bonds floated by cities to raise capital for public infrastructure. University-based regional science and applications centers link scientists and communities to apply climate science to address problems like long-term management of flooding, extreme heat, and drought. AGU recently established the Thriving Earth Exchange to help connect these groups and encourage additional projects. The American Public Health Association has supported research on and the application of interrelated climate and health solutions, including through public-facing fact sheets. The work of these and other groups provides a foundation of data, models, tools, and case studies that can be assessed to develop tested practices and usable knowledge.

Collaborative Learning About Climate Risk Management

SCAN will organize collaborative learning and assessment processes focused on such challenges as managing wildfires, planning renewable and resilient energy systems, and incorporating climate risk in economic planning. It will identify information required to make, implement, and monitor decisions and conduct technical assessments of the quality and usability of scientific methods and data to provide the needed information.

How might this work in practice? Let's take the challenge of preparing communities for increasingly intense flooding. Many municipalities are working with university research centers, consulting firms, grassroots groups, city officials, planners, bond rating agencies, and local businesses to identify and evaluate possible solutions. SCAN will bring together a representative sample of communities and organizations already working on climate-related flooding and catalyze sustained, structured analysis of how each is approaching the issue to identify lessons learned.

The goal is not to support any one jurisdiction but to encourage collaborative learning and create consensus on tested practices across a range of settings. Particularly where there are different approaches available, SCAN will identify which are appropriate for which circumstances. An essential part of this process will be recognizing when information needs are similar and can be met with shared tools and data, and where such approaches are not desirable and can lead to poor decisions.

A flood mitigation method in Boulder, Colo., uses a basinlike shape bounded by rock walls that should contain rising water on the Goose Creek pathway. Credit: Marty Caivano/Digital First Media/Boulder Daily Camera via Getty Images

Returning to the flood management example, the community of practice would identify information and methods needed across the different cases. Communities addressing flooding challenges would likely need data to help project future rainfall intensity and measure how different land use patterns affect runoff. They'll want to integrate results of hydrologic models into geographic information systems to understand the implications of different flood control options (e.g., ecosystem-based approaches versus traditional gray infrastructure such as flood barriers). Their policy makers will need methods to assess benefits and costs of the options and scenario planning tools for engaging community groups in planning.

Scientists and communities working in a network such as SCAN will be in a better position to assess the rigor of different approaches and establish which are best suited to specific cases. The resulting knowledge can be used to develop tools and data sets, professional standards, training, and other resources needed to scale up and accelerate action.

A Backbone Organization

As SCAN grows, it will build a distributed, sustained national network of networks focused on an array of high-priority adaptation and mitigation challenges. It will identify needs of climate risk managers, prioritize objectives, form new communities of practice, and extend climate assessments using knowledge to accelerate adaptation and mitigation.

SCAN will serve as a backbone organization for state, local, and tribal groups; professional societies; community-based organizations; academic and private research organizations; business interests; and federal programs. It will build partnerships with federal institutions and highlight research needs for consideration by scientists and funding agencies. SCAN is also committed to supporting the needs of marginalized and particularly vulnerable communities.

The IAC's report notes that this sort of sustained engagement is difficult to maintain in the context of federal research programs, partly because of legal and structural challenges related to the Federal Advisory Committee Act and other regulations. A nonfederal consortium could begin mobilizing immediately, and it would have greater flexibility to integrate user groups into the assessment process.

Next Steps and Request for Input

The IAC's report provides new ideas for adding to the practice of assessments as they have been conducted since the Global Change Research Act of 1990. SCAN will begin to apply and improve these ideas but needs to secure funding for a 3- to 5-year start-up phase. We have the elements of a self-sustaining business model but need resources to begin convening pilot communities of practice as soon as possible to develop tested practices, guidelines, data sets, communications tools, and other resources to help communities.

SCAN seeks to work with federal agencies as opportunities arise, including building on the results of the NCAs and other source and providing feedback on research needs. We also emphasize the need for allocating federal resources to advance planning and engineering practices and technologies for new and existing infrastructure, including support for updating codes, standards, and best practices in a range of professional settings.

Along the way, SCAN will engage in adaptive management to learn from these early experiences and refine the proposed approach to applied assessments. It must establish processes that ensure the credibility and transparency of its own efforts, including managing any perceived or actual conflicts of interest, for example, between financial sponsorship and review of methods or data. And it will need to improve understanding of how to convene and manage the interactions of practitioners, scientists, and other participants.

As the conveners of SCAN, we seek input from those with interests in improving climate change resilience and preparedness and invite them to join us to address the challenges. For information on initial leadership and engagement opportunities, visit SCAN's interim website: www.climateassessment.org. It is urgent to accelerate climate mitigation and adaptation to avoid unmanageable impacts of climate change. Better assessments can't overcome all the barriers, but they can be an important source of support for communities and jurisdictions on the front lines of climate change.

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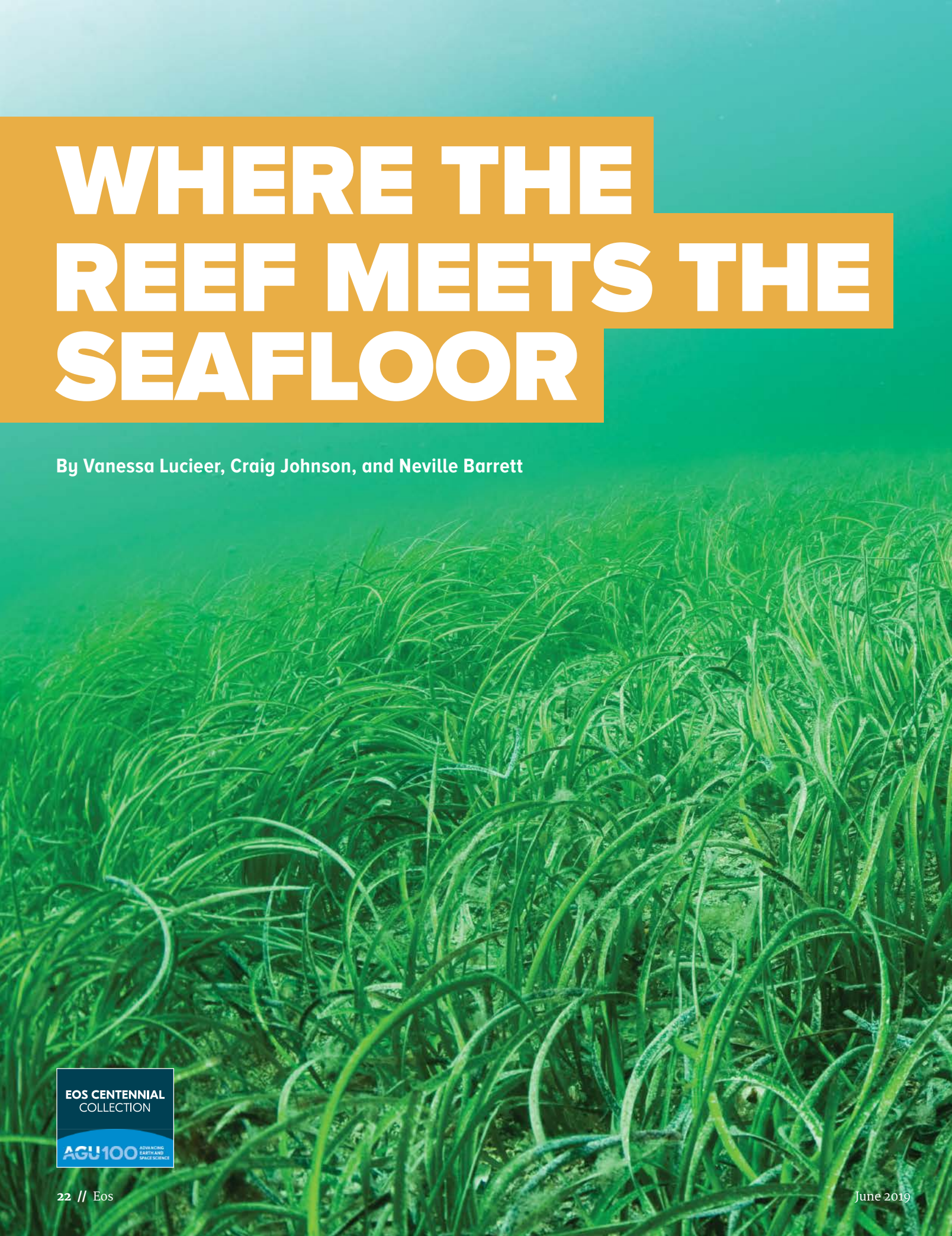
WHERE THE REEF MEETS THE SEAFLOOR

By Vanessa Lucieer, Craig Johnson, and Neville Barrett



EOS CENTENNIAL COLLECTION

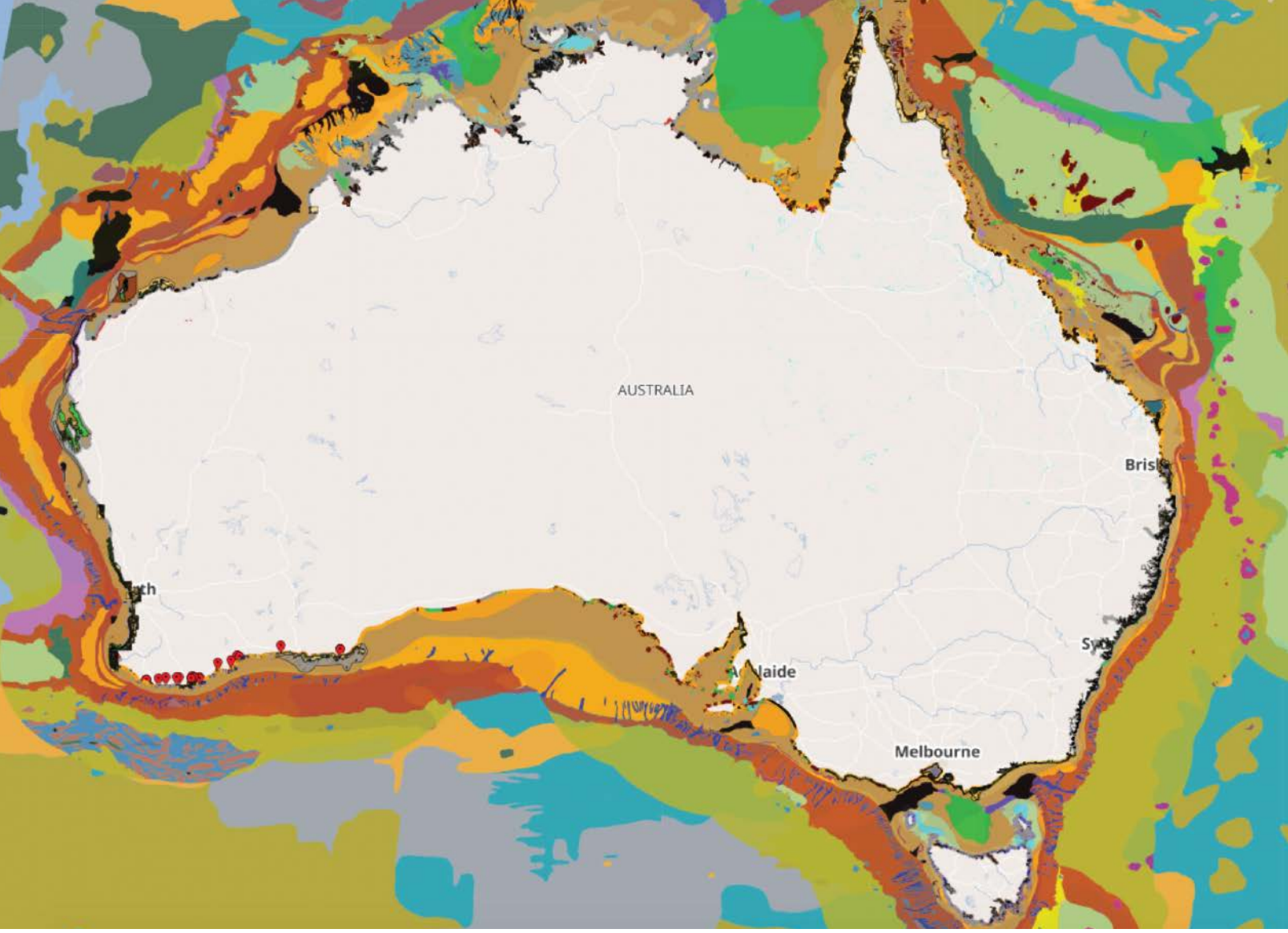
AGU100 ADVANCING EARTH AND SPACE SCIENCE

Seamap Australia integrates seafloor maps with information on plant and animal habitats, environmental stressors, and resource management to create a first-of-its-kind resource.

Imagine that the ocean could be drained to reveal the landscape of the seafloor around Australia. Now imagine that we could overlay on this landscape a map of the various seafloor types and the ways that marine animals and plants are distributed across them. Even better, imagine being able to easily visualize all these factors in relation to resource management boundaries or factors that place stress on marine environments.

Draining the ocean isn't possible, of course, but a large team of Australian scientists has done the next best thing. By collating spatial information on seafloor habitats from a wide range of collabo-

Seagrass near Port Hughes, South Australia. Credit: Michael Patrick O'Neill/Alamy Stock Photo



Users can visualize specific data about marine habitats around Australia using the interactive mapping service Seamap Australia. This image includes 74 layers showing data about habitats ranging from coral in Moreton Bay off the coast of Queensland to the seagrass in Western Australia's Oyster Harbour at three separate points in time. Credit: Seamap Australia

rating agencies and universities, they've produced Seamap Australia, an interactive mapping service and database that spans the coastal marine region from the coastline to the shelf break, 200 meters below the surface of the water. The extent of the survey data represents all marine habitat surveys to 2017, comprising a total of 6.5% of Australia's marine jurisdiction, which at 13.9 million square kilometers is the third largest in the world.

This resource makes Australia the first continent to have released a benthic marine habitat map with a singular, nationally consistent classification scheme. This information release is relevant to the current motivations of the international community as we work toward mapping the gaps in bathymetric data across the world's oceans. Seamap Australia is a national habitat map derived from both bathymetry and associated ground truthing of biological communities and sediment composition.

Beyond Bathymetry

Other organizations have produced data viewers for seafloor maps. The International Hydrographic Organization along with the U.S. National Oceanic and Atmospheric Administration (NOAA) have released the Data Centre for Digital Bathymetry (DCDB) data viewer, just as Geological Survey Ireland and the Marine Institute have produced Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR). However, these viewers are solely for bathymetric data, not data classified into seafloor habitats.

Bathymetric data are the foundation of benthic habitat mapping. From high-resolution bathymetry data, we can extract information on the surface structures and geological features of the seafloor—its geomorphology. This information, in turn, gives us clues about such seafloor habitats as reefs and sediment.

From high-resolution benthic habitat maps, environment managers can visualize where the habitats are that need protection, such as reefs and sea grasses. They can also identify areas where marine life production is at its highest.

Putting Seamap Australia to Use

In the first months of its release, Seamap Australia was already being used widely, particularly by government agencies. These include Australian government agencies such as Parks Australia—the agency now has ready access to habitat and bathymetry data within marine parks and

reserves nationwide. Feedback on government needs will help to clarify future plans to include information on threatened species and cultural values, which will be used to address future stressors.

The Australian Department of Agriculture and Water Resources uses Seamap Australia for biosecurity management in determining habitat suitability for, and distribution of, marine pest species. The National Environmental Science Program Marine Biodiversity Hub uses Seamap Australia for end-to-end delivery of data and information to meet state-of-the-environment reporting to the Australian government—an internationally accepted framework for assessing resilience, emerging risks, and outlooks for the marine environment. Seamap Australia has proven to significantly reduce the time and effort required to locate and download reliable and relevant marine spatial data.

This resource makes Australia the first continent to have released a benthic marine habitat map with a singular, nationally consistent classification scheme.

In Australia, less than 25% of the seabed within Australia's exclusive economic zone has been bathymetrically surveyed at high resolution. Australia is striving to coordinate its seabed mapping activities to bring government, industry, and universities together to fully use the skills, resources, and data available. Initiatives such as Seamap Australia have the capacity to develop a collaboration between the national and international community where

*The red handfish (*Thymichthys politus*) is a rare and critically endangered species found only in Tasmania, Australia. Handfish crawl rather than swim, using their handlike pectoral and pelvic fins. Seamap Australia assists efforts to protect species like this by integrating information on seafloor habitats with bathymetric maps for resource management and environmental studies. Credit: Auscape/Universal Images Group/Getty Images*

National initiatives such as Seamap Australia support an environment in which the public and private sectors can come together.

the development of spatial analysis tools and better standards for habitat classification can be registered, assessed, and shared.

A Challenging Effort

Scientists faced many technological challenges in the development of Seamap Australia. Seeking and accessing available seabed habitat data were the first hurdle: The marine community needed to be encouraged to upload their spatial data into national geodatabases where they could be harvested for this project.

After clearing the first hurdle—finding the data—classifying the data was the second challenge to be solved. Not every country enjoys Australia's level of access to resources for marine surveys, but even Australia presented some difficulty. There is no coordination of survey effort nationwide, so knowing where data have been collected was the first knowledge gap that had to be filled. Seamap Australia scientists also learned that although national geospatial agencies might produce survey data, they do not process these data to a level at which they can be used to produce maps such as habitat maps.

Expert development of a single habitat classification schema enabled us to assimilate disparate data sources of

*The critically endangered spotted handfish (*Brachionichthys hirsutus*) is found only in Tasmania's Derwent estuary. Credit: Rick Stuart-Smith/Reef Life Survey, CC BY 3.0 (bit.ly/ccby-3.0)*

variable scale, resolution, and collection technology to create the continental-scale spatial layer. From a big data perspective, the website needed to condense petabytes of unprocessed field data into a single unified mapping layer.

The primary role of Seamap Australia was to maximize performance and usability by reducing data to a manageable size (the total collection is about 25 gigabytes). However, our success relied on overcoming competing interests of contributors, establishing a culture of data sharing, and achieving national agreement on a classification schema and the associated vocabulary.

All seafloor habitat data sets used by Seamap Australia are now publicly accessible from the platform under a Creative Commons license. We recognized the need for a central aggregation service, so we scoped the requirements for a system that would deliver a simple and intuitive visualization tool based on a distributed data model.

Developers considered the most relevant technology for interoperability and integration with other systems. Seamap was designed to be scalable, involving careful trade-offs around data access and computation. Technologies used to achieve performance at large scales included load balancing and caching, a stateless application architecture, and distribution across multiple hosts to reduce the impact on a single server. A custom application program interface (API) enables such novel features as construction of "on the fly" cross sections of the seabed, and it provides innovative "smart" selection of data sets most relevant at different spatial scales for download in a variety of formats.

Moving the Field Forward

It is widely recognized that making data findable, accessible, interoperable, and reusable (FAIR) is the way forward for research. Anyone can easily find, access, use, and share FAIR data.

Collaborative partnership with Seamap Australia will foster growth of knowledge of marine environments and ecosystems within the vast jurisdiction of the Australian marine estate. Only the future will tell whether Seamap Australia has helped to address this goal, but for this project to succeed, future surveys will need to accede to the principles of FAIR data.

National initiatives such as Seamap Australia and international initiatives such as Seabed 2030 support an environment in which the public and private sectors can come together. This type of collaboration paves the way to provide ocean science, data, and information to inform policies for a well-functioning ocean, one of the two major goals of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), which supports the 2030 Agenda for Sustainable Development.

Projects such as Seamap Australia enable new projects of national scope that are relevant in terms of scale (nationwide) and timeliness (almost live) to the United Nations Decade of Ocean Science. This type of effort is the only way that we can improve knowledge of our vast marine estate and complete the remaining 75% of Australia's bathymetric map.

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Navigating the Future of Oceanographic Research

By Alice Doyle, Daniel J. Fornari, Elizabeth Brenner, and Andreas P. Teske

E/V **Nautilus** *afloat in Half Moon Bay, Calif. Credit: The Ocean Exploration Trust/Nautilus Live*

EOS CENTENNIAL COLLECTION

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Scientists planning research cruises must develop new systems to handle the massive logistics involved today.

Over the past few years, challenging logistics and the intricacies of obtaining marine science research authorizations have complicated executing oceanographic cruises. Coordinating scientific research teams from many disciplines and nations with available research vessel facilities and crews involves significant investments of time and resources. These factors, along with the increasing complexity of interacting with various government entities around the world, have revealed the need for a renewed effort by scientists and operators within the U.S. Aca-

R/V Sally Ride, *operated by the Scripps Institution of Oceanography, arrives in Seattle, Wash., after a cruise to maintain moorings, along with several ancillary projects, at Global Station Papa near the Alaska Gyre in the North Pacific. Academic oceanographic research aboard U.S. Academic Research Fleet vessels currently includes large multidisciplinary experiments with extensive arrays of instrumentation and requires complex shipping logistics that often involve foreign ports. Credit: Eric Buck*

demic Research Fleet (ARF) to work together to ensure that federally funded field research is well coordinated and successful.

Marine science research builds core knowledge about coastal and deep-ocean processes. But more than that, this work has far-reaching implications for societal impacts associated with ocean and climate phenomena, and it provides science-based assessments of complex Earth-ocean processes and hazards that can inform national and international policy development.

To be successful and productive, oceanographic field studies require excellent coordination between scientists, ship and facility operators, and funding agency representatives. Oceanographic data collection is expensive: In most cases, public funds support science and operations. Safe, efficient, and cost-effective field data acquisition is essential. It is also a reality that the current global geopolitical environment has created both opportunities and challenges to conducting oceanographic research in foreign waters.

A diverse group of oceanographic scientists, University-National Oceanographic Laboratory System (UNOLS) ship operators, and federal agency program managers convened a UNOLS working group to review a range of topics concerning planning and execution of U.S. oceanographic field research. The primary focus of the deliberations involved work in international waters, where ships enter and return to foreign ports, as well as work involving field studies within the exclusive economic zones of foreign nations and the requisite planning, logistics, and permitting involved with those efforts.

The committee polled many ARF operators involved with supporting fieldwork in foreign and international waters throughout the world's oceans to better understand their protocols, and they discussed best practices and communications methods that each operating institution used in their work to support scientists using their ships and facilities.

Below are some recommendations that were developed to help guide scientists, agency program managers, and academic vessel operators in their varied collaborative functions as they carry out productive oceanographic research in the 21st century. The subcommittee produced a final white paper (bit.ly/UNOLS-white-paper) and appendix (bit.ly/UNOLS-appendix) that can be accessed online, and these provide more detailed, specific information on some of the key topics the committee discussed.

An Extensive Enterprise

Each year, U.S. federal agencies spend hundreds of millions of dollars funding basic research in the Earth and ocean sciences. The National Science Foundation (NSF) alone supports approximately 24% of all federally funded research conducted at U.S. academic institutions. In the United States, the NSF funded an average of more than 140 research cruises a year between 2016 and 2018, with principal investigators and science participants from nearly every state and territory.

UNOLS serves to coordinate academic oceanographic research in the United States through participation by 59 member institutions that provide access to the oceans through various means, along with the 18 ships in the ARF. Oceanographic research often requires coordinated ship and vehicle facilities; recent additions include moored and cabled arrays that provide 24/7 monitoring at seafloor laboratory sites. At these sites, sophisticated technologies enable field data acquisition and analysis of large volumes of spatially and temporally correlated data.

The current global geopolitical environment has created both opportunities and challenges to conducting oceanographic research in foreign waters.

Planning Strategically

We identified a need for all academic research vessel operators to compare their approaches to cruise planning and to aim at a more consistent ARF-wide consensus regarding the timing and communication protocols for that planning effort. Revised protocols should allow ship operators to better coordinate with the diverse community of scientists that use ships and the

Vessel operators and scientists must develop new communication strategies to accomplish the many details required for oceanographic field research to be successful and cost-effective.

The National Oceanic and Atmospheric Administration ship Okeanos Explorer, *pictured here, is the only U.S. federal vessel dedicated to exploring the ocean. Credit: NOAA*

myriad details involved in conducting oceanographic fieldwork in foreign waters, as well as in U.S. coastal regions where smaller ARF vessels operate. For instance, academic vessel operators should strive to have a single point of contact within their organizations to ensure that communications and action items with scientists are clearly established and successfully resolved.

By the same measure, scientists need to be directly involved in the details of cruise planning and logistics with ship operators, especially when working within exclusive economic zones of foreign nations and when shipping scientific equipment into or out of foreign ports. On a case-by-case basis, judiciously applied proactive strategies may include expedition-style shipping that anticipates the needs of multiple consecutive cruises and safekeeping of critical equipment on board to avoid holdups in problematic ports. These strategies require careful advance coordination among multiple principal investigators and the operating institution.

Vessel operators and scientists must develop new communication strategies to accomplish the many details required for oceanographic field research to be successful and cost-effective. Normal facility costs involved in executing seagoing science programs (e.g., port costs, crane charges to load or unload equipment, and clearance fees related to embarking and disembarking science personnel) are now generally consistent throughout the ARF. This consistency is one very positive outcome that the committee recommendations presented in the UNOLS white paper. That said, it is important that the principal investigator and operator discuss all port call operations to clearly understand responsibilities, logistics, and projected costs.

Lining Up the Permits

Scientific principal investigators and chief scientists have the responsibility to familiarize themselves with the requirements of obtaining necessary visas and permits to conduct research and collect samples within foreign exclusive economic zones. Comprehensive information available from the U.S. State Department can facilitate finding current permit information for research in foreign countries (see the white paper and appendix referenced on page 30). Proactive visa and permit applications are critical, as many countries have tightened their requirements.

Ultimately, it is the scientists' responsibility to identify all types of permitting required and the types of visas that shipboard scientists must have to accomplish the stated research goals. Scientists should investigate these requirements in the proposal writing phase. They should include this information in the proposal project description so that

Okeanos Explorer *docked at the pier in Pearl Harbor, Oahu, Hawaii. Credit: NOAA*

reviewers, panel members, and program officers can properly assess the likelihood of success in gaining the necessary authorizations to conduct the proposed field research.

Transporting Equipment

Shipping science equipment to and from foreign ports is critical for conducting successful research cruises throughout the global ocean. Engaging with reputable U.S. freight forwarders and foreign corresponding agents is essential to ensure proper handling of the equipment and to identify the required customs and freight forwarding documentation. For all cruise-related shipments, science principal investigators and chief scientists should ensure that they have followed well-established protocols and that different science groups using the vessel for a cruise have coordinated their shipments with the ship's operator.

Scientists planning a research cruise can gain valuable information by talking to operators and principal investigators who have previously obtained permits and marine science research authorizations for a particular country and mobilized from specific foreign ports. For this reason, it is important for scientists to widely disseminate knowledge about handling cruise logistics and shipments. Operators and scientists should also share information on complex shipping logistics that pertain to specific countries.

UNOLS is in the process of revising its postcruise assessment report (PCAR) to include sharing of this type of information and the recent experiences of principal investigators shipping to or from foreign ports. For example, cargo storage costs are minor compared with the cost of a late ship departure due to unforeseen shipment delays. To avoid delays, it is crucial to plan equipment shipments to arrive in foreign ports well before the scheduled ship arrival. Commerce liaisons at many U.S. embassies commonly maintain lists of reputable freight forwarders and shipping agents with local experience and will share this information with science parties and ARF operators upon request.

Working Together to Ensure Success

Collaboration continues to be a hallmark of U.S. oceanographic research. Successful collaborations include a robust proposal submission and review process, coordi-

nated funding of highly capable vessels and facilities required to conduct science at sea, and the UNOLS consortium of ARF vessel operators to coordinate schedules and improve oceanographic capabilities at all levels for future researchers.

Scientists and vessel operators are key stakeholders in conducting oceanographic research, but ultimately, global citizens benefit from new knowledge of ocean and Earth processes. Thus, developing and improving new approaches to coordinate and streamline planning and execution of 21st-century oceanographic research will benefit everyone.

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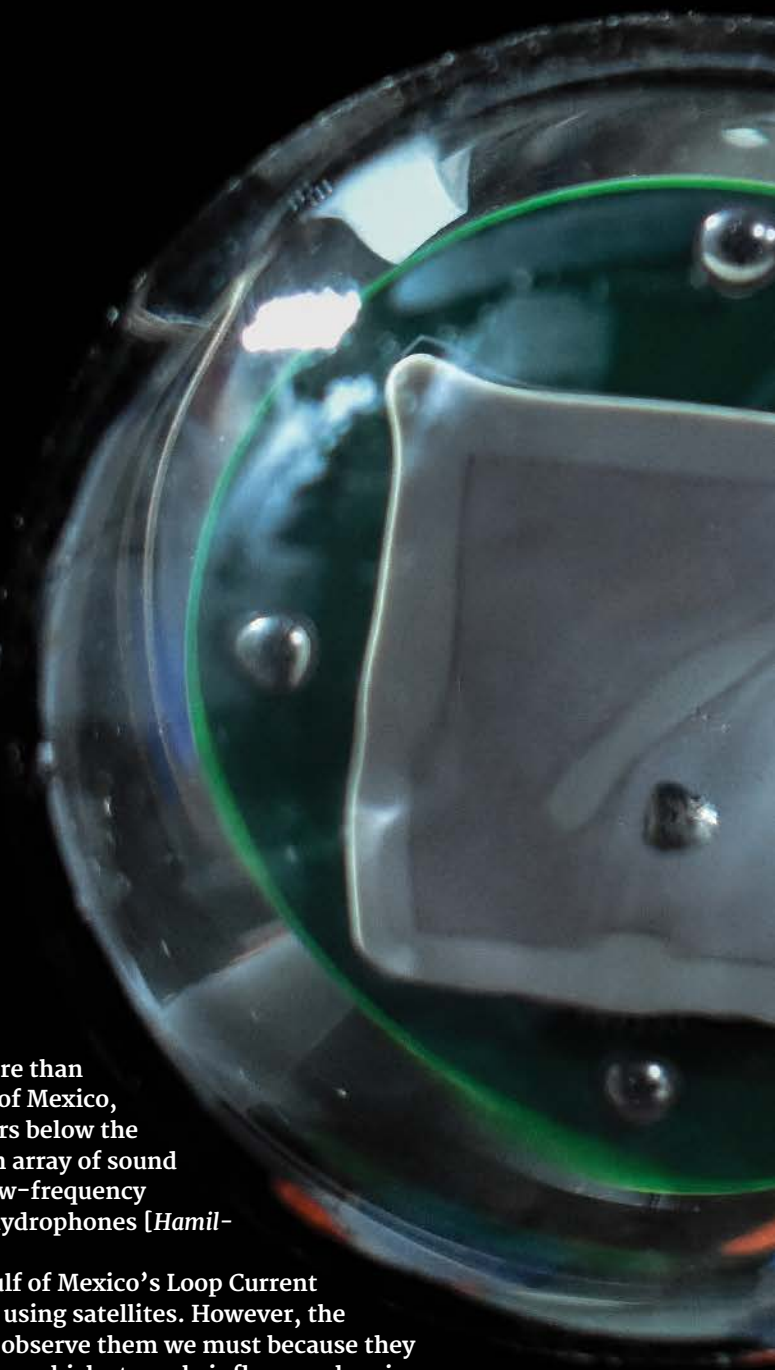
Deep Floats Reveal Complex Ocean Circulation Patterns



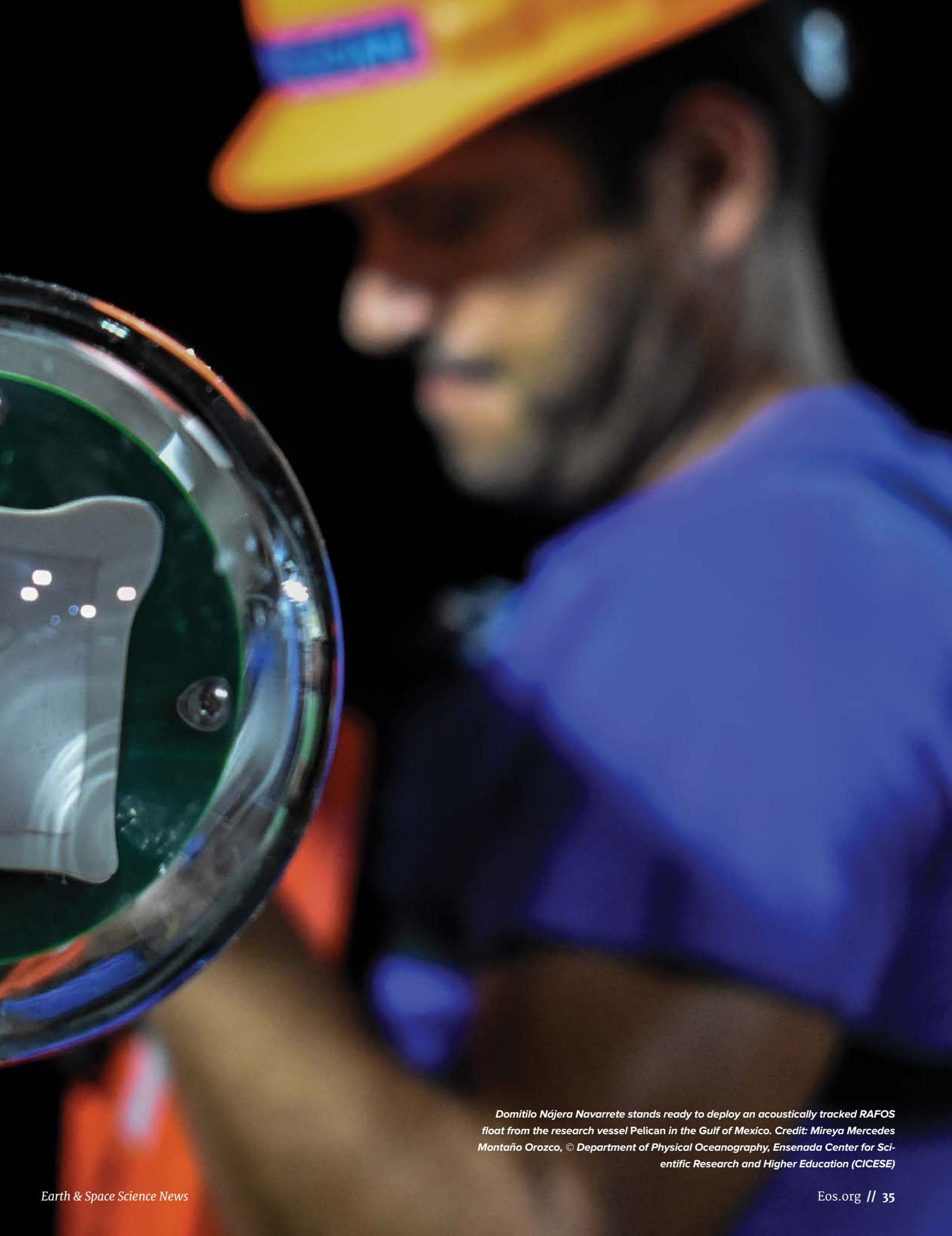
Acoustically tracked floats drift far below the ocean's surface, providing fresh discoveries about deep-sea currents. A new archive gathers decades' worth of float data into a central repository.

By Andrée L. Ramsey, Heather H. Furey, and Amy S. Bower

Between 2011 and 2015, oceanographers released more than 150 acoustically tracked floats throughout the Gulf of Mexico, where they followed the ocean currents 1,500 meters below the surface. The scientists tracked these floats using an array of sound sources, moored to the ocean floor, that emitted low-frequency tones that the floats picked up with their built-in hydrophones [*Hamilton et al.*, 2016].

It's now relatively easy to monitor surface currents like the Gulf of Mexico's Loop Current and its associated eddies and to track how these currents evolve using satellites. However, the currents below the surface are more challenging to observe. But observe them we must because they are critical to predicting the evolution of the Loop Current system, which strongly influences hurricane development and how oil spills spread.

Oceanographers routinely deploy different types of drifting instruments in the ocean to track the movement of currents on and below the surface and measure changes in properties such as water



Domitilo Nájera Navarrete stands ready to deploy an acoustically tracked RAFOS float from the research vessel Pelican *in the Gulf of Mexico. Credit: Mireya Mercedes Montaño Orozco, © Department of Physical Oceanography, Ensenada Center for Scientific Research and Higher Education (CICESE)*

Amy Bower and a technician with a RAFOS float. Credit: Tom Kleindinst, © Woods Hole Oceanographic Institution

temperature and salinity along their drifting paths.

Surface floats can be tracked continuously via GPS. Profiling floats drift untracked at depth; every 10 or so days, they rise to the surface to get their position from GPS and transmit data they collected during their ascent. A third type of float, the acoustically tracked floats we describe here, goes about its business on its own, saving the data it collects for months to years, after which it pops to the surface and transmits its data to satellites overhead.

Nearly 50 years ago, scientists developed a technique for long-range acoustic float tracking to trace out the intricate pathways of ocean currents below the surface. Since then, thousands of acoustically tracked floats have been deployed to measure currents in many regions of the global ocean. Their high-resolution trajectories have revealed a rich diversity of energetic water motions far below the sea surface.

We have created an archive of all acoustically tracked float data to provide better public access to this unique and valuable resource. In 2017, we established a new repository for all acoustically tracked subsurface float data at the National Oceanic and Atmospheric Administration's Atlantic Oceanographic and Meteorological Laboratory (AOML). The new repository is an updated, quality-controlled, streamlined version of the data set previously stored at the World Ocean Circulation Experiment Subsurface Float Data Assembly Center (WFDAC).

Acoustic Float Tracking in the Deep Ocean

The extreme hydrostatic pressures and the inability of light to penetrate below the near-surface layer make it challenging to observe deep-ocean currents. Acoustically tracked floats help to address this challenge by providing information about the speed and direction of currents along their path (this is called a Lagrangian approach). Ever since scientists developed the capabilities to acoustically track these deep-sea floats over long ranges (thousands of kilometers) with high resolution (as fine as several kilometers) [*Rossby and Webb,* 1970], oceanographers have been able to observe complex subsurface currents in the same way that GPS-tracked surface floats are used to describe surface currents on a wide range of spatial and temporal scales [*Richardson,* 2009; *Rossby,* 2016].

Today's acoustic float observing system consists of a basin-wide or regional array of at least three moored low-frequency sound sources and a fleet of floats [*Rossby et al.,* 1986], ballasted to drift at constant pressure or density for as long as several years. A micropro-

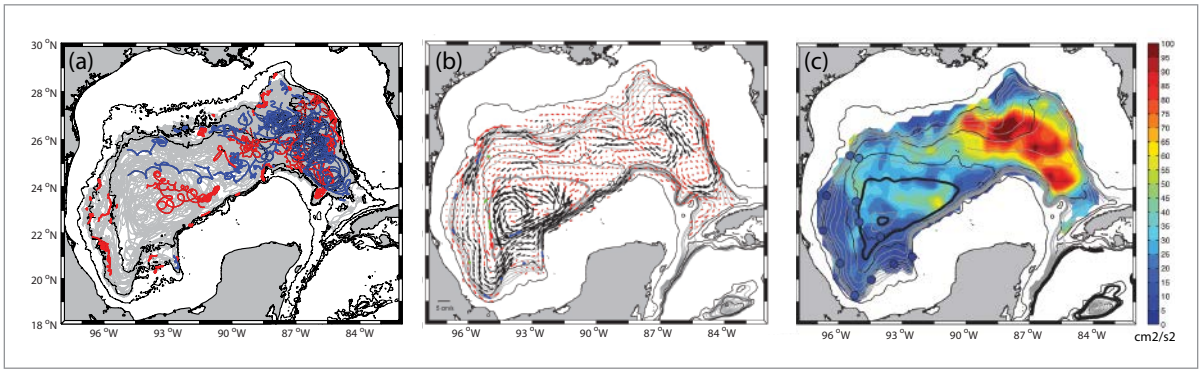


Fig. 1. (a) Deep (1,500 and 2,500 meters) RAFOS float trajectories in the Gulf of Mexico (gray lines) with segments highlighted that show clockwise (red) and counterclockwise (blue) coherent eddies. (b) The mean gridded velocity field and (c) mean eddy kinetic energy (EKE) field of the deep layer derived from the float velocity ovbservations. Figures 1b and 1c reprinted from Pérez-Brunius et al. *[2018], © American Meteorological Society. Used with permission.*

cessor in each float is programmed to listen for the sound sources at intervals from 6 to 48 hours, depending on the desired trajectory resolution, and to record the times of arrival (TOAs) of the acoustic signals. Temperature and pressure measurements are made on the same sampling schedule.

At the end of the mission, the float returns to the surface and transmits the stored data via the Iridium satellite network. After the mission, the TOAs are converted to acoustic travel times from source to float, and these travel times are used to calculate distance using the speed of sound in seawater. The float position at each time step is determined on the basis of the intersection of range circles from each sound source.

The float trajectories have produced fundamental revelations regarding the importance of mesoscale turbulence—or eddies—in the transport of properties and energy in the ocean. These floats are presently the only tool available to measure ocean currents with high spatial resolution at any depth in the water column. A single float track can reveal an unknown feature of the deep circulation, whereas larger numbers of float trajectories can be combined to quantify dispersion and other statistical properties of motion in the deep ocean.

> Currents below the surface are critical to predicting the evolution of the Loop Current system, which strongly influences hurricane development and how oil spills spread.

Discoveries with Acoustically Tracked Floats

In the late 1970s, a research group from the University of Rhode Island used acoustically tracked floats to reveal energetic subsurface coherent vortices (eddies), starting with observations of a lens-shaped layer of warm, salty water near the Bahamas. This layer had a diameter of some 100 kilometers, and it was centered at a depth of about 1,000 meters, spinning clockwise with a rotation period of 12 days [*McDowell and Rossby,* 1978]. The temperature and salinity in the eddy core indicated that it had probably formed some 6,000 kilometers away, where outflow from the Mediterranean Sea enters the North Atlantic. These observations allowed the researchers to identify these eddies (named "Meddies") as a new long-distance transport mechanism in the ocean.

Acoustically tracked floats have also been used to describe the kinematics and dynamics of the eddy-rich Gulf Stream, North Atlantic Current, California Undercurrent, and Agulhas Current. They have demonstrated distinctions between the interior and boundary pathways of Labrador Sea Water from the subpolar to subtropical North Atlantic. These floats have also provided insight into the structure and pathways of the Deep Western Boundary Current, dispersion in the Antarctic Circumpolar Current, and more.

Surveying the Gulf of Mexico's Deep Currents

The 2011–2015 Gulf of Mexico study illustrates the unique capabilities of acoustically tracked floats to observe the velocity field of the subsurface ocean on a wide range of spatial scales.

These floats were unable to escape from the gulf easily, so they provided dense sampling of the deep currents throughout the basin (Figure 1a). By grouping the float velocities in geographic boxes and averaging them, a clear pattern of deep currents emerged, including a counter-

clockwise narrow boundary current encircling most of the gulf, a deep counterclockwise gyre over the deepest part of the basin, and several mesoscale features under the Loop Current in the eastern gulf (Figure 1b) [*Pérez-Brunius et al.*, 2018].

The strength of the velocity variability, or eddy kinetic energy, was 4 times larger under the Loop Current than it was in other subsurface regions, indicating a coupling between the upper and lower layers of the eastern gulf (Figure 1c). Using a mathematical technique called wavelet analysis, *Furey et al.* [2018] also discovered a population of deep coherent vortices, including a new Meddy-like eddy formation process from the boundary current in the western gulf (Figure 1a). These fluid-trapping eddies were not detectable on the surface: Their very existence would be completely unknown without these float observations.

RAFOS floats aboard the R/V Hakon Mosby *await deployment. These floats spend up to 2 years in the ocean, after which they surface and transmit their data to satellites. Scientists can then download the data directly to their computers. Credit: Marieke Femke de Jong*

A New Repository for Acoustically Tracked Float Data

The database contains float data with a high temporal resolution (sampling periods between 6 and 48 hours), collected using the early Sound Fixing and Ranging (SOFAR) floats (which emit signals that can be detected by hydrophones at fixed locations), RAFOS floats (SOFAR backward, because these floats receive sound signals rather than send them), and profiling floats tracked acoustically while drifting at depth.

Most important, we have significantly expanded the database by adding new float data. This addition increased the archive of float projects from 29 to 51, expanding the total number of individual float trajectories from 1,248 to 2,197, an increase of 76%.

This comprehensive database replaces the WFDAC data archive, and it can be downloaded in an easily accessible, consistent, and concise format from AOML's website (bit.ly/AOML-NOAA-Float). The data are available in NetCDF and MATLAB "mat-file" format, and they are searchable by region and depth, among other parameters. This archive will continually grow as researchers collect and add new float data.

Creating and maintaining a single, comprehensive, and internally consistent archive will facilitate continued analysis of this unique and valuable resource, allowing more comprehensive regional and depth-dependent comparisons of velocity statistics. These analyses will prove invaluable for validating numerical model simulations and advancing our understanding of the physical mechanisms that determine the character of the deep-ocean circulation.

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EOS CENTENNIAL COLLECTION

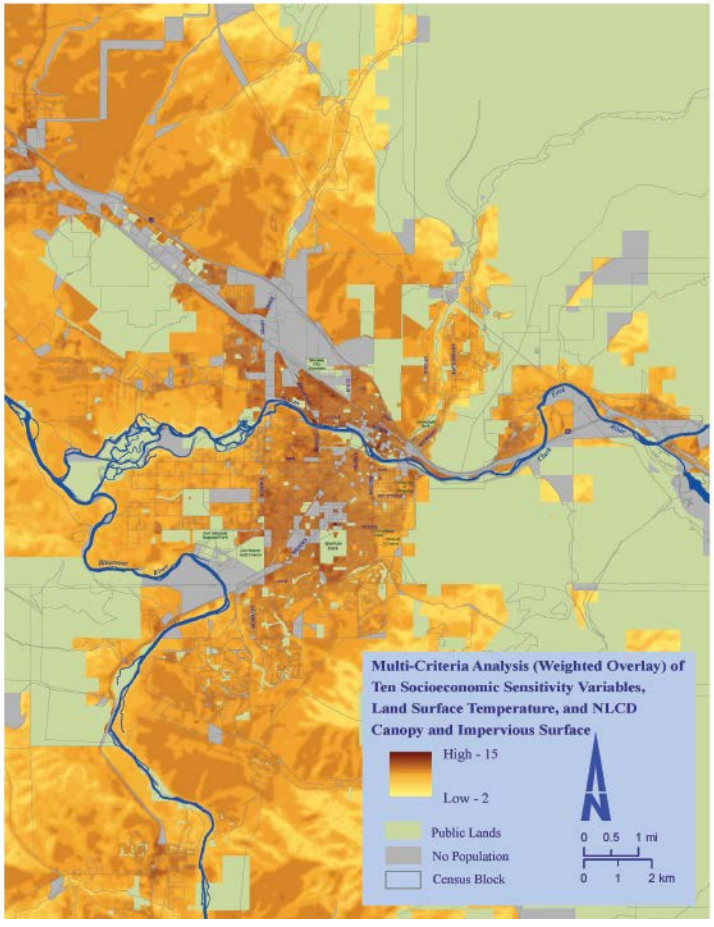
Mapping Heat Vulnerability in Communities

Confronted with increased health risks to humans resulting from climate change, leaders in several U.S. cities are striving to make climate-related health information accessible at a local scale. Now these communities are developing tools at the grassroots level to inform city planning, address needs for services, and identify areas for green infrastructure and cooling interventions.

Like many health threats, climate change is expected to disproportionately affect vulnerable populations, such as the elderly, young children, families living in poverty, and people with chronic diseases. From small rural cities to densely populated metropolitan centers, communities are developing resiliency efforts to ameliorate these escalating threats and inform local decision makers.

In a small but growing urban center surrounded by ranching communities in western Montana, increased temperatures and threats to air quality are exacerbated by hot spots contributing to the urban heat island effect. Chase Jones and Amy Cilimburg, community leaders in Missoula, recently partnered with a team of scientists through the Thriving Earth Exchange to take steps toward providing evidence-based recommendations to urban planners and policy makers to address sensitive areas within their community.

By overlaying U.S. Census demographics for sensitive populations with heat exposure variables, the team successfully mapped the vulnerability down to individual city blocks. "Because we have forced the data to this fine scale, city planners and health department officials are able to see where vulnerability may vary within a neighborhood and focus immediate efforts there," said Julie Tompkins, a graduate student at the University of Montana and a member of the science team. The group has used the map to provide recommendations for city building codes that should alleviate the urban heat island effect.



A heat vulnerability map developed by the Missoula, Mont., Thriving Earth Exchange project team. Credit: Julie Tompkins

Tompkins, along with her adviser, Anna Klene, expects that this type of tool will inform urban planning as climate change–related health needs continue to grow. "This project has been presented to governmental, health, and environmental groups. The feedback we received has been positive toward data-based identification of specific areas for services," said Tompkins. This project extends and enhances the work of Missoula's Summer Smart program, which aims to prepare the community to thrive amid increasing summer wildfire smoke and heat by helping Missoulians to be physically, mentally, and economically healthy and resilient.

As the Missoula team continues to share its findings with policy makers and the community, residents in a South Bronx, N.Y., neighborhood are leading grassroots resiliency planning with similar outcomes in mind. The Hunts Point Heat Project team, another Thriving Earth Exchange partnership, wants to inform the community about extreme heat and urban heat island effects while equipping them with tools and skills to influence green infrastructure planning. Like the Montana initiative, this project will identify hot spots within the community and make that information publicly available through maps and other channels, allowing the community to intervene and advocate for themselves.

"In the case of extreme heat here in Hunts Point, community leaders understand that 'urban heat island' is an issue, and that our community is very heat-vulnerable due to high heat exhaust from local industries and diesel-fueled trucks but also due to our low vegetative surface coverage," said Fernando Ortiz, the climate preparedness and resiliency organizer at the Point Community Development Corporation. Ortiz has partnered with atmospheric scientist and remote sensing specialist Brian Vant-Hull and ISeeChange director Julia Kumari Drapkin. They plan to integrate data regarding land use and land cover, air temperature, surface temperature, and demographics into an extreme-heat vulnerability map hosted on an online dashboard. The information can be used to improve the community's ability to respond to extreme heat, identify target areas for mitigation activities, and drive potential policy changes in the future. "Working with scientists allows us to better understand how we can accurately measure heat and map it to create efficient and effective interventions and recommendations," said Ortiz, "and better prepare and educate our community about staying cool."

As the threat of health risks associated with climate change becomes more significant, community-led resiliency efforts and partnerships with scientists can influence decision makers with evidence-based recommendations that will protect their communities from the worst effects of climate change.

By **Kelly McCarthy** (kmccarthy@agu.org), Centennial Communications Program Manager, AGU; and **Zack Valdez,** Thriving Earth Exchange, AGU

EOS CENTENNIAL COLLECTION

AGU Launches Ethics and Equity Center

Tens of thousands of scientists visited the poster hall at AGU's Fall Meeting 2018. The new AGU Ethics and Equity Center will provide comprehensive resources and tools designed to support this community across a range of topics linked to ethics and workplace excellence. Credit: Event Photography of North America Corporation

In the next century, our species will face a multitude of challenges. A diverse and inclusive community of researchers ready to lead the way is essential to solving these global-scale challenges. While Earth and space science has made many positive contributions to society over the past century, our community has suffered from a lack of diversity and a culture that tolerates unacceptable and divisive conduct. Bias, harassment, and discrimination create a hostile work climate, undermining the entire global scientific enterprise and its ability to benefit humanity.

As we considered how our Centennial can launch the next century of amazing Earth and space science, we focused on working with our community to build diverse, inclusive, and ethical workplaces where all participants are encouraged to develop their full potential. That's why I'm so proud to announce the launch of the AGU Ethics and Equity Center, a hub for comprehensive resources and tools designed to support our community across a range of topics linked to ethics and workplace excellence. The Center will provide resources to individual researchers, students, department heads, and institutional leaders. These resources are designed to help share and promote leading practices on issues ranging from building inclusive environments, to scientific publications and data management, to combating harassment, to example codes of conduct. AGU plans to transform our culture in scientific institutions so we can achieve inclusive excellence.

Resources Including Access to Legal Consultation

A pilot initiative through the Center will provide free access to consultation with a legal adviser, available to AGU students, postdocs, and untenured faculty members experiencing harassment, bullying, discrimination, retaliation, or other misconduct. Many victims of harassment report feeling alone, scared, ignored, and betrayed. This free legal consultation service is intended to let targets know that they are not alone and to help them chart a course forward. This pilot program is unique in the science community, and we look forward to measuring its benefits.

Overall, the AGU Ethics and Equity Center is designed to help you meet your ethics goals. In addition to the resources described above, visitors will find professional development and ethics-related resources for individual scientists and students, as well as information for organizations and institutions that are looking to implement best practices or update their codes of conduct. The Center will also be a home for information on upcoming ethics- and equity-related workshops, as well as a place where groups can request custom workshops tailored to their own specific needs.

A Partnership Effort

The AGU Ethics and Equity Center is a natural progression from the update of AGU's ethics policy 2 years ago to recognize sexual harassment as scientific misconduct and our additional AGU policies and practices implemented since then. Led by AGU, the Ethics and Equity Center benefits greatly from partnerships with the National Center for Professional & Research Ethics, the American Geosciences Institute, the Association for Women Geoscientists, the Carnegie Institution for Science, the Earth Science Women's Network, the Geological Society of America, the International Association for Promoting Geoethics, and the Ecological Society of America. By partnering in this effort, organizations help build and support workplace excellence across the total science community. The ongoing strategic direction of the AGU Ethics and Equity Center will be overseen by an advisory group of ethics experts and experienced leaders from across scientific disciplines and sectors.

Through the AGU Ethics and Equity Center and as a Centennial initiative, we hope to inspire and aggressively support a more vibrant, equitable, and inclusive Earth and space science community into the future. Science is strongest when a diverse set of voices is not simply at the table or in the lab but encouraged to share their perspectives and scientific ideas. We all benefit from more diverse viewpoints to improve our science as we look to another wonderful century of discovery and science for humanity.

The Center includes a pilot initiative to provide free access to consultation with a legal adviser.

Visit the AGU Ethics and Equity Center at ethicsandequitycenter.org.

By **Robin Bell** (president@agu.org), President, AGU

A New Way to Analyze Evidence of Martian Oceans

An artist's rendering of what Mars may have looked like 4 billion years ago with an ocean covering about half of its surface. Credit: European Southern Observatory/M. Kornmesser

At the end of the 19th century, an astronomer named Percival Lowell first peered up at Mars and observed some dark lines with powerful implications—an extensive network of canals. He was thrilled to see what he considered evidence of an advanced civilization sculpting the Martian landscape as his fellow earthlings were constructing the Suez and Panama Canals.

Despite Lowell's enthusiasm, these Martian canals were merely an optical illusion caused by the primitive telescopes of the day. But Giovanni Schiaparelli, the scientist who first observed the channels that Lowell interpreted to be canals, mapped out Martian seas and continents as well. Since his time, some studies have supported the idea that Mars had ancient oceans, long since dried up; others have challenged it.

Scientists today are still asking questions about Mars's watery past. Current evidence strongly suggests that there was once liquid water on the surface, but exact determinations of where, when, and how much still remain. The answers to these questions will give astronomers a greater understanding of Martian atmosphere, landforms, and potential for life.

Now *Sholes et al.* present a method for analyzing possible shorelines to determine whether they are truly wave-generated ocean rims or other landforms.

Most of these potential shorelines were mapped on the basis of low-resolution images from the Viking mission in the late 1970s and early 1980s and other orbital images of similar quality. These lower-quality images made mapping ocean rims like trying to identify a face through a fogged window. Modern, high-resolution images offer the chance to clear the glass, so to speak.

The researchers started with today's higher-quality images and applied a method that has already been used to identify ancient shorelines on Earth. They combined this method with traditional mapping tools like photogeologic mapping and spectral analysis.

The scientists examined a possible shoreline in a promising three-crater system open to the northern plains, a potential ocean. They found that when examined at high resolution, these shorelinelike landforms broke down and did not match what they would have expected of an ocean shoreline. The geologic patterns were instead more consistent with differences in erosion over layered rock types.

These results don't necessarily refute the idea of a Martian ocean: It is possible that these landforms represent shorelines that have broken down much more than any we have seen on Earth, but the researchers suggest that it would take extremely compelling evidence to support that kind of claim. Still, their work does not preclude the possibility of other shorelines elsewhere on the planet, and they offer their methods as a way for scientists to reexamine possible shores with updated, high-resolution images, clearing the foggy glass and rooting out the truth about water history on Mars and elsewhere in the solar system. (*Journal of Geophysical Research: Planets*, https://doi.org/10.1029/2018JE005837, 2019) **—Elizabeth Thompson, Freelance Writer**

How Do Main Shocks Affect Subsequent Earthquakes?

When a fault ruptures during an earthquake, its motion deforms the surrounding crust. The resulting changes in stress often generate additional, smaller earthquakes known as aftershocks. Since the late 19th century, scientists have described how the rate of aftershocks decreases systematically over time. However, the equally fundamental effect of how a main shock influences the aftershock size distribution has not yet been quantified.

Gulia et al. present a new approach to determining this impact. They applied a stacking procedure to 31 high-fidelity records of earthquake sequences that included large (magnitude ≥ 6) tremors in California, Alaska, Japan, and Italy to analyze the effects of main shocks on subsequent earthquake statistics. Stacking is a commonly applied technique in signal processing to enhance the signal-to-noise ratio; this is the first time the approach has been applied to time series of earthquake size distribution.

The researchers' results indicate that immediately following each main shock, the average size distribution of the aftershocks—called the *b* value—increases by 20%–30% and typically remains elevated for at least the next 5 years. This trend implies that the chance that larger earthquakes will subsequently occur decreases considerably, especially in the immediate vicinity of the affected fault, where the observed *b* value increase is the most pronounced.

On the basis of these findings, the authors propose a new empirical relationship to describe how *b* values change over time. Because most current forecasting models typically overestimate the risk associated with aftershocks, the proposed equation should provide an important basis for more realistic statistical assessments of aftershock hazard. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL080619, 2018) **—Terri Cook, Freelance Writer**

Children help salvage and remove debris after the 2015 earthquake in Nepal. New research explores how main shocks might affect damaging aftershocks in earthquakes like this one. Credit: NurPhoto/NurPhoto/Getty Images

Explaining the Genesis of Superdeep Diamonds

Although the vast majority of diamonds form in Earth's lithospheric mantle at depths between 140 and 200 kilometers, about 1% of mined diamonds originate at much greater depths. As the only direct samples from Earth's sublithospheric regions, these "superdeep diamonds" offer unique geochemical information about our planet's inaccessible interior.

Despite the seeming ubiquity of temperature and pressure conditions favorable to diamond formation throughout the deep mantle, analyses of inclusions in superdeep diamonds indicate that most form within two narrow zones: between 250 and 450 kilometers and between 600 and 800 kilometers in depth. To date, no hypothesis has satisfactorily explained the cause of the intermediate diamond-forming gap, which lies within the mantle transition zone.

Zhu et al. propose a novel explanation for superdeep diamonds' puzzling depth distribution. Building on previous research suggesting that these unusual gems result from reactions between iron in the mantle and carbonates in subducting slabs of oceanic crust, the team conducted a series of laser-heated, diamond anvil cell experiments to test whether the interactions are feasible under the pressure-temperature conditions present in these settings.

By tracking diamond formation in real time, the team was able to determine the rate and conditions under which diamonds were produced from the reactions between metallic iron and magnesite, a magnesium carbonate mineral. The results indicate that diamonds can form at the mantle-slab interface and that higher temperatures promote carbonate-metal reactions, whereas higher pressures inhibit them.

The authors observed a threefold drop in reaction rate at pressures and temperatures corresponding to depths below about 475 kilometers. The only exception they found was at conditions equivalent to 600- to 800-kilometers depth, where subducting slabs encounter the top of the lower mantle. The researchers suggest that the resulting stagnation causes the accumulation of the reactants and the slabs to warm up, creating conditions once again favorable for diamond formation.

In addition to illuminating the importance of reaction rates to the depth distribution of superdeep diamonds and offering an explanation for their rarity within the mantle transition zone, this study demonstrates the feasibility of using real-time tracking to boost our understanding of the reaction kinetics of complex mantle-slab interactions. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL080740, 2018) **—Terri Cook, Freelance Writer**

Very Warm Water Observed Along West Antarctic Ice Shelf

The front of the western Getz Ice Shelf, one of the greatest sources of basal ice shelf melt in Antarctica. Credit: NASA

One of the most important sources of the dense, oxygen- and nutrient-rich bottom waters that drive global ocean circulation is Antarctica's Ross Sea. The cold, salty waters that form in this deep embayment play a crucial role in regulating heat and the availability of oxygen and vital nutrients throughout the world's oceans.

A significant source of freshwater flowing into the Ross Sea is basal melt from the 34,018-square-kilometer Getz Ice Shelf, which stretches for 650 kilometers along the West Antarctica coast. Because the coastal current steers meltwater from this ice shelf into the Ross Sea, the Getz Ice Shelf's accelerating basal melt rate has the potential to alter bottom water formation there. Yet despite the region's importance, dedicated observations near the Getz Ice Shelf's western front have been extremely limited to date.

Now *Assmann et al.* present 2 years of continuous velocity and temperature records from several moorings deployed at depths of 600–800 meters in a trough that cuts across the continental shelf west of Siple Island. This is one of the areas where warm Circumpolar Deep Water, which has been linked to the rapid thinning and melting of several West Antarctic ice shelves, can reach the Getz Ice Shelf.

The data show that there is a continual flow of Circumpolar Deep Water through the Siple Trough. Although this water often undergoes slight cooling or freshening as it approaches the continent, the data indicate that on frequent occasions undiluted deep water of up to 1.5°C—some of the warmest ever observed at an ice shelf front in Antarctica—reaches the western Getz Ice Shelf front.

The authors' analysis indicates that a combination of wind stress and upwelling at the edge of the continental shelf controls the presence of the warm deep water in this area, although the authors caution that the paucity of data from this region limits their ability to draw robust conclusions. Regardless, this paper is likely to be of great interest to oceanographers and climate scientists who are grappling with the rapid changes occurring in a region with wide-ranging impacts on Earth's oceans. (*Geophysical Research Letters*, https://doi.org/10.1029/2018GL081354, 2019) **—Terri Cook, Freelance Writer**

Ocean Warming Resumes in the Tropical Pacific

EOS CENTENNIAL COLLECTION
AGU100 ADVANCING EARTH AND SPACE SCIENCE

Waves crash against a seawall in La Jolla, Calif. Higher Pacific sea levels increase coastal flooding risks. Credit: iStock.com/SherryVSmith_Images

Following a significant increase in globally averaged surface temperatures during the last quarter of the 20th century, this warming trend decelerated between 1998 and 2013. Because the slowdown did not match the sustained increase in anthropogenic greenhouse gas emissions, this so-called global warming hiatus triggered intense scientific and public debate. Numerous scientists have argued that the hiatus resulted from a redistribution of heat from the upper to the deep oceans that is associated with natural variations in Earth's climate system such as the El Niño–Southern Oscillation and the Pacific Decadal Oscillation.

Cha et al. present evidence that since 2011, the tropical Pacific Ocean has been shifting toward more El Niño–like conditions that coincide with a resumption of global warming. Using hindcast simulations from the Regional Oceanic Modeling System combined with ensemble empirical mode decomposition statistical analyses, they determined that the tropical Pacific is experiencing a slow, decadal-scale shift that is distinct from interannual, El Niño–like variability.

The results indicate that the observed changes are strongly correlated with a shift in trade wind patterns related to an alteration in the phase of the Pacific Decadal Oscillation. Because these winds help control the speed of the Equatorial Undercurrent, the new pattern has altered the tropical Pacific's upper ocean circulation and contributed to the regional redistribution of heat, resulting in sea surface warming in the central eastern tropical Pacific. The authors argue that these changes have contributed to substantial increases in sea level in the central eastern tropical Pacific, as well as subsurface cooling and corresponding decreases in sea level in the western tropical Pacific.

By linking changes in trade wind patterns to ocean circulation and surface warming trends, the researchers offer convincing support that the Pacific Decadal Oscillation and other natural, longer-term variations in climate may contribute substantially to ocean warming. Because this proposed mechanism has important implications for predicting sea level and ocean warming on decadal timescales, they argue that ocean-atmosphere interactions, which were not included in this study, should be incorporated into future research to better understand climate-related processes in the tropical Pacific. (*Geophysical Research Letters,* https://doi.org/10.1029/2018GL080651, 2018)

—Terri Cook, Freelance Writer

Ocean Sciences

Coordinator & Instructor/Asst. Teaching Professor, Hydrographic Science

The School of Ocean Science and Engineering (SOSE) at The University of Southern Mississippi (USM) invites qualified applicants for a full-time, 12-month, position as Coordinator & Instructor (or Assistant Teaching Professor, if holding a terminal degree) of the Hydrographic Science B.S. and M.S. programs in the Division of Marine Science. These two programs are recognized at the Category B and A levels, respectively by the International Hydrographic Organization, the International Federation of Surveyors, and the International Association of Cartographers. 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.

Applicants must hold a M.S. degree in hydrography, oceanography, or a related field with 5 years or more of hydrographic surveying experience. Preference will be given to candidates with a Ph.D. in hydrography, oceanography, or a related field and post-doctoral experience, and a demonstrated record of service, grant development, communication, and commitment to diversity. The candidate is expected to coordinate, execute, and continue to develop a comprehensive academic program in hydrography, at the undergraduate and graduate level, in accordance with International Hydrographic Organization (IHO) standards. The undergraduate program is a 4-year curriculum providing a Bachelor of Science degree in Marine Science with emphasis in Hydrography. The graduate program is an intensive 1-2 year curriculum with significant classroom coursework and field exercise, including a capstone project. The successful candidate is expected to develop and deliver courses in hydrography and related sciences and should demonstrate the potential to contribute across disciplines and promote the continued interdisciplinary growth of the academic and research programs within the SOSE. The candidate can expect to be involved in research activities with the Hydrographic Science Research Center, but the primary focus of this position is teach-

ing. Salary packages will be nationally competitive and commensurate with experience. Applications must be submitted online at https://jobs.usm.edu. For inquiries about the position, contact Stephan Howden, Chair of the Search Committee, at 1-228-688-5284 or Stephan.howden@usm.edu. Review of applications begins 1 May 2019 and continues until the position is filled, with an anticipated start date of August 2019.

The University of Southern Mississippi is an Equal Opportunity/ Affirmative Action Employer.

Instructional Assistant Professor of Oceanography

The Department of Oceanography at Texas A&M University invites applications for a full-time non-tenure track Instructional Assistant Professor. This is a 9-month appointment for an initial three-year term, renewable contingent on performance and continued funding. We seek an energetic educator to lead efforts to develop cutting-edge fundamental Ocean Observing and Analysis courses, and expand our catalog of online courses. The successful candidate will teach two courses per semester using effective pedagogical techniques in a combination of classroom and online settings, and develop new online course materials. Teaching opportunities also include field, high impact learning, and study abroad courses.

The successful candidate may augment the 9-month appointment with research funding or by teaching undergraduate research and field courses and/or other courses in their area of expertise. In addition to teaching, the successful candidate is expected to make contributions to departmental service and will have opportunities to explore cutting-edge teaching technologies or practice. This appointment includes the ability to seek extramural funding, conduct collaborative research with other members of the faculty, use department facilities, and publish research results. At the time of employment, candidates must have a Ph.D. in Oceanography or a related discipline in addition to higher education teaching experience.

The College of Geosciences at Texas A&M University is a unique institution committed to fundamental Earth systems research across four Departments: Atmospheric Sciences, Geography, Oceanography, and Geology and Geophysics. The College hosts the Texas Sea Grant, the Geochemical and Environmental Research Group (GERG), and the International Ocean Discovery Program (IODP). The college has established a teaching/research facility in Costa Rica and a teaching facility near San Miguel de Allende, Mexico. This appointment includes the opportunity to work across departments and programs in the College and lead international coursework to maximize educational opportunities for our undergraduates.

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

The University is dedicated to the goal of building a culturally diverse and pluralistic faculty and staff committed to teaching and working in a multicultural environment. We strongly encourage applications from women, underrepresented ethnic groups, veterans, and individuals with disabilities. Texas A&M University also has a policy of being responsive to the needs of dual-career partners (http://dof.tamu.edu/Faculty-Resources/dual-career-partner-placement). The College of Geosciences is committed to creating a diverse and inclusive climate for faculty, graduate students and undergraduate students. We actively work to recruit and retain a diverse cohort of undergraduate students. We seek a colleague with a track record that will complement our education mission to train a diverse pool of students for future success in applied, academic, and government positions as geoscientists.

Interested candidates should submit electronic applications to: http://apply.interfolio.com/52944 and must include the following: curriculum vita, statement of teaching philosophy, statement of research interests, and the names and addresses of at least three references. Screening of applications will begin May 1, 2019, and will continue until the position is filled.

Questions regarding the position may be directed to the Chair of the Instructional Assistant Professor Search Committee by emailing Dr. Steve DiMarco at sdimarco@tamu.edu

Planetary Sciences

Scientist, Small Bodies of the Solar System

The Jet Propulsion Laboratory, California Institute of Technology invites applications for a Scientist in areas relevant to understanding small bodies of the Solar System, including comets, asteroids, Kuiper Belt objects, and Centaurs. The Scientist

will be responsible for maintaining a research portfolio focused on conducting cutting-edge scientific research within the small bodies field, including using ground-based observatories, space-based mission data, and/or theoretical modeling. The Scientist will develop an independently-funded research program, publish findings in the peer-reviewed literature, and collaboratively pursue new mission and/or instrument opportunities focusing on the exploration of small bodies.

This position requires the following qualifications:

- PhD in Astronomy, Planetary Science, or a related scientific discipline;
- Advanced knowledge of one or more of the following areas related to small Solar System body science: discovery, characterization of compositional/physical properties; dynamical, geophysical, or geological modeling;
- Demonstrated experience in conceiving, defining, and conducting self-directed scientific research;
- Experience in acquisition, analysis, and/or interpretation of ground-based or spacecraft mission data of small bodies;
- A strong interest in applying the above technical skills to planetary exploration;
- A demonstrated professional reputation as a productive researcher with a track record of publications in peer-reviewed journals;
- Excellent oral (including public speaking) and written communication skills, and the ability to work as part of a team.

The following qualifications are preferred:

- 2-3 years of related post-doc experience;
- Demonstrated interest in utilizing the next-generation astronomical observatories (e.g. JWST, LSST) and/or planetary science space missions;
- A history of writing successful proposals, including observing proposals.

Please visit https://jpl.jobs/ (Job ID 2019-10610) for a full description. Complete applications will include a cover letter describing the applicant's vision for their role at JPL as a leader and contributor in the field of small body research, a curriculum vita including a bibliography of refereed and other work, a statement on research experience and research objectives, and contact information for at least three professional references. Applications received by June 15, 2019 will receive full consideration.

Leibniz-Institut für Ostseeforschung Warnemünde

Universität Rostock Traditio et Innovatio

At the Leibniz Institute for Baltic Sea Research – Warnemuende (IOW) the position of the

Director

is available from 1st October 2021.

The IOW is a member of the Leibniz Association (WGL e.V.). With its four scientific departments Physical Oceanography and Instrumentation, Marine Chemistry, Biological Oceanography and Marine Geology, it conducts basic marine research within the framework of a multi-year research programme. The focus is on coastal, marginal and shelf seas with a special focus on the Baltic Sea. Through an administrative agreement with the Federal Maritime and Hydrographic Agency, the IOW is charged with the tasks of environmental monitoring of the Baltic Sea within the framework of HELCOM.

The position of the director encompasses also a

W3 professorship for Earth Systems Analysis

at the University of Rostock.

IOW and the University of Rostock invites applications of outstanding scientists in earth system analysis – preferably in marine science. Experiences in leadership, science administration and management are required. The Director is responsible for the scientific management of the IOW and for representing the Institute externally and internally. In particular, impulses for research design and structures and the lead in the program budget of the IOW as well as constructive cooperation in the profile line Maritime Systems of the Interdisciplinary Faculty of the University of Rostock are expected. The teaching obligation is 2 SWS.

For further inquiries, please contact:
Prof. Dr. Detlef Schulz-Bull, chair of appointments committee
Telefon: +49 381 5197 310
e-mail: detlef.schulz-bull@io-warnemuende.de

Qualifications are as per § 58 of the Higher Education Act of the State of Mecklenburg-Vorpommern (LHG M-V). Details will be explained on request.

Please direct your application with the usual documents ***no later than 30th June 2019*** preferably by e-mail to:

dekan.mnf@uni-rostock.de or to

Universität Rostock
Dekan der Mathematisch-Naturwissenschaftlichen Fakultät
18051 Rostock

For the full announcement, please consult the internet at:
www.uni-rostock.de/stellen/professuren/

Greetings from the Pacific!

I'm Rika Anderson from Carleton College, and I study the incredible diversity of microbes and viruses that inhabit the ocean. In this photo, two swimmers balance on the back of HOV *Alvin* as they work through the choreographed process of recovering the sub to the deck of R/V *Atlantis*. The sub had just completed a successful dive to hydrothermal vents on the East Pacific Rise, 2,500 meters below, to collect samples for me and for all of the other early-career scientists (ECS2018) on board. Once it was safely back on board, I began a long night of filtering seawater and helping my colleagues process their samples.

—Rika Anderson, Carleton College, Northfield, Minn.

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ADVANCING EARTH AND SPACE SCIENCE

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Etna International Training School of Geochemistry, Etna Volcano (Italy)

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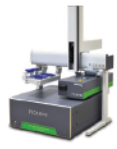
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