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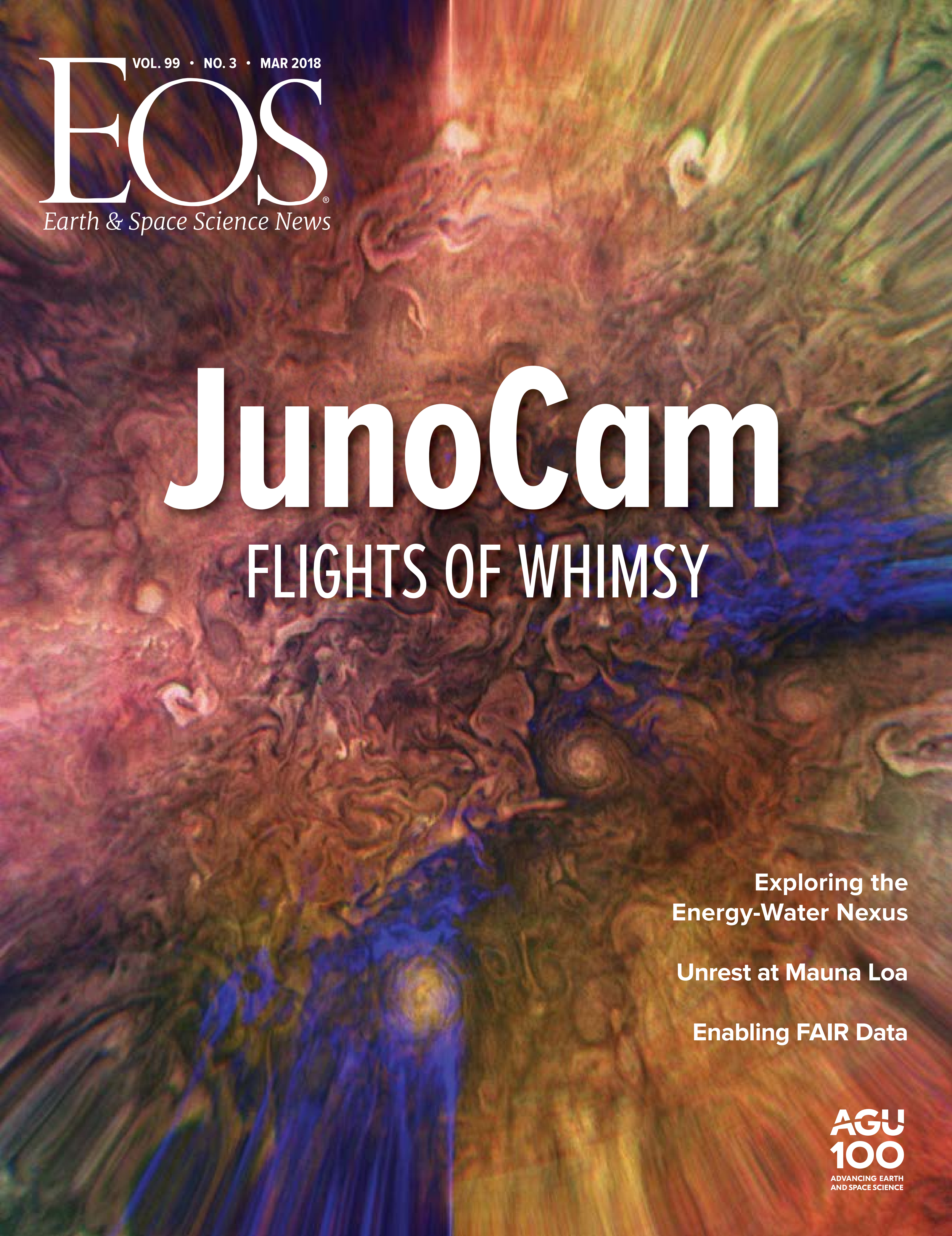

JunoCam

FLIGHTS OF WHIMSY

Exploring the Energy-Water Nexus

Unrest at Mauna Loa

Enabling FAIR Data

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ADVANCING EARTH AND SPACE SCIENCE

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An image of Jupiter's south pole, when radially stretched and falsely colored, starts to resemble the iris of an eye. Credit: RobertT; Original image: NASA/Juno Mission

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Christine W. McEntee, Executive Director/CEO

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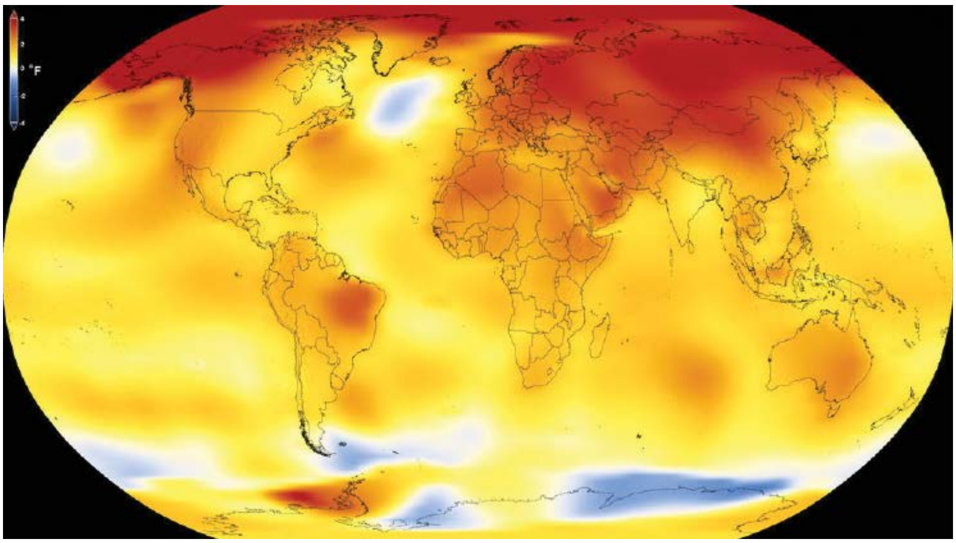
Global Average Temperatures in 2017 Continued Upward Trend



This map shows Earth's average global temperature from 2013 to 2017, compared with the average temperature from 1951 to 1980. Yellows, oranges, and reds show regions warmer than the 1951–1980 average, with redder hues indicating greater warmth. Credit: NASA's Scientific Visualization Studio

Earth's average surface temperature in 2017 placed second or third highest on record, according to new analyses by NASA and the National Oceanic and Atmospheric Administration (NOAA).

NASA's analysis, released on 18 January during a press conference, showed that 2017 is the second-hottest year on record and that the average global temperature rose 0.9°C (1.6°F) above the 1951–1980 average. The size of the temperature increase was calculated from thousands of measurements from more than 6,000 weather stations, ship- and buoy-based observations of sea surface temperatures, and measurements across Antarctic research stations.

An analysis from NOAA, released during the same press conference, ranked 2017 as the third-warmest year on record. Specifically, NOAA scientists found that temperatures rose 0.84°C (1.5°F) above the 20th-century average (1901–2000).

"Despite colder than average temperatures in any one part of the world, temperatures over the planet as a whole continue the rapid warming trend we've seen over the last 40 years," said Gavin Schmidt, director of NASA's Goddard Institute for Space Studies in New York, at the press conference.

The World Meteorological Organization (WMO) also released a 2017 climate report on 18 January that placed last year among the top three warmest years on record. According to WMO's figure for 2017, the world's average surface temperature has risen 1.1°C since preindustrial times. The year 2016 remains the warmest on their record, with temperatures reaching 1.2°C above those of the preindustrial era.

Atmosphere to Ocean

At the NASA/NOAA press conference, Deke Arndt, chief of the climate monitoring branch at NOAA's National Centers for Environmental Information, described warming trends in different layers of the Earth system. He explained that temperatures in the middle troposphere, between 3,000 and 10,000 meters altitude (where most commercial jets fly), ranked third or fourth warmest on record, depending on which group assembled the data. The upper ocean, which scientists know captures much of the excess energy trapped in the atmosphere, also reached its largest heat content on record in 2017, Arndt said.

The Warming North

In the Arctic, which warms at a rate faster than the rest of the globe, minimum sea ice extent continued to fall in 2017, the newly released analyses show. Similar results were highlighted in December, when NOAA released its annual Arctic Report Card (see http://bit.ly/Showstack-2017). Scientists concluded in that report that the mean Arctic temperature exceeded the average by 1.6°C in 2017 (the second-highest average after 2016) and that March 2017 had the lowest maximum sea ice extent on record.

Observations of Arctic conditions in 2017 "confirm that the Arctic shows no signs of returning to the reliably frozen state that it was in just a decade ago," said Jeremy Mathis, director of NOAA's Arctic Research Program, when the report card was unveiled in December 2017.

At play here is a key feedback mechanism, Arndt noted at the January press conference. Sea ice, with its bright white surface, reflects solar energy back into the atmosphere, helping to cool surface temperatures. But when sea ice melts, it exposes the darker surface of the underlying water, which absorbs solar energy. And the more sea ice that melts, the more energy is absorbed—a positive feedback mechanism of accelerating warming and ice loss, he said.

ENSO Effects

Some warmer than average temperatures can be attributed to a global climate phenomenon called the El Niño–Southern Oscillation, or ENSO. Two distinct temperature and weather trends make up ENSO. One is El Niño, in which the tropical Pacific Ocean warms; the other is La Niña, in which it cools. El Niño and La Niña can bring anomalously cool or warm, or dry or wet, conditions to different regions of the world. On small timescales, the El Niño effect can amplify warming signals.

Spanning all of 2015 and the first third of 2016, for example, warming from an extreme El Niño fed into overall observed warming. However, Schmidt stressed that even when scientists statistically remove the effects of El Niño and La Niña from the record, 2017 is still one of the warmest years on record. WMO's analysis, similarly, showed that 2017 was the warmest year without an El Niño. What's more, studies have shown that as more greenhouse gases are released, extreme El Niños could become more frequent.

By **JoAnna Wendel** (@JoAnnaScience), Staff Writer

Climate Change Is National Security Risk, Congress Members Warn

A bipartisan group of more than 100 members of the U.S. Congress urged President Donald Trump to recognize climate change as a national security risk, and they called on him to reconsider this "omission" from the administration's National Security Strategy issued on 18 December 2017.

"As global temperatures become more volatile, sea levels rise, and landscapes change, our military installations and our communities are increasingly at risk of devastation. It is imperative that the United States address this growing geopolitical threat," states the letter, signed by 106 members of Congress and released on 12 January (http://bit.ly/climate-letter-2017). Signatories include Rep. Elise Stefanik (R-N.Y.), chair of the House Committee on Armed Services' Emerging Threats and Capabilities Subcommittee, and Rep. James Langevin (D-R.I.), the committee's ranking Democratic member.

The letter, which they also sent to Secretary of Defense James Mattis, quotes testimony Mattis gave before the committee in January 2017. He stated then, "I agree that the effects of a changing climate—such as increased maritime access to the Arctic, rising sea levels, desertification, among others—impact our security situation."

The letter also notes that the National Defense Authorization Act, which Trump signed into law on 12 December 2017, states that climate change "is a direct threat to the national security of the United States" and calls for a report on vulnerabilities to military installations and combatant commander requirements resulting from climate change over the next 20 years.

"Failing to recognize this threat in your National Security Strategy represents a significant step backwards on this issue and discredits those who deal in scientific fact," the letter to Trump states.

Stark Difference from the Obama Strategy

The White House's National Security Strategy differs starkly from the Obama administration's February 2015 strategy, which identified climate change as a top strategic risk to the country, and a September 2016 White House memorandum that cited threats of climate change to national security.

"Leaders throughout the defense and intelligence communities agree that climate change poses a direct threat to our national security, a position that was affirmed by Congress in the 2018 National Defense Authorization Act signed into law by the president himself," Rep. Langevin told *Eos.* "We have not yet received a response to our bipartisan request; however, it is my hope that the President will take this opportunity to listen to his own national security experts and reincorporate climate change into the National Security Strategy."

"Not So Fast"

"The significance of this letter is that it demonstrates there is bipartisan support in Congress for addressing climate security issues," John Conger, senior policy adviser with the Center for Climate and Security, told *Eos.* The center is a Washington, D. C.–based nonpartisan policy institute. Conger served in the Department of Defense (DOD) as principal deputy undersecretary from 2015 to 2017. Earlier at DOD, he oversaw a portfolio including climate change and energy security while performing the duties of the assistant secretary of defense for energy, installations, and environment from 2009 to 2015.

Conger said that when the "very forward leaning" Obama administration moved ahead on climate initiatives, Congress said, "not so fast." Now, with the Trump administration trying "to take a step back on climate," Congress is again saying, "not so fast."

"There are clearly many Republicans who think that [climate security] does need to be addressed [and] it shouldn't be ignored," he continued.

"It's encouraging to see members of Congress, both Republicans and Democrats, urging the president to include climate change in the National Security Strategy," Mark Reynolds, executive director of Citizens' Climate Lobby, told *Eos.* The lobby is a nonpartisan grassroots advocacy organization based in Coronado, Calif. "The mass migration of millions of climate refugees will create humanitarian crises and destabilize nations. Our armed forces, already stretched to the max, will be called upon to respond to these crises, and so it is foolhardy to ignore the risks posed by climate change."

Letter Sends a Strong Signal

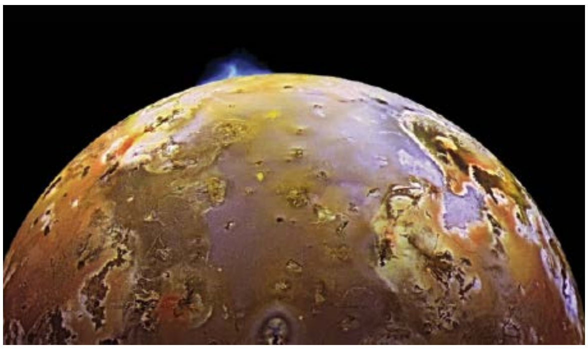
David Michel, a fellow in the environmental security program at the Stimson Center, a nonpartisan policy research center in Washington, D. C., noted that Trump based his administration's new National Security Strategy on four pillars: protecting the United States from threats, promoting American prosperity, preserving peace, and advancing American influence. "The strategy's failure to recognize global climate change as a serious threat to U.S. welfare at home and our interests abroad undermines all four of these goals. The recent letter to the president, signed by a bipartisan group of over 100 representatives, reflects this conviction," Michel told *Eos.*

Although Michel said he doubted that the letter would change the president's mind, "it does send a strong and public signal of support to the Department of Defense and other agencies for their continuing efforts to identify, evaluate, and prepare for the growing climate risks to America's security and global stability alike."

A bipartisan letter from 106 members of Congress to the Trump administration notes that U.S. military installations are increasingly at risk as global temperatures become more volatile, sea levels rise, and landscapes change. Pictured are U.S. aircraft carriers in port at Naval Station Norfolk in Virginia, the world's largest naval station, in December 2012. Credit: Stocktrek Images/Getty Images

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

Scientists Discover Stromboli-Type Eruption on Volcanic Moon



NASA's Galileo mission captured this composite image of an eruption on Jupiter's moon Io in 1997. The erupting volcano is Pillan, close to Io's equator. Credit: NASA/JPL/University of Arizona

Twenty years ago, "something huge, powerful, and energetic happened at the surface of Io," said Ashley Davies, a volcanologist at NASA's Jet Propulsion Laboratory in Pasadena, Calif. Davies and his colleagues think they've discovered a type of eruption never before spotted on one of the most volcanically active bodies in the solar system.

The researchers stumbled on the eruptive evidence in data from NASA's Galileo orbiter mission, which explored the Jupiter system from 1995 to 2003. They think that the data reflect a Strombolian eruption, a violent event named for Italy's energetic Stromboli volcano.

But wait, you ask; didn't Galileo plunge into Jupiter's atmosphere at the end of its mission, way back in 2003? Well, yes, it did. But the orbiter at that point had collected so much data about the Jovian system and its Galilean moons (Ganymede, Io, Callisto, and Europa) that scientists still haven't waded through them all, even 14 years later.

Davies presented the unpublished research in December at the 2017 AGU Fall Meeting in New Orleans, La. (http://bit.ly/Io-Davies-2017).

Serendipitous Data

Io's surface is constantly gushing lava—every million or so years, the moon's entire surface completely regenerates. From towering lava fountains that can reach 400 kilometers high to violently bubbling lava lakes that burst through freshly cooled crust, these oozing lava fields can stretch many thousands of square kilometers.

On this 3,600-kilometer-diameter moon, eruptions take place "on a scale that simply isn't seen on Earth today but was once common in Earth's past," Davies said. The scale, frequency, and intensity of Io's eruptions make it a perfect analogue of early Earth, he continued, back when our blue planet was just a barren hellscape of lava.

Davies found evidence for the eruption he reported at the Fall Meeting in data from Galileo's Near Infrared Mapping Spectrometer (NIMS), which took pictures of the moon in the infrared wavelengths. This instrument allowed researchers to measure the thermal emissions coming off the volcanically active moon.

Stromboli Eruption

While looking through the NIMS temperature data, Davies and his colleagues spotted a brief but intense moment of high temperatures that cooled unusually quickly. This signal showed up as a spike in heat from a region in the southern hemisphere called Marduk Fluctus. First, the researchers saw a heat signal jump to 4–10 times higher than background levels. Then, just a minute later, the signal dropped by about 20%. Another minute later, the signal dropped by another 75%. Twenty-three minutes later, the signal had plummeted to the equivalent of the background levels.

This signature resembled nothing Davies had seen before from Io. The lava flows and lava lakes are familiar: Their heat signals peter out slowly because as the surface of a lava flow cools, it creates a protective barrier of solid rock over a mushy, molten inside. Heat from magma underneath conducts through this newly formed crust and radiates from Io's surface as it cools, which can take quite a long time.

This new heat signature, on the other hand, represents a process never before seen on Io, Davies said: something intense, powerful, and—most important—fast.

There's only one likely explanation for what the instruments saw, explained Davies, whose volcanic expertise starts here on Earth. Large, violent eruptions like those seen at Stromboli are capable of spewing huge masses of tiny particles into the air, which cool quickly.

As chance would have it, Galileo was likely in the right place at the right time to see the signatures of such an eruption on Io.

Composition Questions

Why do scientists care about an eruption on a moon nearly 630 million kilometers away?

The temperature of Io's lava reveals what kind of material makes up the moon, Davies said. For instance, if the rising magma erupts at temperatures of 1,800 or 1,900 K, it's probably composed of komatiite, a rock extremely low in silicon. This rock is found rarely on Earth today, although scientists think it was commonly found during the Archaen eon 2.5–3.8 billion years ago, Earth's early volcanic days. However, if the magma erupts at 1,400 or 1,500 K, that means it's made primarily of basalt.

The lava's composition and temperature, in turn, can tell scientists what's going on in the moon's interior. Scientists aren't yet sure how the stretching from Jupiter's gravity affect Io's innards. Some have hypothesized that the grinding from the gravitational pull heats Io's interior enough to produce a subsurface magma ocean.

"Instead of being a completely fluid layer, Io's magma ocean would probably be more like a sponge with at least 20% silicate melt within a matrix of slowly deformable rock," said Christopher Hamilton, a planetary volcanologist at the University of Arizona's Lunar and Planetary Science Laboratory, in a prior press release about the push and pull of tidal forces on Io. Hamilton was not involved in this research by Davies and colleagues.

To help refine such hypotheses, scientists need the composition of melt and how hot it gets, Davies explained. But figuring out the precise heat of Io's lava is tricky because regardless of its starting temperature, it cools relatively quickly. So even if the lava is made of komatiite, scientists may not be able to catch the signal before it cools to a temperature resembling that of basalt.

The good news about large, Stromboli-type eruptions is that they expose vast areas of lava at incandescent temperatures. "So what we end up with is an event, if you can capture it, that will show a lot of lava at the temperature it erupted," Davies said.

Current and future probes can then home in on Marduk Fluctus for more detailed surveys to reveal such precise temperature data, Davies explained. However, until such future instruments launch, scientists still have mountains of Galileo data to get through.

By **JoAnna Wendel** (@JoAnnaScience), Staff Writer

Corn's Ancestor Could Help It Go Green

Ears of corn (maize), showing a wide range of colors and shapes that reflect different varieties. Credit: International Maize and Wheat Improvement Center, CC BY NC-SA 2.0 (http://bit.ly/ccbyncsa2-0)

Corn has changed dramatically since humans in Mexico first encountered its ancestors nearly 9,000 years ago. These changes can readily be seen by examining teosinte, corn's ancient forebear and a plant that still grows today.

Teosinte looks more like a weedy grass than a potential meal. An ear of teosinte contains just 5–12 kernels, each of which is sealed tightly in a stony casing.

But it's the part of the plant that grows below ground that's now intriguing scientists. Researchers think that studying teosinte's roots may provide the key to one day making corn more adaptable and less reliant on chemical fertilizers.

Corn, or maize, became the sugary, high-yield crop it is today through thousands of years of selective breeding and, in the past century, the use of chemical fertilizers. "By domesticating and breeding modern maize, we may have [decreased] some of its ability to adapt to organic agricultural systems that are less reliant on the synthetic fertilizer that we've been spoon-feeding it for the past 60–70 some years," said Jennifer Schmidt, a plant scientist at the University of California, Davis.

Prior studies have cataloged how humans have shaped corn above ground, but Schmidt and her colleague Amélie Gaudin did something different. They looked for differences in the bacteria and fungi that colonize the roots of teosinte and modern corn. Schmidt presented her team's research in December at the 2017 AGU Fall Meeting in New Orleans, La. (http://bit.ly/Schmidt-2017).

Teosinte Versus Corn: An Evolution of Roots

Conventional agriculture is highly reliant on chemical fertilizers, which can pollute air, contaminate water, and even create oxygen-poor "dead zones" in the ocean. Reducing the amount of fertilizer used to produce food may necessitate the development of crops that thrive without nutrient-rich fertilizers, Schmidt told *Eos*. In other words, she explained, if we want a different kind of agriculture, we may need a different kind of plant.

Big-time commercial crops like corn have been engineered to thrive on large, conventional farms where they are packed into tight rows and their roots are regularly inundated with food and water. By selecting the plants that grow best under these conditions, we've changed corn's roots, Schmidt continued. Modern corn has fewer, thicker roots, which grow straight down as though they're all inside a narrow tube. These qualities allow corn to efficiently transport lots of nutrients without competing against the plant in the next row of the field.

Teosinte, on the other hand, sends out a large number of thinner, highly branched roots that are better suited to hunting down nutrients and water when they're less available. Researchers like Schmidt think that the adaptations that allow teosinte to thrive in such conditions could give us insights into how to make corn a more efficient and eco-friendly crop.

Clues in the Microbiome?

As corn's roots have diverged from those of teosinte and adapted to modern agriculture, researchers think that the microscopic communities that the plants foster in the surrounding soil may have changed too. To help themselves extract more usable nutrients from the soil, plants often form symbiotic relationships with bacteria and fungi near their roots. They even attract specific types of bacteria and fungi by sending out sugars and chemical signals through their roots—food to encourage the growth of their preferred microbiome. In return, the microbes convert essential nutrients like nitrogen into forms the plant can use.

Schmidt and Gaudin are on a quest to identify the genes behind the bacterial and fungal relationships that allow teosinte to succeed in the wild, where nutrients can be scarce.

The team grew two types of modern corn and five varieties of teosinte in a controlled environment. The researchers compared teosinte and modern corn in terms of how fast they grew as well as the microbial and fungal communities found around their roots. They also conducted the experiment using different types of soil: One soil came from an organic farm, and another came from a conventional farm; both had been farmed using these techniques for at least 25 years.

Both modern corn and teosinte grew better in the organic soil, the scientists found. Teosinte is a smaller plant than modern corn, but when the team assessed new growth during the experiment relative to the size of the whole plant, teosinte—with its branched, searching roots—emerged as superior in the organic soil. This means that teosinte's new growth was a bigger percentage of the whole plant compared with that of modern corn. The team also found that the fungal communities around the teosinte roots differed from those

A comparison of teosinte and modern corn. Credit: NSF

found at the roots of modern corn. Unexpectedly, the bacterial communities for teosinte and corn were similar.

"It's important to note that this study was conducted with soils that have been farmed for 25 years," said Timothy Bowles, an agroecologist at the University of California, Berkeley, who was not involved in the research. "These soils may have lost some of the wild microbes" that help teosinte thrive, he explained.

Bowles suggested that future studies using wild soils from teosinte's natural habitat might reveal bigger differences between the bacteria around the roots of teosinte and modern corn.

Helping Corn Fend for Itself

Identifying the traits that allow teosinte to thrive in organic soils could allow us to create crops better suited to the techniques of sustainable agriculture. The goal is to find the genes behind teosinte's success and breed them into new varieties of corn created specifically for more eco-friendly farming.

This study looked at only a few varieties of teosinte, but its findings encourage assessing even more. "One of the promising things coming out of this work is that it shows variation in the communities colonizing the roots of these plants—that variation has a genetic component that we can screen plants for," said Bowles.

So could we breed more eco-friendly corn? Perhaps. But "plant breeding is a long process; it could take 10–20 years to create something commercially available," said Schmidt. It also depends on the interest on the part of companies developing new crops.

"It's promising that there is so much interest in developing microbial products to replace fertilizers," said Schmidt. "This goes one level below that, so you're changing the seed instead of the soil."

By **Alex Fox** (email: almfox@ucsc.edu; @Alex_M_Fox), Science Communication Program Graduate Student, University of California, Santa Cruz

A Decade of Atmospheric Data Aids Black Hole Observers

The Atacama Pathfinder Experiment (APEX) 12-meter telescope in Chile's Atacama Desert, shown here, will join others to image the immediate surroundings of a black hole in April. Credit: European Southern Observatory/H. H. Heyer, CC BY 4.0 (http://bit.ly/ccby4-0)

A worldwide collaboration of radio astronomers called the Event Horizon Telescope (EHT) is taking a close look at the atmosphere here on Earth to get a better view of an elusive area of deep space. Thanks to the astronomers' recent modeling of the past 10 years of global atmospheric and weather data, they can now predict when nine radio telescopes and arrays scattered around the world are most likely to have the clear view they need to make their extraordinary simultaneous observations.

Their quarry is the perilous boundary of a black hole, called the event horizon, and the surrounding region of space. Their target is not just any black hole: It's the hulking, supermassive black hole that lurks at the heart of the Milky Way.

"You have to get all the participating observatories to collectively agree to give the EHT folks time on the sky when they ask for it…and that's a big deal," said Scott Paine, an astrophysicist at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, Mass., who also happens to be an atmospheric scientist.

Trying to ensure that EHT scientists would make the most of valuable worldwide observing time, Paine advised that they approach the problem scientifically using global atmospheric records. Along with EHT director and SAO astrophysicist Sheperd Doeleman, he spearheaded the creation of a model that predicts the probability of good simultaneous observations at all sites using data gathered by the National Oceanic and Atmospheric Administration (NOAA). Using this new model, the EHT collaboration is coordinating a weeklong observing campaign that will take place in April (see http://eventhorizontelescope.org).

It's not the first time the collaboration will peer at our galaxy's central black hole, which is known as Sgr A*(pronounced "Sagittarius A-star") and is about 4 million times the mass of our Sun. The inaugural attempt took place in April 2017, and they geared up to try again this year, with the expectation of better results. This April and into the future, they hope to achieve the best "seeing" possible for the collection of EHT telescopes and arrays, thanks to newly developed tools for selecting dates and times of optimal meteorological conditions for the overall observing network.

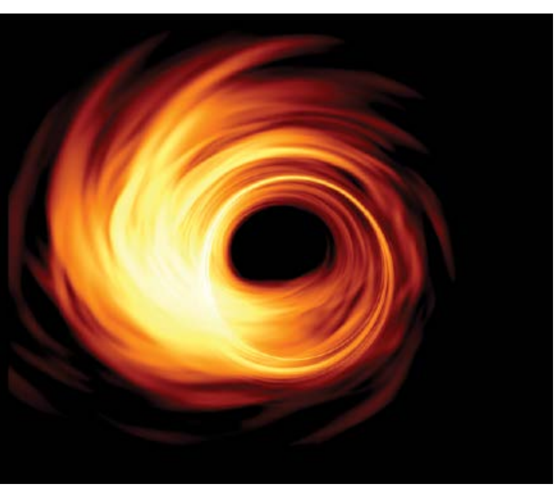
"These tools allow us to determine the ideal observing windows for EHT observations and to assess the suitability and impact of new EHT sites," said Harvard University undergraduate student Rodrigo Córdova Rosado in a recent presentation of this work. Córdova Rosado, a junior who worked on the project with Paine and Doeleman, presented a poster about this research on 9 January at the 231st meeting of the American Astronomical Society at National Harbor in Maryland (see http://bit.ly/Cordova-Rosado-poster).

A Worldwide Telescope Array

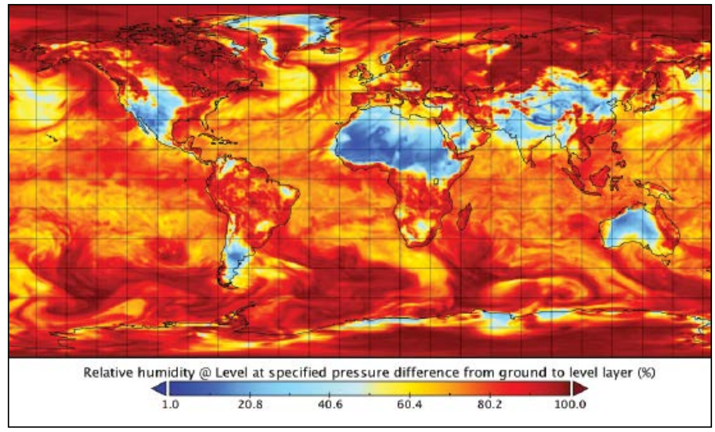
Although a black hole, by definition, does not emit light, gas and dust surrounding the black hole emit copious light as the incredible gravity of the black hole pulls the material into itself. The brilliant glow, in turn, silhouettes the black hole.

Because of the black hole's ultracompact size, imaging its immediate environment requires an observing technique called very long baseline interferometry (VLBI). VLBI coordinates observations from multiple radio telescopes around the globe to amplify the light from a target and increase the signal-to-noise ratio of an observation. The wider the physical footprint of the array used in VLBI is, the stronger and clearer the radio signal is. Astronomers have used VLBI to view stars coalescing from giant gas clouds, and they plan to use it to glimpse protoplanets forming in circumstellar disks.

EHT's nine radio telescopes and arrays at seven observing sites compose the largest VLBI array in the world. Getting onto the observing schedule at any one of the telescopes is competitive, and negotiating for simultaneous observing time on all nine is even more difficult.



A simulation of light emitted by hot gas as it orbits a black hole, viewed from 45° above the orbital plane, similar to what EHT hopes to see. Brightness indicates the intensity of the emitted radio frequency light. The black hole's intense gravity bends light emitted from inner parts of the accretion disk around its event horizon, creating the black hole silhouette seen in the center. Credit: Hotaka Shiokawa



A map of worldwide relative humidity data on 2 February 2012 from NOAA's Global Forecast System. The color gradient shows areas of low (blue) and high (red) relative humidity between 0 and 30 millibars above ground-level pressure—essentially the relative humidity at the surface for GFS data. Researchers with the Event Horizon Telescope collaboration extracted data from maps such as this, generated for many atmospheric layers, to determine the humidity along an observing direction. Credit: Córdova Rosado et al., 2018, http://adsabs.harvard.edu/abs/2018AAS...23115714L; data from NOAA/National Centers for Environmental Information

A Two-Pronged Predictive Approach

Deciding when to observe requires solving two problems at once, according to Paine. "There's the strategic problem," he said, "that is, which week or two weeks are you going to ask for from the observatories."

The second is a tactical problem. "Once you've got your block of time, and you're allowed to use a certain number of days within an allocated period, which ones are you going to trigger observations on?" He added, "We've been looking at both problems."

That's where NOAA comes in. Córdova Rosado tackled the first problem by gathering global weather data from NOAA's Global Forecast System (GFS) recorded from 2007 to 2017 at approximately 6-hour intervals. Because EHT observes using radio waves, the researchers were primarily interested in records of relative humidity, ozone mixing ratio, cloud water vapor ratios, and temperature at each of the sites because each of those atmospheric conditions affects the quality of observations. Córdova Rosado ran those data through an atmospheric model that Paine had created to calculate how opaque the atmosphere appears at EHT's observing frequency of 221 gigahertz, or a wavelength of 1.4 millimeters.

According to Vincent Fish, a research scientist at the Massachusetts Institute of Technology (MIT) Haystack Observatory in Westford, coordinated, ground-based radio observations of the galactic center thrive at 221 gigahertz. "At longer observing wavelengths," he explained in an MIT press release, "the source would be blurred by free electrons...and we wouldn't have enough resolution to see the predicted black hole shadow. At shorter wavelengths, the Earth's atmosphere absorbs most of the signal." Fish was not involved in this research.

EHT Sites Prefer It Dry

Córdova Rosado statistically combined each of the yearly opacity trends to calculate for each day of the year the probability that Sgr A* would have favorable observing conditions simultaneously at all seven sites. The team found that the second and third weeks of April were the best times of year for EHT to observe Sgr A*. The middle of February was a good backup observing window for both the Milky Way's center and another black hole target.

Some sites, like the South Pole Telescope and the Atacama Large Millimeter/Submillimeter Array (ALMA) in Chile, offer remarkably stable opacities throughout the year because the areas enjoy consistently low humidity. For more variable Northern Hemisphere sites, the winter months provide the most favorable observing conditions.

According to Paine, each of the EHT sites may serve a different purpose for each target, either to act as a mission-critical observing location or to enhance the image quality. The team may not need perfect conditions at all sites for every observation.

More Telescopes, More Targets

Although climate change has undoubtedly affected the 2007–2017 NOAA meteorological data, it hasn't significantly influenced the humidity levels that are the most important factor for getting clear radio observations, Paine explained.

Paine described the EHT atmospheric model as the first step in creating what he called a "merit function" that he and his colleagues will use to assess the value of conducting observations on a particular day. Continued access to NOAA's GFS data, he said, will be critical to making the best use of limited observing time.

"[NOAA's] resources are not only used for weather and climate tasks, but they're also getting leveraged for things like astronomy," he said. "We're fortunate to have this resource for optimizing very expensive astronomical observations."

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

Integrating Water Science and Culture for Urban Sustainability

Water and Environmental Global Challenges
Miami, Florida, 23–25 May 2017

Coastal cities increasingly experience flooding events. Population growth and critical socioeconomic dynamics highlight the scientific, cultural, and societal knowledge gaps that affect safe urban development—gaps that raise risk and life uncertainty for coastal dwellers under these hydrologic extremes.

To address these critical scientific and cultural topics, an international workshop was organized by the Institute of Water and Environment of Florida International University (FIU) and the Water Resources Research and Documentation Center of the University for Foreigners Perugia in Italy (see http://bit.ly/water-workshop). Attendees included academics and experts from various Earth and environmental sciences and from engineering, architectural, sociohumanistic, hydroinformatics, and digital geography (geographic information system) disciplines. The workshop also was attended by representatives from the University of Florence and the World Water Assessment Programme of the United Nations Educational, Scientific and Cultural Organization.

This first Italy–U.S. bilateral workshop had several main objectives: to debate the state of knowledge and research; identify common problems and emerging challenges; and establish an innovative, multidisciplinary research and cultural exchange program among Italian universities and FIU. The event had three sessions.

During the first session, presenters discussed existing graduate academic programs and ongoing research related to water sciences and infrastructure design from a security and sustainability perspective for coastal urban systems. The debate confirmed the maturity of water infrastructure design as a research field, with remote sensing and information and communications technology (e.g., in situ ground and water monitoring technology, hydroinformatics, crowdsourced data, and geospatial modeling) advancements contributing to effective understanding, managing, and forecasting of extreme events.

Nevertheless, during the subsequent sessions on common problems and emerging challenges, invited speakers from Italy and the United States confirmed that the complexity and uncertainty of water phenomena still challenge scientists to provide novel guidelines for sustainable engineering approaches. This is especially so in historic cities where social, cultural, architectural, and archaeological constraints limit the applicability of modern solutions.

Presenters recommended investigations into the effectiveness and durability of solutions that rely on structural (“gray”) approaches versus nonstructural (“green” and “blue,” or land- and water-based natural resource) approaches. They also stressed the importance of integrated multisectoral research to help tackle actual and future societal needs in coastal settings.

Workshop outcomes provided a basis for identifying future main research topics, as well as pertinent questions that need to be answered:

- The sea-land interface represents one of the most challenging and multidisciplinary research topics. This is especially true in a context of sea level rise, subsidence, and saltwater intrusion, among other coastal issues that are affecting sustainable development worldwide. How could possible solutions to these issues effectively consider the social and cultural components?

High tides can cause nuisance flooding, even on sunny days, as shown in this 17 October 2016 photo of downtown Miami, Fla. Credit: B137/Wikimedia Commons, CC-BY-SA-4.0 (http://bit.ly/ccbysa4-0)

• Great technical and economic efforts are being devoted to the worldwide implementation of gray engineering approaches (e.g., coastal barriers, gates, and sediment movement works). How can we evaluate the long-term impact of these efforts on human safety and maintenance efficiency? In addition, how can we consider human perception and behaviors linked to the effect of large gray infrastructure?

• Green remediation actions, ecosystem services, and nature-based solutions seem a viable technical solution in the long term, and citizens are well disposed to noninvasive green or blue solutions. How will we address the cultural gap between these solutions and short-term decisions and policy-making approaches, which are still prone to implementing gray solutions?

Participants also recommended the following future actions:

• develop joint Ph.D. programs integrating water science with social and cultural studies

• develop applied research that engages active citizenship and big-data science as a central part of next-generation decision-making processes for smart and sustainable urban systems

• identify and develop large-scale demonstration and living labs for testing the effectiveness of noninvasive solutions, compared with large gray infrastructures

The historic urban landmarks and coastal landscapes of Miami, Fla., and Rome, Italy, will be used as starting case studies. Although Rome's historical center isn't directly on the coast, city managers are facing significant issues with constant nuisance flooding on the coastal land reclamation domain (e.g., the Ostia archaeological area and surroundings), which is home to informal settlements and inefficient water infrastructures. Our case studies will form the basis for extending research investigations and solutions to the global domain.

A flooded Tiber River surrounds Tiber Island in Rome, Italy. Although Rome and Miami, Fla., have very different climatic, hydrologic, and cultural settings, they share similar concerns about flooding and water quality. Credit: ROMAOSLO/iStock/Getty Images

The authors thank FIU Institute of Water and Environment director Todd A. Crowl for his significant work in the writing of this meeting report. We also thank all the academic partners, institutions, and other entities who are supporting our joint effort (see http://bit.ly/workshop-partners).

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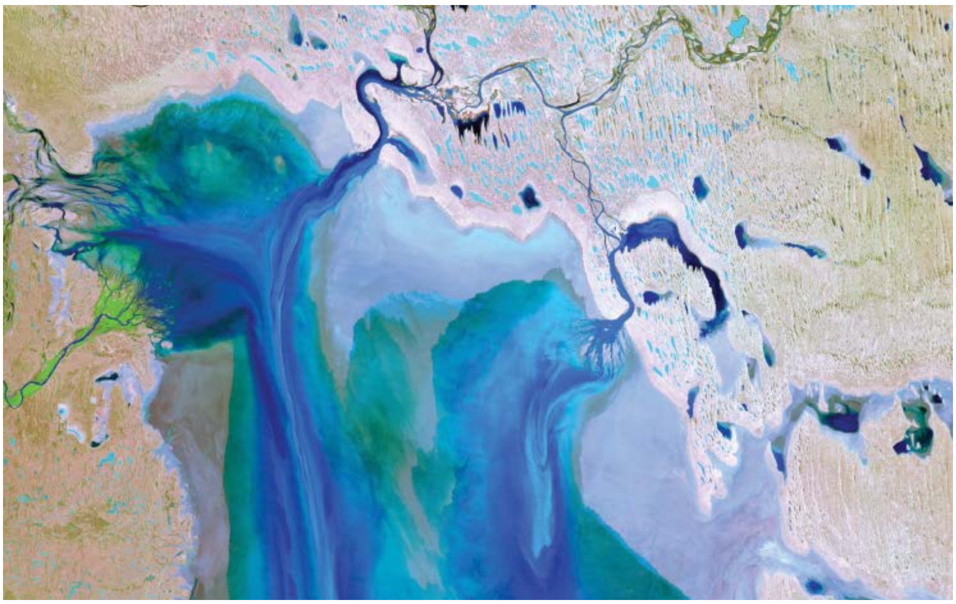
Observing Life near the Ocean's Surface with Satellites

Third International Ocean Colour Science Meeting
Lisbon, Portugal, 15–19 May 2017



Landsat 5 Thematic Mapper image of the northwestern corner of Lake Eyre North in Australia, after floods in March 2011. Credit: USGS/NASA; Norman Mueller and Leo Lymburner, Geoscience Australia

Ocean color (OC) satellites provide a global, long-term view of the oceans from space and greatly improve our understanding of ocean processes. These processes include the role of phytoplankton in marine ecosystems and the links between phytoplankton primary production, carbon fixation, and climate change. The satellite ocean color radiometry (OCR) data stream also supports a range of research and societal applications, including water quality monitoring; harmful algal bloom detection; management of marine resources, including fisheries and aquaculture; and climate and biogeochemical research.

Ocean color scientists and representatives from various space agencies, hosted by the International Ocean Colour Coordinating Group (IOCCG), met to improve collaboration and advance OCR research. The Third International Ocean Colour Science Meeting (IOCS-2017) aimed to inform participants about cutting-edge research and agency mission plans and to get participants to agree on requirements for sustained OC research and operations.

The keynote speaker, Paula Bontempi (NASA), pointed out the need to move the science of OC remote sensing beyond current capabilities and to begin exploring new questions and enabling new discoveries regarding Earth's living oceans.

Speakers at the meeting addressed some of these potential new approaches:

- Active lidar measurements from space present an unprecedented opportunity to complement the passive OC data record and retrieve quantitative phytoplankton properties. Lidar can provide information not available from OCR, including vertical distribution of ocean constituents, data retrievals through clouds, and night and high-latitude sampling.
- Data with very high spatial resolution (e.g., from Sentinel-2 and Landsat 8) have led to new applications for observing coastal and inland waters. We can now observe sediment transport and patchy algae distribution, and we can monitor water quality.
- Planned hyperspectral OC remote sensing instruments could shed light on oceanographic processes previously hindered by current limitations in spectral band coverage (e.g., benthic substrate types, improved atmospheric correction, aerosol characterization, phytoplankton functional types, and coral reef health).
- New in situ approaches like the Imaging FlowCytobot can characterize the size and taxa of phytoplankton. This information can be used to validate satellite data.

Breakout groups discussed collective challenges and knowledge gaps. Atmospheric correction (AC) of hyperspectral data is extremely difficult; possible solutions include targeted spectral subsampling, increased parameterization of ocean-atmosphere models, and adopting a decision tree approach as an alternative to full inversions. In situ instrumentation advances for hyperspectral remote sensing (hyperspectral backscatter measurements, compact flow cytometry, and microscopy) can help parameterize radiative transfer models.

Satellite remote sensing offers a unique perspective on inland and coastal waters, and it can help us assess water quality and understand biogeochemical processes. AC is also challenging in these waters because of land adjacency effects, trace gases near cities, and extremely turbid waters. The bio-optical complexity of these waters affects algorithm accuracy and the quality of satellite products that transition across open-ocean, coastal, and inland waters.

The optical water type classification approach (see http://bit.ly/optical-water-type) offers a promising avenue for improved algorithms in coastal waters, but the fundamental issue impeding the progress of algorithm development is the lack of in situ measurements to describe water types. Community support is essential to making in situ data available for evaluating AC and bio-optical algorithms. Many breakout groups strongly encouraged data sharing and data publication.

All presentations, poster abstracts, and a full meeting report that includes recommendations are available at the IOCS-2017 meeting website (http://iocs.ioccg.org). IOCS-2017 was sponsored by the European Commission, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Space Agency, NASA, Thales Alenia, and Airbus. The next IOCS meeting will take place in May–June 2019 in Busan, South Korea.

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Keeping Our Focus on the Subseafloor

The R/V Langseth *in port in Valparaíso, Chile, in January 2017. Credit: Nathan Bangsv*

Seventy percent of Earth's surface geology is under water, but let's face it: There are few options for exploring beneath the seafloor, and the limited number of techniques for subseafloor exploration presents a challenge. But with modern seismic imaging, this challenge is surmountable, and the opportunities are extremely exciting.

The real challenge at present is finding financial support. We need a new funding commitment in the United States to offset recent declines in National Science Foundation (NSF) seismic facilities support. We are at a juncture where an increment of additional support from U.S. funding agencies, academic institutions, and/or private contributions for seismic facilities will have a leveraging effect with tremendous science impact for a broad community. With less support, we will still progress, but with substantial new challenges and uncertainty throughout marine science.

During marine seismic surveys, ships use pneumatic sound sources to generate acoustic waves beneath the water's surface. Long floating arrays of hydrophones pick up the sound waves, reflected back by subsurface sedimentary layers and crustal structures, to provide a detailed picture of the geology below the ocean floor.

This technique provides invaluable information for the scientific and petroleum exploration communities alike. However, research funding reductions continue to hamper the marine geoscience community's ability to collect seismic data in areas of scientific interest.

Although relatively few scientists are directly involved in collecting these data, a much larger community relies on the data they produce. Thus, a dwindling data stream produces ripple effects that extend far beyond the scientists and crews who go to sea.

The science community needs to understand what those ripple effects mean. Below, we've outlined a few options that we see as the most likely in the future.

An increment of additional support for seismic facilities will have a leveraging effect with tremendous science impact for a broad community.

Seismic Techniques Provide Context

Data from beneath the ocean floor come from several sources, and each type has its own strengths and limitations.

Drilling and piston coring provide valuable samples for establishing lithologies, ages, geochemistry, and physical properties, but they provide only a keyhole view beneath the ocean floor. Cores are only a few centimeters wide, and the information we gain is generally limited by depth of penetration and the cost of coring expeditions.

Electromagnetic methods are designed for a broader view, but they provide only bulk property constraints, averaged over the sampling area.

The reality is that only marine seismic data have the resolution to enable seeing into the subsurface, to reveal regional geologic structure, and to help us understand the broader context of "ground truth" sampling from cores.

We have some amazing seismic data analysis techniques available to us: 3-D imaging, full-waveform inversion, and vertical profiling. We also have technologies to gather these data: Large spatial deployments of ocean bottom seismometers (OBSs), for example, are now possible with government-supported OBS instrument pools in the United States and other countries. Advanced multichannel seismic (MCS) reflection platforms, like the United States' R/V *Marcus G. Langseth*, are equipped with multiple hydrophone arrays and streamers, which can be as long as 15 kilometers. And we have improved computational facilities for data analyses.

Together, these capabilities allow us to "see" into the subseafloor to address fundamental geologic questions on ocean crust formation and evolution, subduction zone earthquake genesis, fluid migration within the crust, continental rifting, and so forth.

More Technology but Fewer Cruises

However, the availability of high-quality seismic images is in decline. The International Ocean Discovery Program (IODP) Science Evaluation Panel (SEP), scientific ocean drilling's primary review body, sent the following statement for programmatic review in 2015 (see http://bit.ly/IODP-SEP-2015):

> *The [SEP] wishes to convey concern regarding the increased pressures on the acquisition of academic active-source seismic data, some of which by design is conducted in support of scientific ocean drilling. Continued reduction in the international marine geoscience communities' ability to collect seismic data in areas of scientific interest is jeopardizing the scope and*

impact of IODP science. The SEP consensus is that the IODP should stress the importance, both to member country funding agencies and environmental permit organizations worldwide, of high-quality subsurface images for science and safety in connection with expected continuation of IODP.

The SEP concern is justified. From 1995 to 2005, the R/V *Maurice Ewing,* then the primary U.S. seismic acquisition facility, conducted on average 4.7 seismic (MCS and OBS) cruises each year (in addition to higher-resolution surveys) and participated in multiship vertical seismic profiling projects. In contrast, during the past decade, the R/V *Marcus G. Langseth,* the *Maurice Ewing*'s successor ship, has conducted an average of 3.2 cruises each year, with only five total in 2016 and 2017.

This decline raised questions explicitly addressed in the 2015 National Academy of Sciences' decadal survey of ocean sciences (see http://bit.ly/NAS-sea-change): Should the National Science Foundation consider divestiture of this expensive facility to maintain a healthy balance between spending on technology and infrastructure and spending on science? Are seismic facilities serving too few scientists to justify such infrastructure?

Worth the Investment?

To address these questions, the University-National Oceanographic Laboratory System (UNOLS) conducted a survey in June 2016 to assess the community's seismic needs. Response was excellent; in 2.5 weeks, 263 people completed the survey. (As a comparison, the virtual town hall that surveyed the ocean sciences community as input to the National Academy of Sciences report generated about 400 responses over 20 weeks.)

The UNOLS survey confirmed that although a minority of the respondents acquire data at sea, and most of those are senior scientists (at least 20 years post-Ph.D.), the seismic data they collect are used by many more. Half of the respondents considered themselves nonspecialists who rely only on processed seismic data and interpretations, without other involvement.

The majority of respondents had never submitted an NSF proposal to acquire seismic data; 75% had not served as a primary investigator (PI) or co-PI on a seismic acquisition and processing project in the previous 5 years. Many stated that they do not have the background to acquire seismic data. However, 94% said that they plan to use seismic data in the future, primarily through collaborations.

The most commonly cited reason for not serving as a PI on a *Langseth*-type acquisition cruise was a lack of background in seismology or know-how with acquisition, processing, and interpretation techniques. Processing seismic reflection data requires extensive technical knowledge, advanced computer systems equipped with appropriate (often expensive) software, and generally 1–2 or more years of postacquisition processing effort.

Overcoming these challenges is not practical or even possible for many; the pool of seismic specialists will remain small. Yet the UNOLS survey confirms the demand for seismic data beyond the small number of PIs who acquire and process them. Therefore, a loss of acquisition facilities would have wide-reaching effects on the Earth sciences.

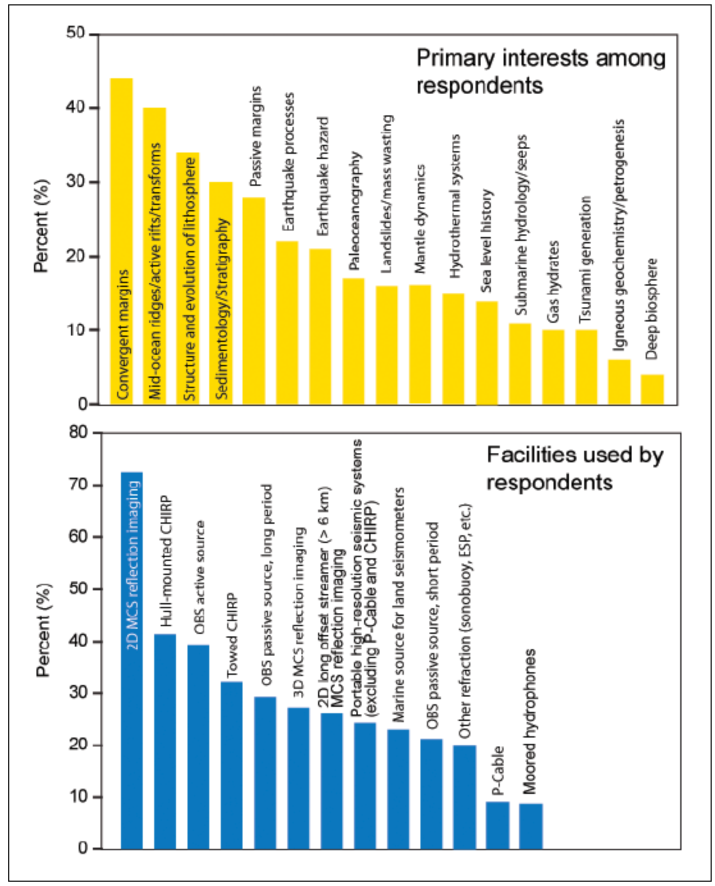


Fig. 1. Results of a June 2016 UNOLS survey to assess the scientific community's needs for seismic data from the ocean floor and below. Shown here are the percentages of respondents for each type of primary interest and the facilities they use. Multiple responses were allowed. Credit: Nathan Bangs

The survey also confirms that many seismic tools (Figure 1) are needed to address the diverse science goals of current and envisioned U.S. Earth science programs, some of which include international partners and span shorelines (e.g., IODP, Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS), and subduction zone observatory).

Weighing the Options

Can we maintain seismic acquisition capabilities with reduced funding? With the exception of the Scripps Institution of Oceanography's high-resolution (short-streamer) portable MCS system, *Langseth* is the only U.S. seismic facility. *Langseth* can acquire 3-D volumes and 2-D data with streamers more than 6,000 meters long, an "aperture" long enough to image at crustal scales.

In August 2016, the NSF Division of Ocean Sciences (OCE) distributed a "Dear Colleague" letter (see http://bit.ly/NSF-letter-2016) stating that "OCE anticipates spending an average of ~$8M per year for ship support and ~$2M for technical support, funding permitting, supporting seismic infrastructure…." At current *Langseth* rates, this amounts to operations for some 90–112 days, only about 75% of the total 120–150 days per year considered viable for any UNOLS vessel.

Operating fewer than 120–150 days in a given year actually increases the cost per day. This makes the *Langseth*'s operational costs stand out even more while limiting support for the highly experienced crew necessary for state-of-the-art seismic operations.

Aside from making *Langseth* a general-purpose vessel and using it to serve other marine science programs, options are limited.

Option 1. One option is to improve efficiency and increase funding. Since 2015, *Langseth* has operated according to a long-range framework to minimize transits and maximize opportunities through developing regional and international collaborations (see http://bit.ly/Langseth-framework). In 2018, *Langseth* is operating offshore New Zealand, with support from that country, Japan, and the United Kingdom, having begun to do so in late 2017. Unfortunately, international support is limited because partner countries must also support their own facilities.

Improved efficiency is also possible through sharing facilities internationally. *Langseth* is currently the most capable academic facility for crustal-scale 2-D/3-D imaging, but it is the only U.S. option for crustal-scale work. Collaboration to exchange *Langseth* with other international vessels would improve both opportunity and efficiency globally; the Ocean Facilities Exchange Group does this within the European Union.

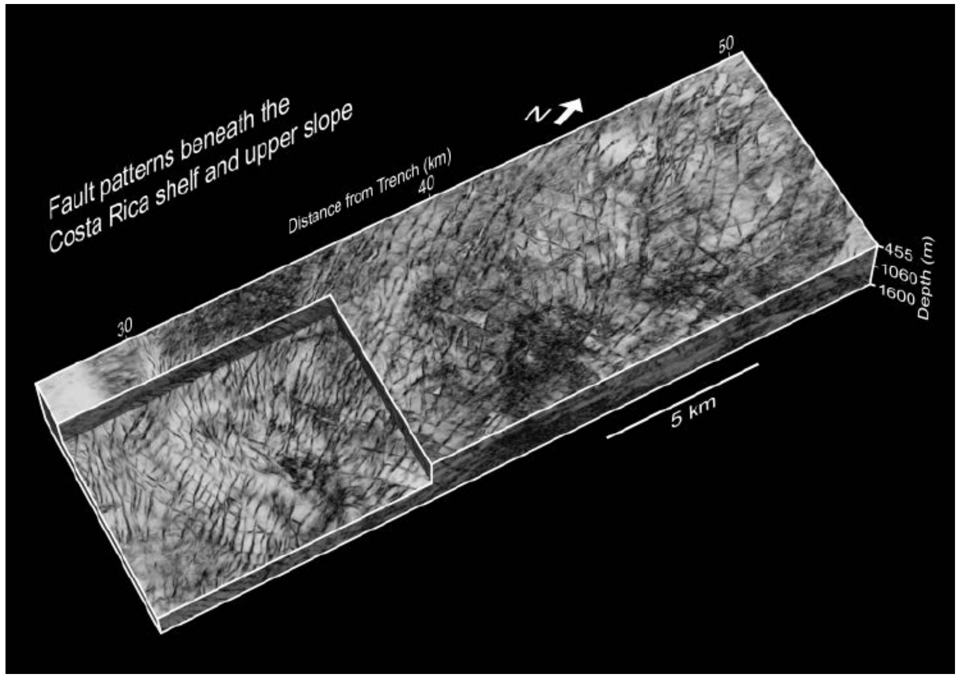
A scaled-back seismic program will affect not only the PIs who responded to the UNOLS survey but also the U.S. institutions they represent through loss of NSF support: those who receive funding for seismic data acquisition and those relying on seismic results. Among international programs affected by scaled-back seismic facilities, IODP stands out. Broad support for seismic facilities from U.S. academic institutions would produce returns for these institutions.

Institutional support could provide *Langseth* operational costs but only through collaborative, multiyear commitments. As NSF described in its 2017 program solicitation "Provision of Marine Seismic Capabilities to the U.S. Research Community," the agency is committed to providing *Langseth* or equivalent capabilities, but the proposed funding levels ($10 million per year) would be problematic for the current model (see http://bit.ly/NSF-marine-seismic). Is any other model viable?

Option 2. Without *Langseth*, there will still be exciting science to do, using data from shorter streamers, archived data, and data available (occasionally and in certain areas) from industry.

Unfortunately, this approach will change the foci of U.S. seismic studies. For example, a reduced seismic imaging capability would limit large, successful international programs like IODP. Progress on understanding the largest earthquakes and tsunamis on Earth generated at subduction zones will be severely compromised in the future without an ability to see deep subduction zone structures and measure physical properties with seismic tools. Science would need to target shallower settings: submarine landslides, gas hydrates, fluid and gas migration, sea level change, and the like, using cheaper, portable (higher-resolution, smaller) seismic systems.

Data would be less complicated and easier to process. Higher resolution could even be 3-D, using P-cable systems available from multiple U.S. institutions. However, these systems can rarely deploy streamers long enough or sources powerful enough to fully characterize even shallow stratigraphy and structure, and they can't address crustal-scale problems at all.



Coherence volume derived from the Costa Rica 3-D seismic data acquired on the R/V Langseth *in 2011. These data show amazing 3-D detail in the subseafloor geology. Dark lines indicate the disruption in the continuity of seismic reflections from a complex pattern of faulting (mostly normal faults here) within margin shelf and slope cover sediment sequences. Horizontal slices are at 455- and 1,060-meter depth. Credit: Nathan Bangs*

Going Commercial?

In 2015, NSF conducted a workshop with invited members from the marine seismic community, primarily the now disbanded *Marcus Langseth* Science Oversight Committee, to consider a long-streamer portable system and commercial contracting (see http://bit.ly/NSF-2015-workshop). The workshop report concluded that the weight and size of portable systems incorporating long (6- to 8-kilometer) streamers with moderate-size, tuned acoustic sources made them impractical for current UNOLS vessels.

Commercial contracting is viable for long-offset 2-D and 3-D acquisition; however, availability could be limited by high costs (especially mobilization costs for work far from oil and gas provinces, where commercial efforts tend to focus), cost volatility, and changes in ship availability due to hydrocarbon market cycles. These cruises would also lack simultaneous multibeam or gravity and magnetics data acquisition, which has historically been available on U.S. seismic vessels, and student training opportunities would be uncertain and problematic.

Commercial contracting occasionally has been used successfully in the past, but it is risky to rely on contracting to maintain a regular, global crustal-scale acquisition program as we do now.

Ironically, this development comes at a time when IODP is increasing its number of operational days. Other exciting developments, such as seafloor geodesy, will also need an understanding of subsurface structure for tectonic context.

There is considerable imaging science to be done, with or without *Langseth*. However, the broad impact of scaling back marine seismic facilities on Earth science makes it time to find more financial support for marine seismic data acquisition.

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When Less Is More: Opening the Door to Simpler Climate Models

Clockwise from top left, a satellite view of Earth, a complex Earth system model depiction, a simpler aquaplanet configuration, and the simplest dynamical core visualization. This hierarchy of models is now being supported by the Community Earth System Model project. Credit: Satellite image: NASA; design by B. Medeiros

Climate change projections rely heavily on computer models to provide a physical foundation for the climate's future. At present, the vast majority of U.S. and international resources for climate modeling are dedicated to the development of so-called Earth system models (ESMs). Such models are constructed to numerically simulate Earth's climate with the greatest possible fidelity and are thus built to include the most comprehensive range of physical, chemical, and biological processes that can be handled on today's most powerful computing systems.

The immense complexity of these ESMs arises from the need to generate the most accurate projections of climate change in the coming decades. These projections play a crucial role in the assessments of the Intergovernmental Panel on Climate Change; they also inform climate-related decision-making in a wide variety of sectors.

Although this modeling approach is important for making accurate projections, it imposes substantial limitations on obtaining a fundamental understanding of the Earth system. The large number of simulated processes and the high resolution at which the simulations are typically performed require that these complex simulations be run on very expensive supercomputers. This requirement greatly limits our ability to explore the models' sensitivities to different system components and climate forcings. As a consequence, our ability to deeply understand the behavior of these models is limited.

In a nutshell, ESMs may be good for simulating the climate system but may not be as valuable for *understanding* it. So we have now added a new set of tools within the Community Earth System Model (CESM) project: a hierarchy of simpler models to foster this understanding. Specifically, we are happy to announce that the next version of CESM will include two simple atmospheric models: a dynamical core (http://bit.ly/dynamical-core) and an aquaplanet (http://bit.ly/aquaplanet-model).

A Hierarchy of Models

Isaac Held alerted the climate science community more than a decade ago to a widening divide between simulating and understanding the climate system [*Held,* 2005]. He noted that a gap had developed between idealized models, which can sometimes be thoroughly understood, and the complex, high-end models (such as ESMs) that comprehensively simulate the climate system but cannot be completely understood because of their complexity.

This gap is particularly problematic for many researchers and students, who often have to work with limited computational resources. Furthermore, simple climate models are key to educational activities in university classrooms and as part of graduate research. They provide an entry point that enables students to master modeling techniques and concepts before moving on to more complex methods.

Held [2005, p. 1610], building on earlier suggestions [*Schneider and Dickinson,* 1974; *Hoskins,* 1983], emphasized that the gap between understanding and simulation could be bridged by developing a hierarchy of climate models:

> *Consider, by analogy, another field that must deal with exceedingly complex systems—molecular biology. How is it that biologists have made such dramatic and steady progress in sorting out the human genome and the interactions of the thousands of proteins of which we are constructed? Without doubt, one key has been that nature has provided us with a hierarchy of biological systems of increasing complexity that are amenable to experimental manipulation, ranging from bacteria to fruit fly to mouse to man. Furthermore, the nature of evolution assures us that much of what we learn from simpler organisms is directly relevant to deciphering the workings of their more complex relatives. What good fortune for biologists to be presented with precisely the kind of hierarchy needed to understand a complex system! Imagine how much progress would have been made if they were limited to studying man alone.*

So how might one proceed in developing such a hierarchy of models for the Earth system? One end of the hierarchy already exists: the most complex ESMs. What is needed now is a set of simpler models, ideally embedded within the same modeling infrastructure as the ESMs. This embedding would allow the simple models to selectively make use of the same components (e.g., the cloud scheme) as the ESM and would enable users to easily set up, run, and analyze any model along the hierarchy, from the simplest all the way to the most complex.

The Community Earth System Model

In the United States, the CESM project is the natural choice for building this hierarchy of climate models. The ESMs made available under the CESM project are developed, maintained, and documented specifically to serve the entire community of climate scientists. The CESM project has a wide user base; all released model versions are thoroughly tested and routinely ported to the latest machines available, an arduous task not easily accomplished by individual investigators in a typical university setting. Crucially, the CESM can be freely downloaded and used by anyone.

With these considerations in mind, we (the authors) informally approached colleagues to explore the general sentiment about developing simpler models for climate science research. In October 2013, we held a special session, "Simpler Models," at the annual Members Meeting of the University Corporation for Atmospheric Research (UCAR). In November 2013, two of us sent a letter to approximately 50 university faculty members engaged in climate modeling research, asking about their interest in developing a model hierarchy within CESM. The response was overwhelmingly positive. We also gathered feedback from the larger CESM user community, and it became clear that there was widespread support for the initiative. In late 2014, we received a formal green light from CESM leadership and the National Science Foundation to start developing an officially supported set of simpler model configurations.

First Steps Toward a Hierarchy of Models

We are now happy to report that after 2 years of work, the fruits of our labors will soon appear. Specifically, with the impending release of CESM 2.0, two idealized atmospheric model configurations—a dynamical core and an aquaplanet—will be made available to the climate science community.

In many ways, these two components constitute the bookends of the atmospheric model hierarchy. The dynamical core model solves the fluid dynamical equations alone, all other physical processes having been immensely simplified. At the other extreme, the aquaplanet model is nearly identical in complexity to the atmospheric component of the ESM itself, the only simplification being that in the model, all landmasses have been eliminated and oceans cover Earth's entire surface.

Earlier versions of such models have existed, in one form or another, at many modeling centers at various times, but the novelty is that these models will now be officially incorporated into the current version of CESM. From CESM 2.0 onward, simpler climate model configurations will be made available, maintained, documented, and updated for use by the entire climate science community. In many ways, however, this is only the beginning.

Filling in the Hierarchy

What happens next? First, we hope that colleagues working in climate science will take advantage of these two model configurations and use them in their research. Second, now that we have opened the door and allowed simpler models to enter the CESM project, we invite colleagues to take the initiative in suggesting and contributing other simplified model configurations to "fill up" the hierarchy. For instance, work is under way for so-called single-column configurations of the atmosphere and the ocean models. We also expect idealized configurations of other components (e.g., the land model) to be released in the near future.

How should the community now go about filling up the levels of the hierarchy? We recommend the following guiding principles for moving forward.

First, there should be a clearly demonstrated need for a simplified model. Second, the community members who are spearheading each effort need to pair up with one or more partners at the National Center for Atmospheric Research to collaborate in the model development. Third, project leaders must assess the resources needed to develop the new simpler model and identify some avenue for funding the development. Finally, developers of simpler models should submit scientific papers to the peer-reviewed literature, explaining the rationale for the usefulness of the new models and describing what novel understanding of the climate system is to be gained from using these simpler models. Ideally, these activities would be coordinated across the community to avoid duplication of efforts.

Toward Models of Lasting Value

We conclude by emphasizing one crucial point in Held's proposal: Models in the hierarchy must be of *lasting value.* ESMs are constantly under development to promptly incorporate the latest findings or methods. However, we believe that at least some of the models in the hierarchy need to be forcefully shielded from the relentless cycle of model improving and updating. If those models are well chosen, their value will come precisely from the fact that they are *not* being updated. Because they remain unchanged, we will be able to understand them in great depth and thus close the gap between simulation and understanding—the ultimate motivation of this entire exercise.

Acknowledgments

We express our gratitude to Eric DeWeaver, director of Climate and Large-Scale Dynamics in the Division of Atmospheric and Geospace Sciences at the National Science Foundation, for his strong and continued support. We are also very grateful to Bill Large, director of the Climate and Global Dynamics laboratory at the National Center for Atmospheric Research, for his invaluable help.

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JunoCam's Flights of Whimsy: From Dragons to Jovey McJupiterface

It's been more than a year and a half since NASA's Juno spacecraft arrived at Jupiter. What has the spacecraft been up to? It's been unlocking the mysteries of the gas giant's gravity, magnetic field, turbulent atmosphere, and brilliant auroras.

But that's not all. The spacecraft also houses JunoCam, its color camera. JunoCam is unique because the public, rather than the mission scientists, determines what spots on Jupiter the camera will image. Before each flyby of the spacecraft, members of the open online JunoCam community propose, discuss, and vote on points of interest that JunoCam should examine up-close.

Here's the fun part: After each flyby is completed, the raw JunoCam images are posted online for anyone to download and process into polished pictures.

Some images created by the public highlight the mission's scientific goals, but other people throw scientific gravitas out the window, looking to hit a more whimsical note. This is, after all, the digital age. Below are just some of these images, created by amateur astronomers, citizen scientists, and artists who looked at Jupiter and saw something a bit different.

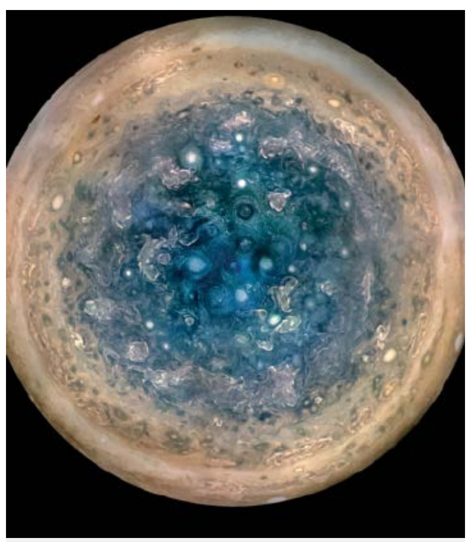
Throughout the span of its approximately 2-year mission, Juno will make 32 polar orbits of the planet, skimming within 5,000 kilometers of the cloud tops. When this issue *Eos* went to press, JunoCam images from the first 11 flybys, called perijoves, were available for the public to work (and play!) with, and more will soon follow. What new artistic pursuits will Juno's journey inspire? We can't wait to find out!

Jupiter as a Work of Impressionist Art

Credit: NASA/JPL-Caltech/SwRI/MSSS/David Englund

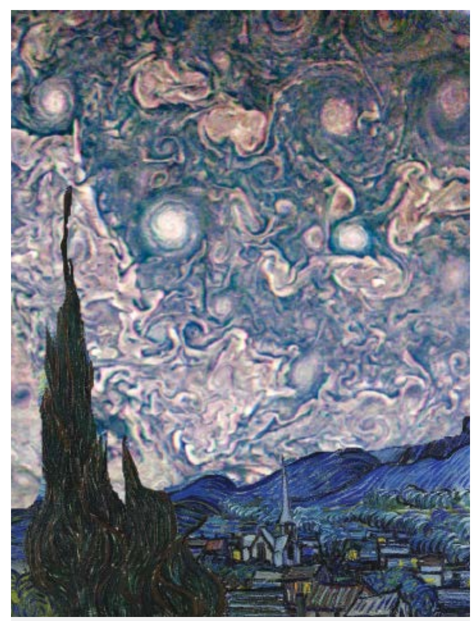
Many astronomers have long considered the swirling storms on Jupiter to be beautiful works of art. This avant-garde interpretation of Jupiter's Great Red Spot pays tribute to French impressionist painter Claude Monet and his famous *Water Lilies* series.

You can view the newest JunoCam images at **http://bit.ly/nasa-junocam.**



Credit: NASA/JPL-Caltech/SwRI/MSSS/Betsy Asher Hall/Gervasio Robles

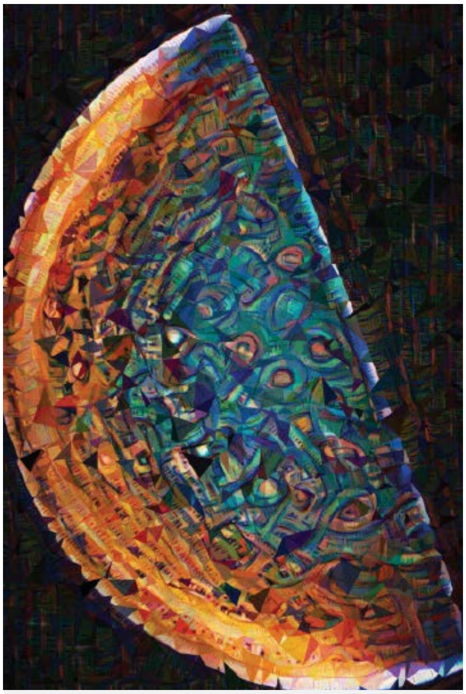
Jupiter's south pole is no slouch when it comes to atmospheric turbulence, spots, and storms. This enhanced-color image from JunoCam's early science results, taken from 52,000 kilometers above the atmosphere, combines snapshots taken over three separate orbits of the spacecraft. The patterns created by Jupiter's complex magnetic field invoke the skies of Vincent van Gogh's Wheatfield with Crows or Imperial Fritillaries in a Copper Vase. Some of the oval cyclone features are 1,000 kilometers wide.



Credit: NASA/JPL-Caltech/SwRI/MSSS/Amelia Carolina Sparavigna

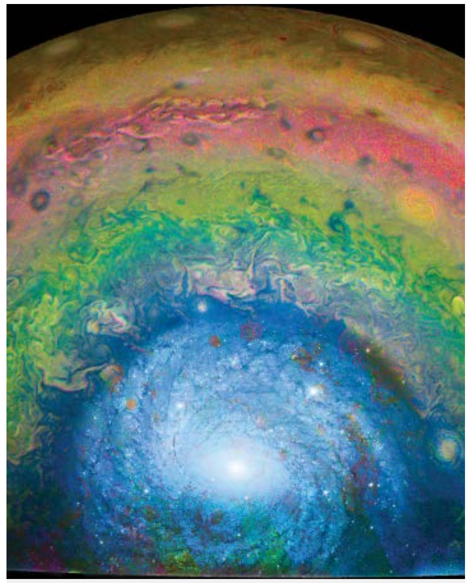
Of course, no astronomy-themed art gallery would be complete without a tribute to van Gogh's The Starry Night. In this interpretation, a false-color image of Jupiter's south pole is the backdrop for the iconic sleepy French village depicted in the painting. Turbulent storms and atmospheric swirls are convincing substitutes for van Gogh's postimpressionist-style sky.

A Mathematical Take on Jupiter



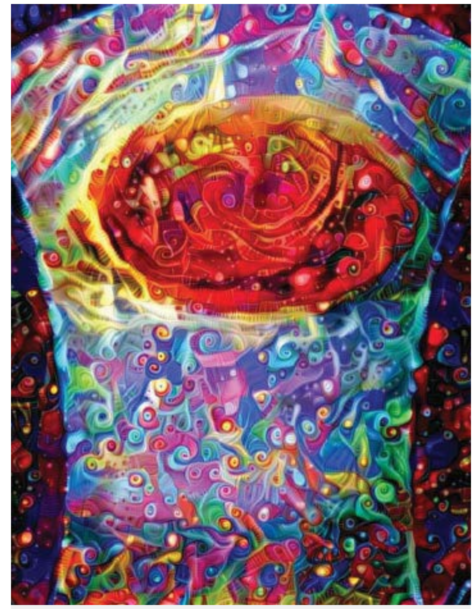
Credit: NASA/JPL-Caltech/SwRI/MSSS/Michael_Ranger

Despite being half in shadow, this geometric take on Jupiter's south pole storms is reminiscent of the symmetrical optics inside a kaleidoscope or the fractal geometry of male peacock feathers.



Credit: NASA/JPL-Caltech/SwRI/MSSS/CosmicRamonet

Some people just can't stop themselves from spicing up their planetary science with a little galactic astronomy. This false-color view looking directly down at Jupiter's south pole interprets the coils surrounding the bright pole as the spiral galaxy NGC 6814. The smaller spiral storms might even be background galaxies or bright foreground stars.



Credit: NASA/JPL-Caltech/SwRI/MSSS/Mik Petter

Is this the Great Red Spot or a psychedelic throwback to the 1960s? Trick question: It's both! Artist Mik Petter created this mesmerizing take on Jupiter's most prominent hurricane by converting JunoCam data into a colorful set of fractal-based swirls, highlighting the turbulence surrounding the centuries-old storm.

Fantasy, Sci-Fi, and Memes—Oh, My!

Credit: NASA/JPL-Caltech/SwRI/MSSS/Jason Major

Forget the Man in the Moon. The face of Jupiter, also known as "Jovey McJupiterface," is looking back at you. By flipping a JunoCam image upside down, one citizen scientist turned two of Jupiter's pearly white storms into eyes suspended above a red, oval-shaped mouth.

Credit: Red Rock Canyon image: Shari Weinsheimer; background star field: Ronald Carlson; composite image: NASA/JPL-Caltech/SwRI/MSSS/@InvaderXan/supernovacondensate.net, CC BY (http://bit.ly/ccby4-0)

Have you ever imagined what it would be like to live on a hunk of imaginary space rock where you could see a planet rise every morning? Wonder no longer! With a little creative image manipulation, snaps of Europa and Io grabbed from NASA's Galileo mission, a foreground rockscape from Red Rock Canyon near Las Vegas, Nev., and a starry background, this JunoCam image of Jupiter is transformed into a science fiction setting.

With piercing eyes, a scaly forehead, nostrils, teeth, and even curling wisps of smoke escaping its mouth, this Jovian dragon could be the stalwart guardian of our lonely solar system. This dragon was born of a JunoCam image containing one pearly white oval storm and a few stripes that was rotated, color enhanced, and mirrored down the center to create a mythical dragon out of Earth's largest sibling.

Credit: NASA/Gerald Eichstät/Seán Doran

Visit https://eos.org/geofizz for more about the lighter side of Earth and space sciences.

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

Editor's Note: We are delighted to bring the GeoFIZZ column back to Eos!

Drnadig/iStock/Getty Images Plus/Getty Images

NEW ONLINE TOOL TEACHES STUDENTS ABOUT THE **ENERGY-WATER NEXUS**

By Emad Habib, Hisham Eldardiry, and Vincent C. Tidwell

The interactions between food production, energy production, and water supplies—sometimes referred to as the food-energy-water (FEW) nexus—are critically important to sustaining society. Two components of this nexus, energy and water, are strongly interrelated: Generating electricity and refining fuel require us to use water; pumping, delivering, and treating water require us to use energy.

Links between the energy and water systems are expected to intensify in the future. Therefore, it is important to understand and foster continued attention to the interdependence between the systems in the energy-water (EW) nexus [*U.S. Department of Energy,* 2014].

Developing educational approaches focusing on this relationship is critical to building the next generation of scientists, engineers, and other professionals in the energy and water supply sectors. However, current undergraduate curricula typically lack the content and resources to address the complexity of the EW nexus, and most of the current educational efforts are focused at the graduate level.

To address this, we have developed a Web platform and a pilot learning module focusing on energy and water in an

Power plants, like this coal-fired plant in northwestern New Mexico, are often located near sources of freshwater that they use for cooling purposes. Credit: Vincent C. Tidwell

effort to address EW nexus educational needs (see http://nexus.hydroviz.org). The HydroViz Nexus platform can be used in upper level undergraduate and graduate courses that deal with water resources and sustainability topics within disciplines such as civil engineering and geosciences. We put particular emphasis on thermoelectric power generation (converting heat from burning fuels into electricity).

A User Experience Example

Efforts to develop meaningful nexus educational experiences that go beyond reading assignments or qualitative-type analysis face several challenges. These include a lack of prior experience on the part of educators who design teaching materials that address the EW systems; a lack of accessibility to and usability of nexus data sets, modeling, and analysis tools; and curriculum constraints.

To overcome these challenges, our platform follows an active-learning approach and includes a set of student-centered activities using actual EW data sets from around the United States. The platform supports easy access to interactive data analysis and visualization tools and engages students in authentic contexts of EW problems at the scale of a hydrologic basin for any of the contiguous states in the United States. In addition, the platform provides embedded support to check student comprehension and provide assistance on demand.

The platform does not require any specialized tools—just an Internet browser and standard spreadsheet software. Open-source geographic information system (GIS) software may also be used but is not required.

TABLE 1. ENERGY AND WATER DATA SETS AVAILABLE IN THE ENERGY–WATER NEXUS PLATFORM

DATA SET	SOURCE
Surface and groundwater uses by different sectors (domestic, power, industrial, agricultural) and nonpotable water resources	Data acquired from individual states and the U.S. Geological Survey [see *Tidwell et al.*, 2014]
Surface water supply: annual flow at HUC8 (subbasin) scales	U.S. Environmental Protection Agency National Hydrography Dataset Plus (http://bit.ly/NHD-Plus)
Groundwater recharge: 1-square-kilometer estimates	U.S. Geological Survey Groundwater Resources Program (https://on.doi.gov/2minn98)
Electricity-generating plants in the United States, energy retail prices and consumption rates, and energy-related carbon dioxide emissions	U.S. Energy Information Administration (https://www.eia.gov/electricity)
Power plant water consumption and withdrawal rates	*Macknick et al.* [2012]
Estimates of population projections	U.S. Census Bureau

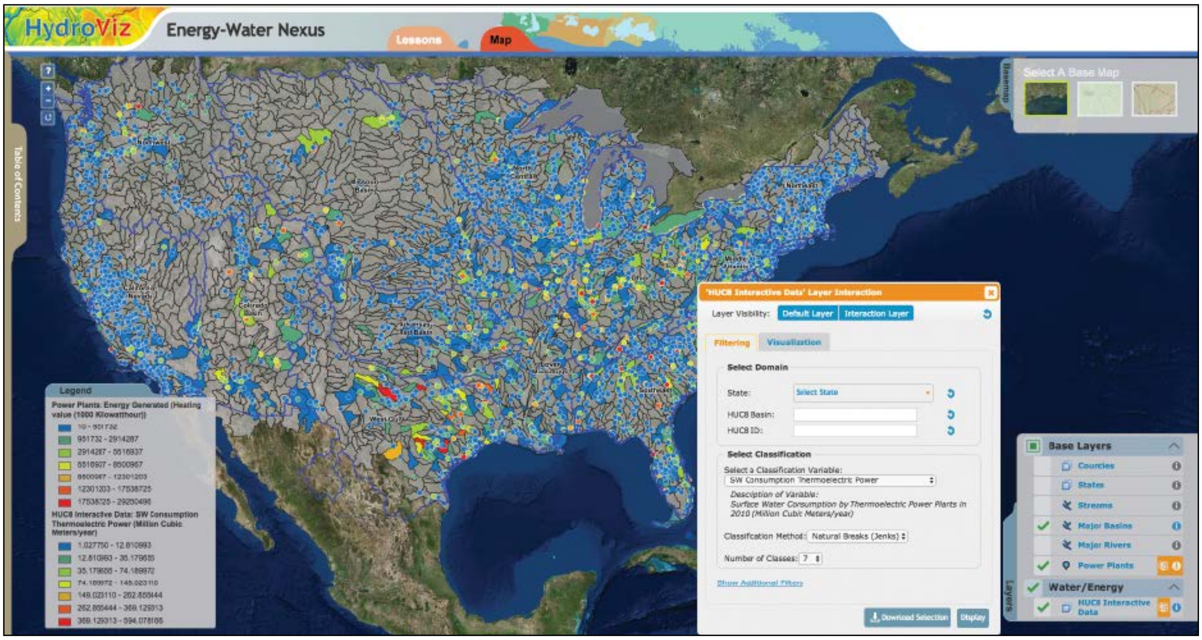


Fig. 1. Interface of the energy–water nexus Web platform, including an interactive map tab for displaying different water and energy data sets and a lesson tab for accessing the educational content and students' quantitative activities.

A Data-Driven Approach

In developing the Web platform, we built a suite of spatially distributed EW data sets over the entire domain of the United States. The data sets include water supply and water use by major sectors of municipal, industrial, agricultural, and thermoelectric power generation (Table 1).

Data on water supply and demand for surface and groundwater sources are provided, as well as projections for water use in 2030 that factor in population growth. The platform houses data on all power plants in the United States, including information on plant capacity, energy generation, fuel type, and cooling technology for each plant. The platform also includes other relevant state-specific information on energy production costs, retail prices, consumption per capita, carbon emission rates, and population projections.

From Data to Knowledge

The Web-based EW nexus platform and the pilot module are housed as part of the HydroViz hydrology education project. The platform interface (Figure 1) integrates a lesson tab that provides access to the full learning content of each section and a map tab with an interactive display of geospatial layers.

A key feature of the interface is a tool that allows selection, filtering, spatial visualization, and basic statistical summaries of the EW data sets. Students can interact with the EW data sets at various spatial scales, from one basin or one state to the entire United States.

The interface provides user support mechanisms in the form of screencasts, tutorials, and interactive quizzes with immediate feedback. The module interface includes sections titled "Rate Your Learning" with survey-type questions to gather student perceptions on whether the module contributed to their learning.

Student-Centered Learning Activities

The module contains 10 learning activities that cover different components (Figure 2) of the EW nexus:

- analysis of water supply and demand
- analysis of stress on surface water and groundwater systems
- sectoral analysis of water stresses
- impact of environmental flows
- analysis of groundwater depletion
- mapping power plants in the United States
- impact of power plant retrofitting on the water system
- water requirements for carbon capture and sequestration technologies
- analysis of water-energy nexus under future population growth scenarios
- use of nontraditional water resources for energy, with cost-benefit analysis

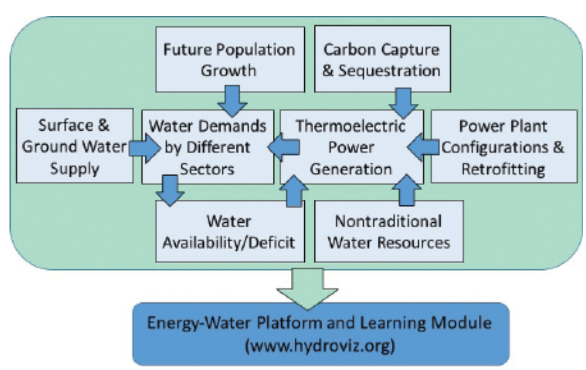


Fig. 2. The platform and the learning module developed in this study address key components of the energy–water nexus and their interconnections.

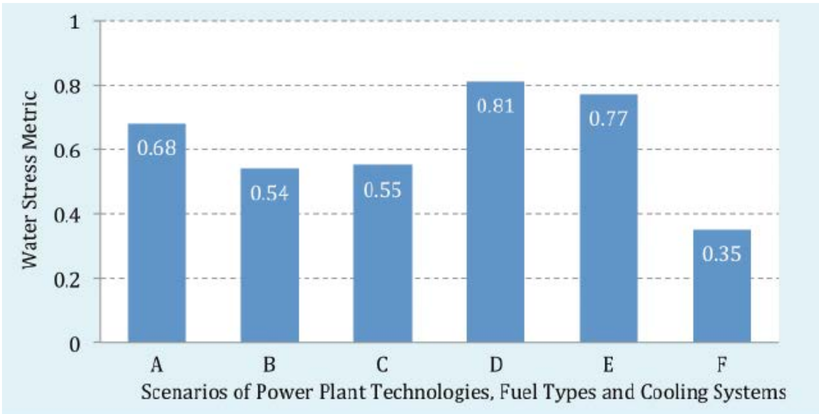


Fig. 3. Students select a basin and analyze different scenarios of power plant configurations in the basin (assigned letters from A to F) to assess the effects on the water system.

We designed these activities using recent research on EW problems as a guide [e.g., *Tidwell et al.*, 2014; *Eldardiry et al.*, 2016]. We also use inductive learning strategies that promote students' engagement in making predictions, observations, and reflections [*Prince and Felder,* 2006].

Each activity starts with a background section to ensure adequate coverage of the subject matter. The platform provides a list of key learning outcomes to ensure students' awareness of their own learning and to assist instructors in designing evaluation metrics and rubrics.

The first set of learning activities guides students to examine water supply from surface water and groundwater sources and water use by the irrigation, municipal and industrial, and thermoelectric sectors. Students calculate water stress indexes at different U.S. basins and identify regions with water availability or shortages.

These activities highlight the alarming rates of groundwater depletion in many U.S. regions. Students then reformulate the water stress indexes focusing on groundwater, identify how much groundwater the thermoelectric sector uses, and explore opportunities for reducing groundwater use by tapping into nontraditional resources like treated domestic wastewater.

The next set of activities focuses on the energy system and the impact of different power plant configurations on water consumption. Students pick a basin in a state of their choice and analyze alternative retrofit and upgrade options for an existing power plant. They then analyze how changing the plant cooling system (e.g., recirculating versus once through), changing fuel type (e.g., coal, natural gas), or limiting greenhouse gas emission (e.g., via carbon capture and sequestration) would affect the water stress in the basin (Figure 3).

In the last set of activities, students assess the interaction of energy and water systems under future scenarios of population growth. These activities are presented as an open-ended problem for which students can pursue the analysis in different directions.

For example, students can project thermoelectric water use according to assumptions about future demand for electricity, which is controlled by population and per capita use. They can vary input parameters (e.g., portfolios of power plants, scenarios of population growth), assess the effect on water use, and predict whether enough water is available (Figure 4). Students then can reflect on how an increase in energy demand may infringe on water availability for other sectors, whether the use of nonpotable

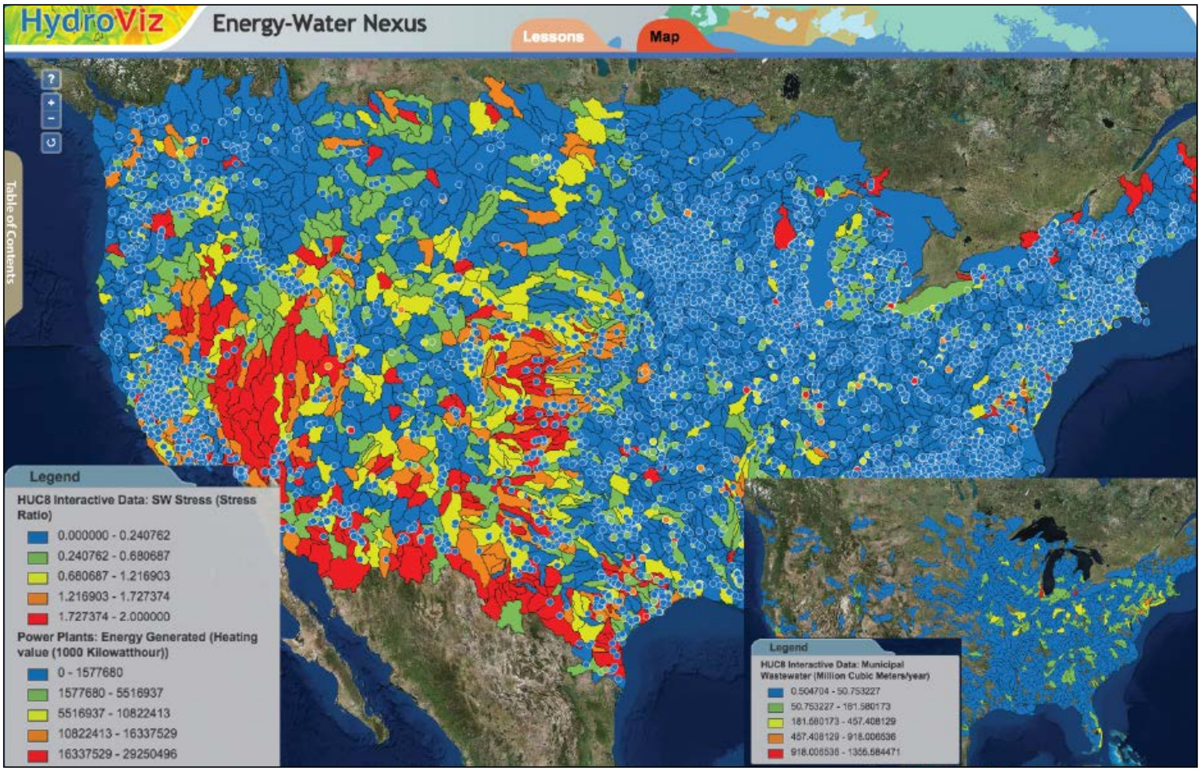


Fig. 4. Students use the energy–water platform to estimate net availability of water-for-energy resources and stresses on the water system under different future scenarios of population growth. Plant retrofitting options, and potential use of nonpotable water resources are shown in the inset.

water resources can alleviate such infringement, and where such alleviation might be most effectively applied.

A Work in Progress

The Web-based platform supports independent instructors who wish to develop their own EW student learning activities. The learning module presented here is a pilot effort for EW education, and we encourage community members to contribute additional EW data sets and modules.

The platform and the module described in this study focus on water use for cooling thermoelectric power plants. However, the data sets built into the platform, the interactive data, and the visualization tools are generic enough to support the formulation of other EW problems driven by specific discipline and curriculum needs.

Future efforts could concentrate on energy-for-water analyses (e.g., large conveyance projects, agricultural pumping, and water treatment) and the economic and policy aspects of the EW nexus under future scenarios of urban development, climate extremes, and growth in energy demands.

This work can also be extended to a more comprehensive model that addresses the full spectrum of the food-energy-water nexus. Assessment of student learning is a critical component of any educational initiative, so a preliminary implementation in our civil engineering department is currently under way to identify areas for improving the platform and to better understand challenges in developing more advanced EW learning activities.

Acknowledgments

This project was funded by a TUES-II grant from the National Science Foundation (award 1122898) with a supplemental FEW award. Hanz Unruh and Seth Benoit from the University of Louisiana at Lafayette tested earlier versions of the module. Upmanu Lall from Columbia University contributed to the initial formulation of student activities.

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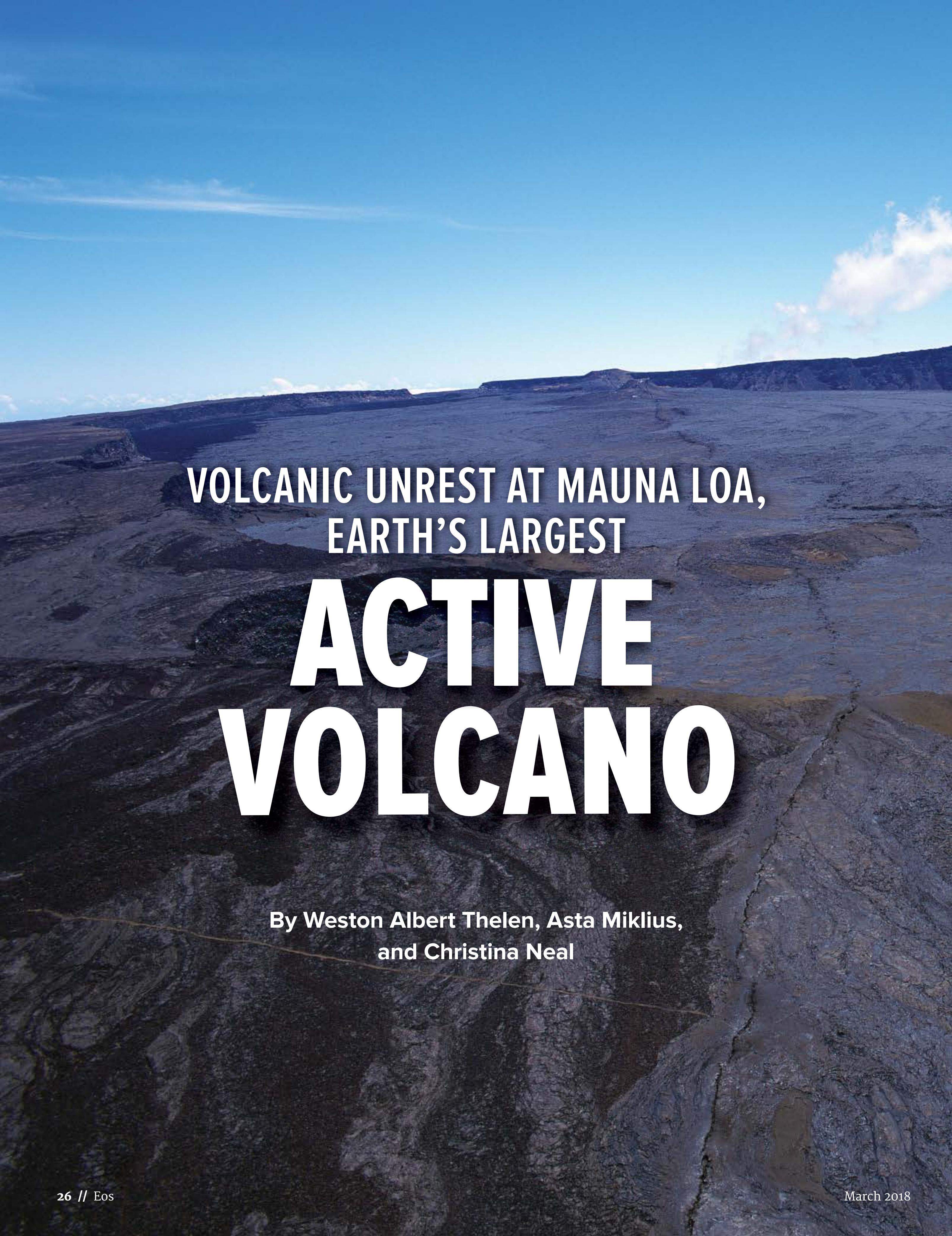

VOLCANIC UNREST AT MAUNA LOA, EARTH'S LARGEST ACTIVE VOLCANO

By Weston Albert Thelen, Asta Miklius, and Christina Neal

Douglas Peebles Photography/Alamy Stock Photo

Mauna Loa is stirring; is a major eruption imminent? Comparisons with previous eruptions paint a complicated picture.

Mauna Loa is showing persistent signs of volcanic unrest. Since 2014, increased seismicity and deformation indicate that Mauna Loa, the volcano that dominates more than half of the island of Hawai'i, may be building toward its first eruption since 1984.

Thousands of residents and key infrastructure are potentially at risk from lava flows, so a critical question is whether the volcano will follow patterns of previous eruptions or return to its now historically unprecedented 33-year slumber.

Mauna Loa has erupted 33 times since 1843, an average of one eruption every 5 years [*Trusdell*, 2012].

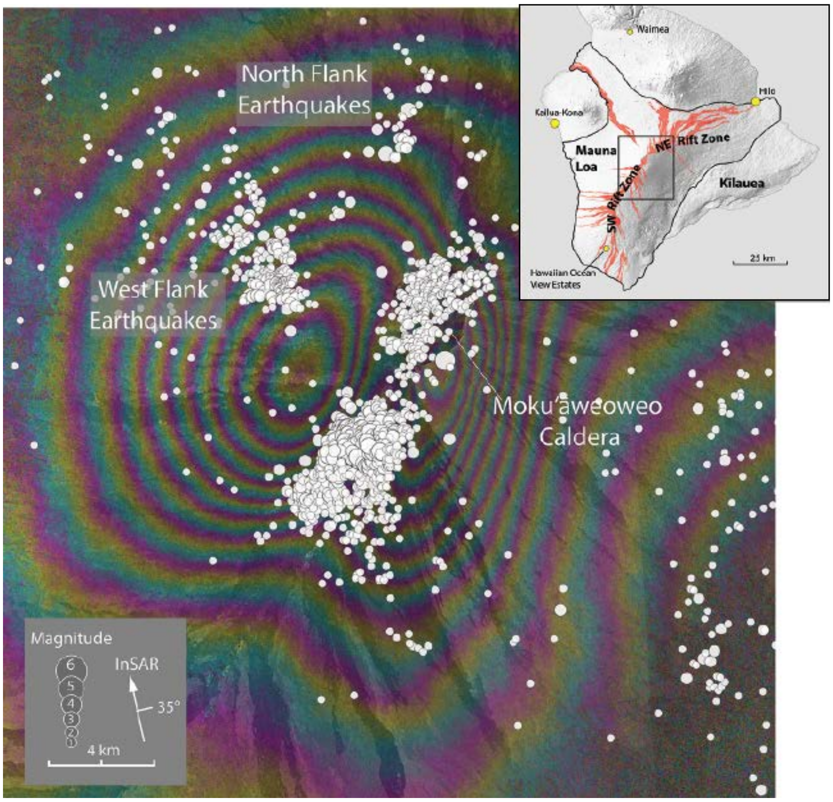

Fig. 1. The Italian satellite system COSMO-SkyMed acquired radar images of Mauna Loa on 1 January 2013 and 30 April 2017 to produce this ascending mode interferogram. Each fringe represents 1.5 centimeters of motion in the line-of-sight direction to the satellite. The butterfly pattern of fringes suggests an inflating tabular body beneath the caldera and uppermost Southwest Rift Zone (see inset map). The sizes of the white dots represent the relative magnitudes of earthquakes that occurred during this period. The arrow at bottom left shows the direction of the satellite's motion. The satellite's interferometric synthetic aperture radar (InSAR) antenna looks to the right of the satellite track, and the radar contacts the land surface at about 35° off vertical. The inset is a digital elevation map of Mauna Loa showing lava flows since 1843 in red. The box shows the approximate extent of the interferogram image. COSMO-SkyMed data were provided by the Agenzia Spaziale Italiana via the Hawai'i Supersite.

Typical of shield-building Hawaiian volcanoes, Mauna Loa hosts a summit caldera and two rift zones, the Northeast Rift Zone (NERZ) and the Southwest Rift Zone (SWRZ; Figure 1 inset).

Since the two most recent eruptions, in 1975 and 1984, monitoring by the U.S. Geological Survey's Hawaiian Volcano Observatory has changed dramatically. Ground-based instruments continuously record signals from global navigation satellite systems (GNSS, of which GPS is one example), measuring the changing shape of the ground surface in near-real time. Interferometric synthetic aperture radar (InSAR) provides extensive spatial coverage of deformation. Seismic monitoring has also improved with the addition of more stations, increased data fidelity, and improved data analysis.

More people live on the slopes of Mauna Loa now than in the 1970s and 1980s, so improvements in monitoring technology are of more than just academic interest.

How does this recent period of unrest compare with the periods just before previous eruptions? How reliable are these comparisons in predicting the next eruption?

The Current Unrest

Several periods of unrest have occurred at Mauna Loa since the 1984 eruption. The shallow magma storage complex started refilling (inflating) immediately following the eruption, but inflation soon slowed and stopped altogether in the mid-1990s (Figure 2). A short-lived inflation episode began in 2002 [*Miklius and Cervelli,* 2003], and another began in 2004. By 2009, inflation had largely ceased. Unlike the current unrest, these previous two inflation episodes were not associated with significant numbers of shallow earthquakes; rather, they started with brief periods of deep seismicity approximately 45 kilometers beneath the surface [*Okubo and Wolfe,* 2008].

The current unrest started in earnest in 2014 (Figure 2). Seismicity rates began to rise above background levels as early as March 2013, and by summer 2014, seismicity and deformation rates had increased significantly. The pattern of ground deformation indicated inflation of a magma storage complex beneath the caldera and uppermost SWRZ, areas that were also the most seismically active (Figure 3).

Beneath the caldera, seismicity consists of mostly small earthquakes (magnitude *M* of less than 2.5) at depths of 2–3 kilometers. These earthquakes occur in swarms lasting days to weeks, separated by months of minor activity. Event rates have been as high as 15 earthquakes per hour, with most earthquakes too small to be formally located.

The uppermost SWRZ has been the most seismically active region during the current unrest, in terms of overall energy release and number of earthquakes. These earthquakes are typically 3–4 kilometers below the surface. Another area of seismicity has been high on the west flank of the volcano, where swarms of small earthquakes (mostly less than *M*2.5) at an average depth of about 7 kilometers typically last days to a week.

In addition to shallow seismicity, there have been several deep (greater than 20-kilometer), long-period earthquakes loosely scattered beneath the summit area. During previous periods of inflation, earthquakes with similar characteristics have been associated with magma ascent [*Okubo and Wolfe,* 2008].

Short-term rates of seismicity and deformation have varied in magnitude, with weeklong to monthlong periods of relative quiescence interspersed within longer-term

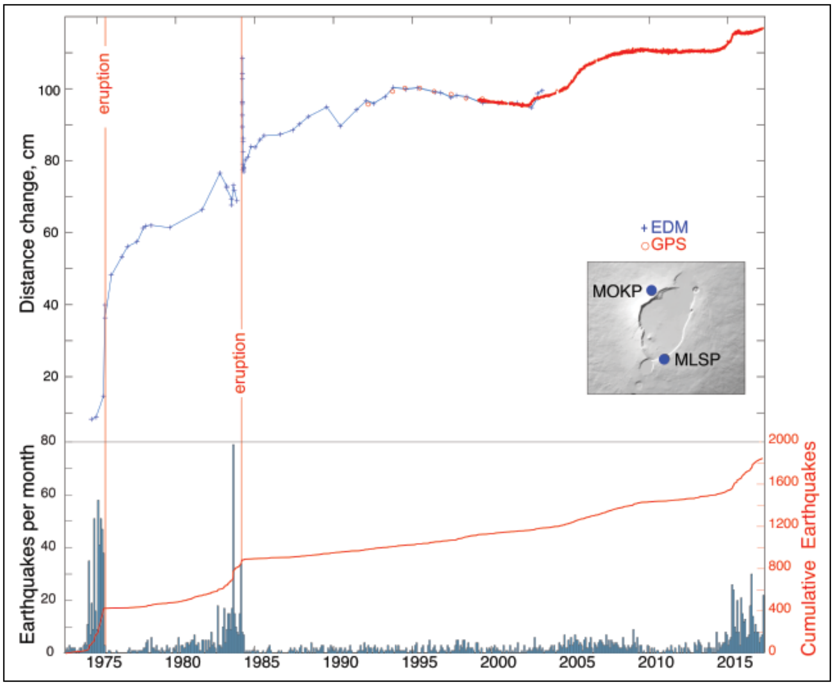

Fig. 2. Changes in distance across Moku'āweoweo, Mauna Loa's summit caldera, and earthquakes shallower than 15 kilometers from 1973 through April 2017 in the same area as in Figure 1. Because today's sensitive instruments can detect earthquakes that previous instruments would have missed, only earthquakes greater than M1.7 *are plotted. Large, abrupt extensions are associated with the formation of volcanic dikes during the 1975 and 1984 eruptions; other extensions are mostly due to accumulation of magma in shallow reservoirs. Note that this distance change is not sensitive to extension across the upper SWRZ, where most of the magma accumulation occurred between October 2015 and mid-2016. (EDM is electronic distance measuring, and MOKP and MLSP are GPS instrument sites.)*

trends of heightened activity. Although there is general long-term correlation between deformation and seismicity rates, there is no obvious relationship between them in the short term.

The spatial pattern of deformation and seismicity has also varied. In fall 2015, after several months of decreased inflation at the summit, seismicity beneath the caldera largely ceased, and inflation in the upper SWRZ increased (Figure 4). In May 2016, inflation and seismicity beneath the caldera slowly resumed, but as of mid-2017, rates are low compared with those seen prior to fall 2015.

Comparison with Past Eruptions

Deformation monitoring networks in place before the 1975 and 1984 eruptions were sufficient to provide long-term indications of inflation that along with increased seismicity, led to a general forecast for the 1984 eruption [*Decker et al.*, 1983]. However, measurements were not frequent enough to evaluate whether there were precursory changes in extension or uplift in the summit area just prior to eruption.

Direct comparison of magma storage geometries and volumes derived from deformation patterns is also not possible because of the limited spatial and temporal extent of the early geodetic monitoring networks. Pre-1984 measurements are consistent with, but cannot confirm, the existence of a large-volume tabular storage complex (a vertical, dikelike body) beneath the summit and

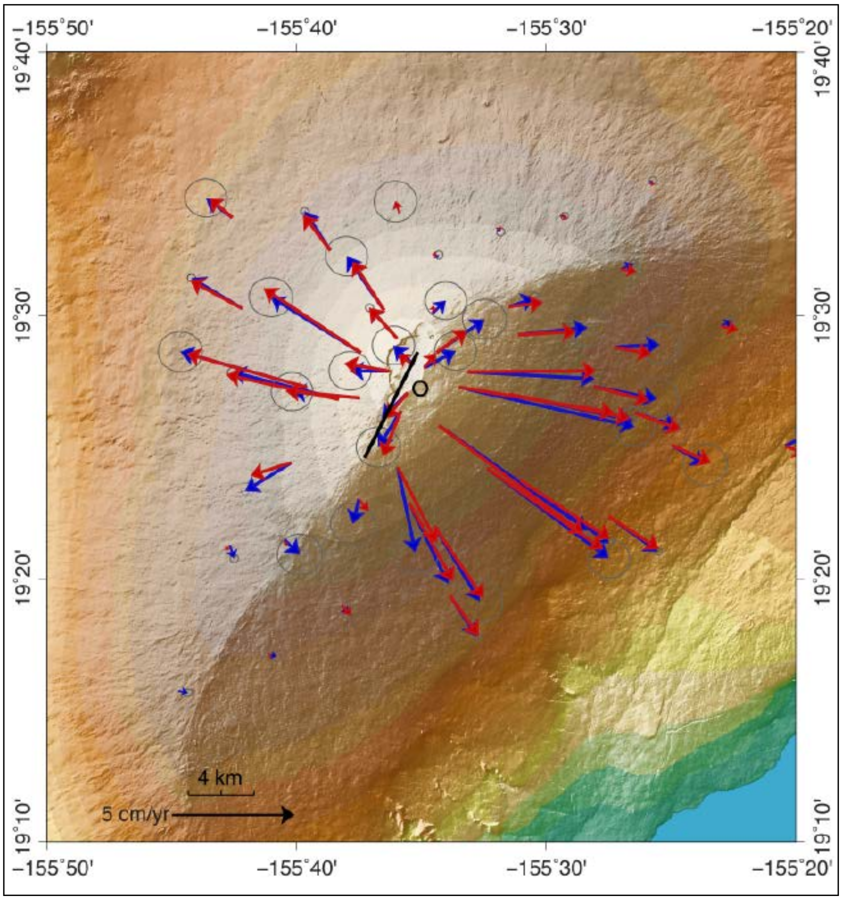

Fig. 3. Blue arrows (with gray 95% confidence error ellipses) show the average horizontal velocities of GNSS stations on Mauna Loa from mid-2014 through 2016. Red arrows represent velocities predicted by a model of a horizontally opening tabular body extending from about 3 to 6 kilometers beneath the summit and upper Southwest Rift Zone and a radially expanding body at about 3 kilometers beneath the southeastern wall of the caldera. The surface projections of these magma reservoirs are indicated by the black line and black circle. The average rate of magma accumulation in these shallow reservoirs is on the order of 13 million cubic meters per year.

upper SWRZ, similar to what we currently model from GNSS and InSAR data.

Similarly, differences in seismic network sensitivity and data processing preclude direct comparison of current seismicity rates with pre-1975 and pre-1984 rates. Patterns in the locations of earthquakes stronger than about *M*1.7, however, are comparable, and these patterns show a clear coincidence between the locations of seismicity during the current unrest and previous preeruption patterns (Figure 5).

Another approach to comparing precursory seismicity is to evaluate cumulative seismic energy release, which mainly reflects energy released by larger-magnitude earthquakes (energy release increases logarithmically with respect to earthquake magnitude). Between 1 May 2013 and 30 April 2017, energy release on the west flank was equivalent to an *M*4.1 earthquake. For the same region, energy releases during the 4 years prior to the 1975 and 1984 eruptions were *M*4.2 and *M*4.5, respectively. In the caldera and uppermost SWRZ, the current energy release sums to *M*4.4, compared with *M*4.9 and *M*4.4 for the 1975 and 1984 precursory periods.

Thus, the energy released during the current 4 or so years of unrest is approaching that released during the 4 years prior to the 1975 and 1984 eruptions. In some volcanic systems, the amount of energy release compared with previous eruptions may be an indicator of whether a period of unrest results in an eruption [*Thelen et al.,* 2010], but this relationship has not been established on shield volcanoes like Mauna Loa.

One to 2 years prior to the 1975 and 1984 eruptions, swarms of small earthquakes increased in intensity. The strongest swarms included hundreds of small earthquakes per day for weeks. Bursts, as they were called, were separated by 3–6 months of relative quiet [*Koyanagi et al.,* 1975]. Recently, swarms on the west flank have increased in number and size, but the durations of the swarms are less than pre-1975 and pre-1984 levels. Similarly, swarms of tiny earthquakes beneath the caldera have not occurred at rates seen in the months prior to the 1975 and 1984 eruptions.

It is interesting that during the days to weeks prior to the past two eruptions, the number of small earthquakes fluctuated instead of building up steadily, even reaching relatively low rates for short periods prior to eruption [*Koyanagi,* 1987; *Lockwood et al.,* 1987]. However, both eruptions had distinct short-term seismic precursors. The 1975 eruption was preceded by less than an hour of strong tremor in the summit caldera area [*Lockwood et al.,* 1987]. In 1984, small (less than *M*0.1) earthquakes increased in frequency, shaking the ground two or three times per minute about 2.5 hours before the eruption [*Koyanagi,* 1987]. Harmonic tremor began about 2 hours prior to eruption, with a large increase in tremor amplitude and a swarm of earthquakes 30 minutes prior to eruption. Seven earthquakes larger than *M*3 occurred during a period from 30 minutes before the 1984 eruption until just over 1 hour after the onset of the eruption.

Is an Eruption in Our Near Future?

Mauna Loa's long history of observed activity aids in forecasting another eruption, but at present, any forecast still contains a high degree of uncertainty. Some aspects of the current unrest are similar to unrest prior to eruptions in 1975 and 1984. Earthquake locations, temporal behavior, and energy release suggest that the volcano may be

following a similar pattern. Other aspects, however, differ from the periods prior to the 1975 and 1984 eruptions.

During the current unrest period, we have not observed the kind of moderate to large flank earthquakes that preceded many historical eruptions [*Walter and Amelung,* 2006], including the 1975 and 1984 eruptions. Also, as of fall 2017, we have not seen the high rates of small earthquakes observed about 7–14 months prior to the 1975 and 1984 eruptions, even though our ability to detect them has improved. Thus, if current unrest follows previous patterns of seismicity, we may expect that the volcano is still many months from eruption.

> Mauna Loa's long history of observed activity aids in forecasting another eruption, but at present, any forecast still contains a high degree of uncertainty.

We must also consider that current unrest might not follow previous patterns, and an eruption could occur without months of elevated microseismicity. It is possible that after years of intermittent inflation, shallow magma storage is exerting pressures already near the breaking point of the overlying rock.

Oblique aerial view looking north-northeast toward the summit area of Mauna Loa volcano (elevation, 4,169 meters) on 15 January 1976. The summit caldera (Moku'āweoweo) is 6 kilometers long and 2.5 kilometers wide. The pit crater in the foreground marks the start of the Southwest Rift Zone. Mauna Kea volcano is on the skyline in the distance. Credit: D. Peterson, USGS

We can't say for certain whether there will be a precursory months-long increase in microseismicity before the next Mauna Loa eruption. However, an eruption will likely be immediately preceded by an hours-long, dramatic increase in small earthquakes (at least one earthquake per minute), strong tremor, and the occurrence of several $M3$ or stronger earthquakes, similar to the lead-up to the 1975 and 1984 eruptions. Real-time deformation data from tiltmeters and GNSS stations will show large anomalies as magma moves from storage reservoirs toward the surface and to the eventual eruption site in the summit area and/or along one of the rift zones or (less likely) from radial vents on the west flank.

It is also possible that current elevated rates of seismicity and deformation may not culminate in eruption anytime soon; rather, this could be yet another episode of unrest that gradually diminishes. During the 25-year repose between the 1950 and 1975 eruptions, seismic unrest in 1962, 1967, and 1970 did not lead to eruption, although in hindsight, each is considered a long-term precursor to the 1975 eruption [*Koyanagi et al.,* 1975].

The high rate of volcanic activity at neighboring Kīlauea volcano complicates assessing the likelihood of a Mauna

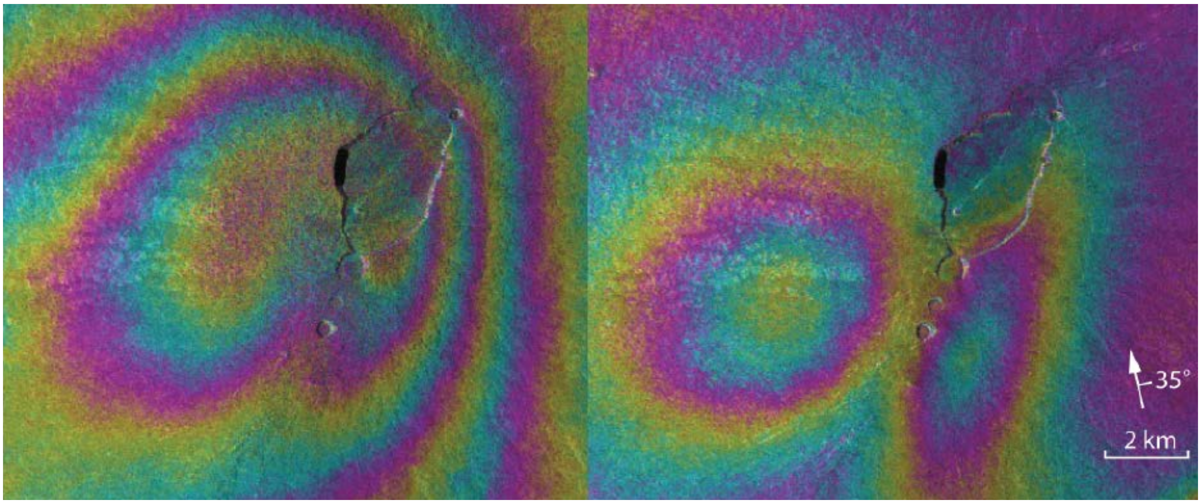

Fig. 4. COSMO-SkyMed ascending mode interferograms show the shift in locus of inflation toward the upper Southwest Rift Zone. Each image covers about the same length of time: (left) 18 March to 9 August 2015 and (right) 24 July to 31 December 2015. Each full-color cycle represents 1.5 centimeters of motion in the line-of-sight direction toward the satellite. Arrow shows direction of motion of the satellite. The SAR antenna looks to the right of the satellite track; the incidence angle is about 35° off vertical. COSMO-SkyMed data were provided by the Agenzia Spaziale Italiana via the Hawai'i Supersite.

Loa eruption in the coming months or years. *Klein* [1982] noted that longer repose intervals at Mauna Loa were statistically correlated with eruptive activity at Kīlauea. Indeed, the current long repose time at Mauna Loa is occurring at the same time as the long-lived Puʻu ʻŌʻō eruption at Kīlauea, which began in 1983 and continues today. Even so, the most recent eruption of Mauna Loa in 1984 occurred during this eruption at Kīlauea, so the impact of nearby volcanic activity on Mauna Loa's behavior over short timescales is unknown.

We can make one forecast with relative certainty: On the basis of nearly 200 years of documented activity, it is highly likely that the next eruption will begin in the summit region and then, within days to years, migrate into one of the two primary rift zones [*Lockwood et al.*, 1987].

It is important to note that seismicity and inflation beneath the uppermost SWRZ do not imply an increased likelihood of eruption along the SWRZ. Similar patterns of seismicity prior to the 1975 and 1984 eruptions did not result in sustained activity in the SWRZ. In 1984, the eruption began at the summit and migrated to the upper SWRZ before activity focused along the NERZ, suggesting that a magma body extending into the uppermost SWRZ—similar to that inferred from current data—was also active prior to that eruption.

Communicating the Hazards

In response to more than a year of persistently elevated rates of seismicity and deformation, the Hawaiian Volcano Observatory (HVO) elevated the Volcano Alert Level (see https://on.doi.gov/2Ex0037) and Aviation Color Code for Mauna Loa to advisory/yellow on 17 September 2015, indicating that the volcano was restless and that monitoring parameters were above the long-term background levels.

Since then, HVO has continued public education efforts and engaged agency partners, including Hawaiʻi County Civil Defense and the National Park Service, to discuss preparedness and response planning. In 2016, HVO installed new web cameras and upgraded real-time gas and temperature sensors in the summit caldera. Alarms have been set to alert scientists to significant changes in several data streams, including real-time seismic amplitude (a measure of seismic energy release), ground tilt, and satellite- and ground-based thermal imagery. Revised maps showing potential inundation zones and likely lava flow paths based on topography derived from digital elevation maps have been prepared.

> Improvements in monitoring networks and alarm systems since 1984 put the Hawaiian Volcano Observatory in a better position to provide early warning and, once an eruption has commenced, help guide emergency response.

As with any precursory volcanic eruption sequence, it will be challenging to choose the correct time to alert authorities and elevate public concern about a possible eruption. Once an eruption has commenced, pinpointing the exact location of the outbreak—especially at night or in cloudy conditions—may not be straightforward and may require the use of new tools such as infrasound. Vent location determines which downslope areas are at greatest risk, so addressing this capability gap is a high priority.

As of this writing, elevated rates of seismicity and deformation continue. Improvements in monitoring networks and alarming systems since 1984 put HVO in a bet-

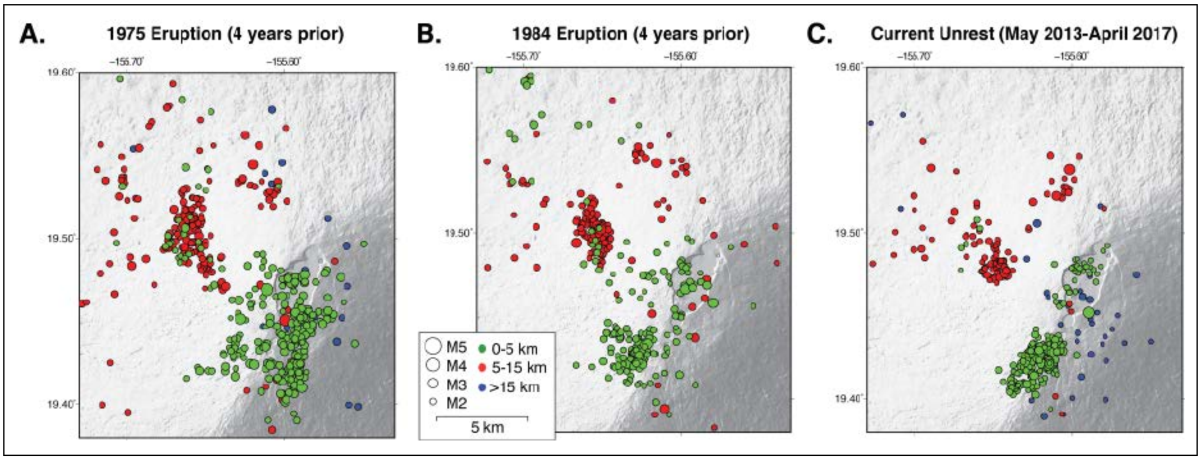

Fig. 5. Earthquake epicenters for (a) the 4 years prior to the 1975 eruption, (b) the 4 years prior to the 1984 eruption, and (c) the latest 4 years of unrest (1 May 2013 to 30 April 2017). Earthquake symbol size is based on magnitude, and color is based on depth. Only earthquakes above M1.7 *are included, in an attempt to compensate for differences in net work sensitivity since 1975. All earthquakes are analyst reviewed. Because the analysis of earthquakes above* M1.7 *is only partially complete for the current episode of unrest, event rates since 2013 may actually be slightly higher than shown here.*

ter position to provide early warning and, once an eruption has commenced, help guide emergency response. Additional efforts to inform and prepare the public for the eventual eruption are an important step in minimizing impacts to life and property.

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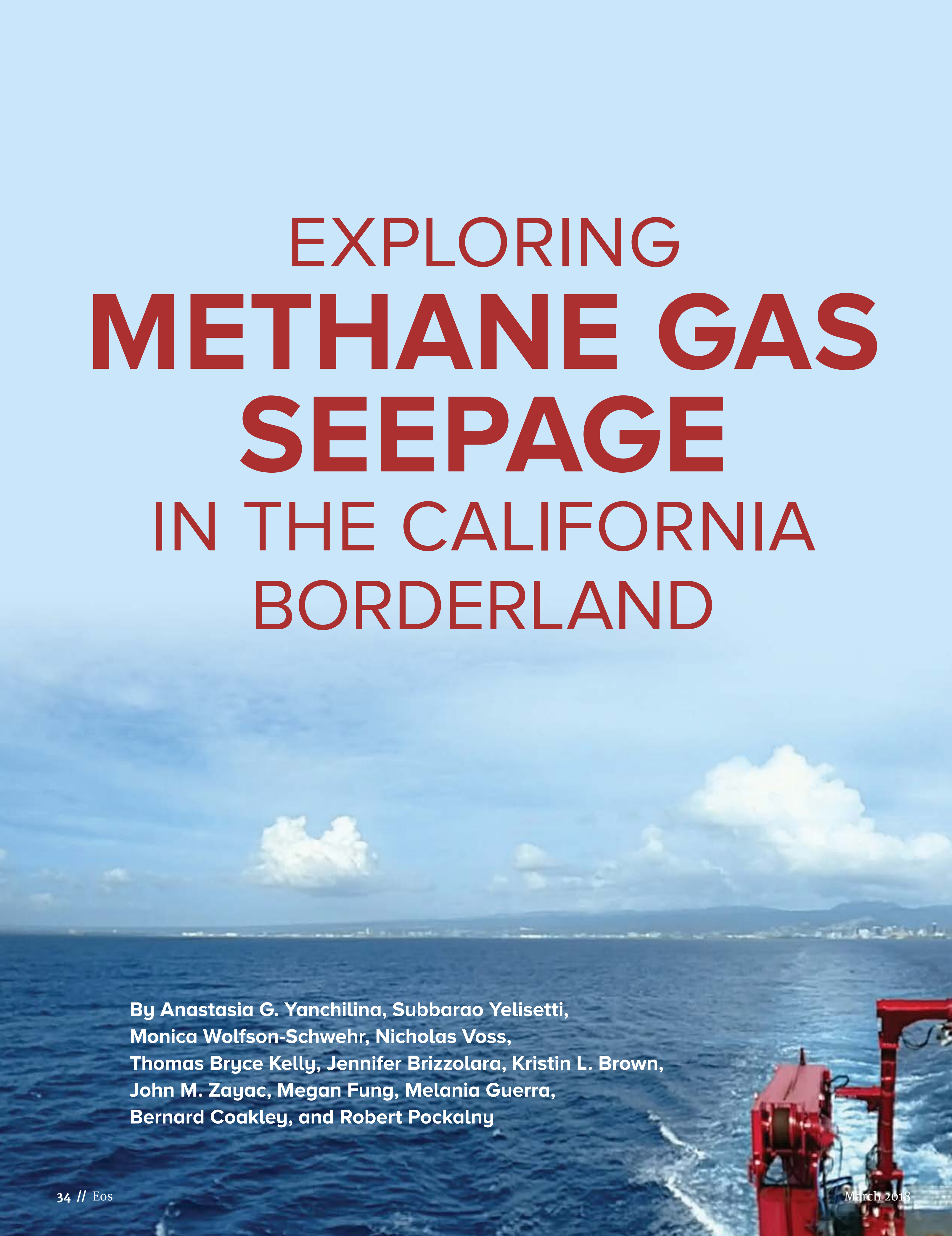

EXPLORING METHANE GAS SEEPAGE IN THE CALIFORNIA BORDERLAND

By Anastasia G. Yanchilina, Subbarao Yelisetti, Monica Wolfson-Schwehr, Nicholas Voss, Thomas Bryce Kelly, Jennifer Brizzolara, Kristin L. Brown, John M. Zayac, Megan Fung, Melania Guerra, Bernard Coakley, and Robert Pockalny

Early-career scientists aboard the 2016 UNOLS Chief Scientist Training Cruise explored recently reactivated underwater methane seeps in the San Diego Trough.

Fluid flow within sediments in the San Diego Trough, off the coast of California, has evolved over the past 5 million years. Early on, hot water and gas spewed from active bounding faults, driven by pressure from overlying sedimentary layers. But now hydrocarbons, including the greenhouse gas methane, seep slowly from the seafloor, driven by buoyancy [*Boles et al.*, 2004].

The methane seepage in the San Diego Trough appeared to taper off starting in 2013, but now it appears to be active again. Changes in hydrostatic pressure due to sea level are not thought to have significantly changed over the past 2–3 years. Could recent earthquake activity have reactivated the methane seeps?

This was one of the questions on the minds of a group of early-career scientists as they took to the sea. From 1 to 17 December 2016, twenty-one graduate students and postdoctoral researchers participated in a marine geology and geophysics expedition on board the R/V *Sikuliaq* as it transited between Honolulu, Hawaii, and San Diego, Calif.

The at-sea scientific and leadership training experience, called the Chief Scientist Training Cruise (CSTC), was organized by the University-National Oceanographic Laboratory System (UNOLS) and was funded by the National Sci-

The R/V Sikuliaq *nears its destination after its transit from Honolulu, Hawaii, across the Pacific Ocean to San Diego, Calif. Credit: Jennifer Brizzolara*

Participants in the UNOLS Chief Scientist Training Cruise split and examine sediment cores during the 2016 expedition from Honolulu, Hawaii, to San Diego, Calif. Credit: Jennifer Brizzolara

ence Foundation. The yearly CSTCs aim to expose and prepare early-career scientists to take on leadership roles in planning, funding, and executing international collaborative seagoing expeditions.

Here we report the progress of a subgroup, whose members designed one leg of the expedition. This subgroup, informed by prior observations of methane seeps and faulting activity in the California Borderland and the Santa Monica Basin [*Maloney et al.*, 2015], made plans to map and observe these features in higher resolution.

Preparing to Come Aboard

The CSTC participants got to work before even stepping on board the ship. During 2 days on land, they worked in subgroup sessions, hosted at the Department of Geology and Geophysics, University of Hawaiʻi at Mānoa, to present competing proposals of feasible science objectives, appropriate target locations, and suitable methodologies that maximized the overall use of the 2-week transit.

The participants gained experience in designing and testing scientific hypotheses, manipulating the ship's onboard technologies, and adhering to limitations imposed by the vessel's capabilities. This scientific decision-making process was accompanied by lessons in managing real-world constraints of seagoing research, like unpredictable weather and team members' scheduling.

As a part of the team's preparation, they reviewed what scientists knew about the methane seeps in the San Diego Trough and decided how best to use their cruise time to help answer several puzzling questions.

Methane's Role

Methane seepage appears to start and stop over periods of a few years, but questions remain about this pulsating behavior and how it is related to the fluid pressure in the area at any given time [*Grupe et al.*, 2015; *Maloney et al.*, 2015]. Previous studies have demonstrated that any variable affecting hydrostatic pressure (i.e., tides and sea level changes) could influence the stability of methane seepage [*Boles et al.*, 2001].

Although most of the methane released from the seafloor dissolves before reaching the atmosphere, methane released in vigorous, episodic bursts could travel farther up the water column (see http://bit.ly/Nautilus-methane-burst for a video of a 2015 episode). If scientists are to make accurate

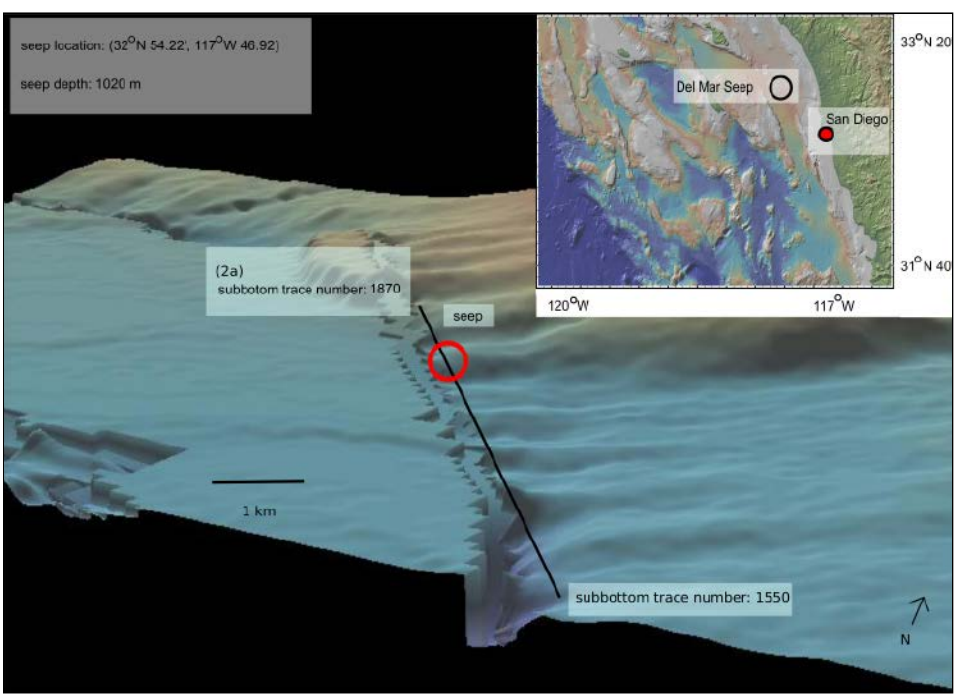

Fig. 1. Location of the Del Mar Seep (32°N 54.22′, 117°W 46.92′). The inset shows the location of the methane seep relative to San Diego, Calif.; vertical exaggeration is 9 times. The solid black line shows the location of the subbottom data profile (Figure 2), corresponding to trace numbers 1550–1870.

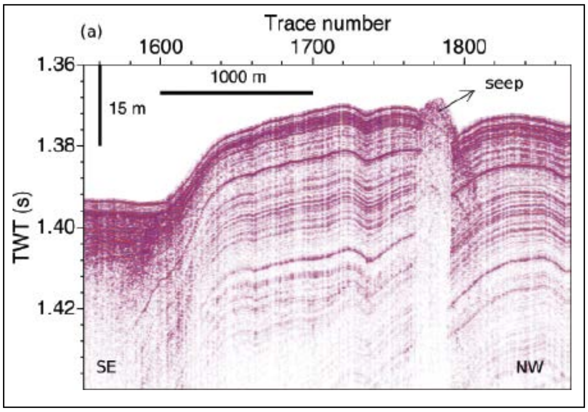

Fig. 2. Subbottom acoustic cross section of the mound associated with the Del Mar Seep (see Figure 1 for the location of the scan line). TWT = two-way travel time of the sonar waves in seconds.

estimates of seep mobilization and the amount of gas released into the ocean and atmosphere, they must understand the processes that control the dynamics of seeps.

Ongoing research is investigating the large-scale processes by which this gas can affect ocean chemistry and greenhouse gas concentrations. At present, however, no one knows how significantly this source contributes to the global methane budget and how that could be altered under a future climate change regime [*Kessler,* 2014].

Active faulting and slumping in offshore environments could alter the dynamics of methane seepage activity [*Paull et al.*, 2008; *Yelisetti et al.*, 2014]. Studies of recent earthquakes off the coast of Southern California suggest that at least some of the faults in this region are, indeed, active [*Hauksson et al.*, 2014].

Bottom-simulating reflectors, structures with acoustic signatures that mimic the seafloor's signal and that are commonly associated with methane hydrates, have previously been observed within the California Borderland and the Santa Monica Basin [*Torres et al.*, 2002]. Earlier research has shown that fluid movement is actively associated with fault rupturing [*Eichbul and Boles*, 2000]. Thus, the extent of these hydrate deposits and the associated methane seepage activity may be connected to seismic activity.

Measuring the Methane

The CSTC participants collected acoustic reflection data using a subbottom profiler. They also gathered multibeam bathymetry and water column data using multibeam sonar with adjustable frequencies to identify active faults and associated methane hydrates (Figure 1).

The survey team revisited the previously surveyed Del Mar Seep located in the San Diego Trough offshore of Del Mar, Calif. Surveyors using multibeam bathymetry, subbottom profiler data, and video from a remotely operated vehicle (ROV) in 2012 were the first to observe this seep's activity [*Maloney et al.*, 2015]. A return survey in 2013 did not detect bubble activity [*Grupe et al.*, 2015], suggesting that the seep was not active at that time.

On 16 December 2016, the team aboard the R/V *Sikuliaq* observed that the seep had become active again. Data from the subbottom profiler helped to determine the exact subsurface location of the methane seep on the basis of disruption in sedimentary layers (Figure 2). The team observed methane seeps covering a 300-meter distance along its scan at a depth of 1,020 meters (Figures 1 and 2).

The seeps appear to be associated with a small mound feature on the seafloor. The shallow subsurface sedimentary layers are shifted by about 7–10 meters on either side of the seep location (Figure 2). Figure 3 shows the location where the team obtained a cross section of the water column multibeam data. Bubbles associated with the seep are visible in the water column (Figure 4).

Valuable Training, Real Research Results

Ongoing questions about how methane seeps start and stop and what happens to the methane once it escapes the seafloor sediments will drive scientific research for years to come. However, the results of this expedition highlight the impact of training early-career scientists and the importance of providing them with adequate tools and resources

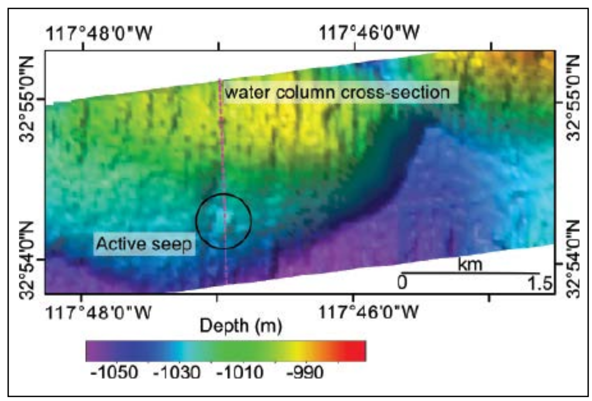

Fig. 3. Multibeam bathymetry of the mound associated with the Del Mar Seep. The grid resolution is 5 × 6 meters, and the vertical exaggeration is 6 times. The dashed pink line represents the location of the water column cross section shown in Figure 4.

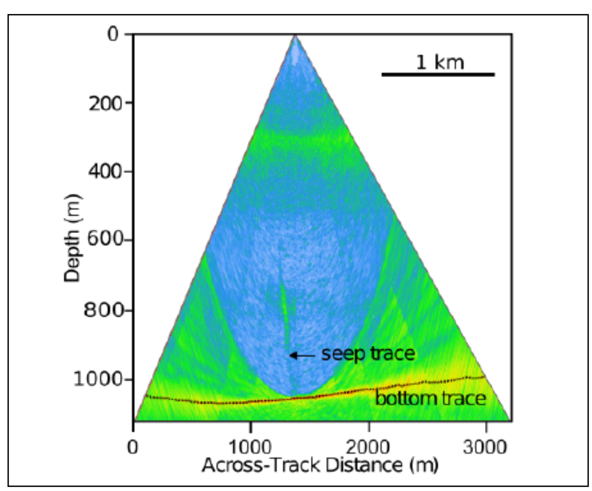

Fig. 4. Water column imagery of the Del Mar Seep from the EM302 sonar. The seep trace identified shows methane rising through the water column. The bottom trace identified represents the depth of the seafloor derived from multibeam bathymetry.

Participants in one of the cruise projects, led by Jacob Beam, prepare to deploy the gravity corer to take sediment cores from the abyssal Pacific as part of a study of biological cycling of iron in marine sediments. Credit: Jennifer Brizzolara

that teach them to plan and execute shipboard work in marine investigations. With the contributions to the community from newer, better prepared generations of marine scientists, ocean exploration will remain at the forefront of critical scientific discoveries.

The 2017 UNOLS CSTC ran from 26 September to 2 October (see http://csw.unols.org), and the participants are processing the data they collected. Additional information about the UNOLS CSTC, a list of all 2016 participants, and a summary of the 2016 expedition can be found on the UNOLS website (http://bit.ly/UNOLS-CSTC-2016).

Acknowledgments

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Enabling FAIR Data Across the Earth and Space Sciences

Participants in a small group session at the 16–17 November 2017 stakeholder meeting discuss solutions that can be leveraged for the Enabling FAIR Data project. (left) Erik Schultes of the Dutch Techcentre for Life Sciences in the Netherlands speaks with (center) Viv Hutchison and (right) Leslie Hsu, both from the U.S. Geological Survey. Credit: Shelley Stall

Open, accessible, high-quality data, along with related data products and software, are critical to ensuring the integrity of published research and facilitating reuse of the data in future work. This is particularly true in the Earth and space sciences, where integrated data sets increasingly provide diverse and important societal benefits and are used in critical real-time decisions. Unfortunately, data preservation and curation are uneven. And even when data are well preserved, they can lack adequate documentation or easy discoverability. The international Future of Research Communications and e-Scholarship organization, FORCE11, which was founded in 2011, has thus proposed that for data to be reusable the infrastructure should follow the Findable, Accessible, Interoperable, and Reusable (FAIR) guiding principles (see http://bit.ly/FAIR-formal-debut).

Thanks to a grant from the Laura and John Arnold Foundation, AGU and other partners have started a project, Enabling FAIR Data, across the Earth and space sciences. The goal of the project is to align publishers and repositories in following best practices to enable FAIR data and to create workflows so that researchers will have a simplified, common experience when submitting their papers to any leading Earth and space science journal. Project information can be found on the website of the Coalition for Publishing Data in the Earth and Space Sciences, and more information is in a recent *Editor's Vox* blog post about the project (see http://bit.ly/FAIRvox).

Project Objectives

1. FAIR-compliant data repositories will add value to research data, provide metadata and landing pages for discoverability, and support researchers with documentation guidance, citation support, and peer review.

2. FAIR-compliant Earth and space science publishers will align their policies to establish a similar experience for researchers. Data will be available through citations that resolve to repository landing pages. Data are not placed in the supplement.

Publishers, data repositories, and supporting organizations will work together to provide easy-to-access directories of repositories, standards for reporting data, and future governance.

This project kicked off with a stakeholder meeting in Arlington, Va., on 16–17 November 2017.

Stakeholder Survey

A survey of key stakeholders (publishers, repositories, and supporting organizations) that began prior to the workshop provided a baseline for how the FAIR data guiding principles currently are perceived and implemented. A total of 256 stakeholders responded by the time of the workshop. A total of 41% of the respondents reported their primary roles as data professionals, 35% as researchers, 8% as publishers, 2% as funders, and 14% in other roles. There was broad diversity across geoscience disciplines, years of experience, gender, and other metrics. Nearly 40% of the respondents were from outside the United States.

Respondents were asked how important each part of the FAIR principles is and how easy or difficult it is to achieve them. Three interesting findings emerged:

1. The greatest difficulty was thought to be around interoperability, with reusability a close second. The first two parts of FAIR (finding and accessing data), although still challenging, were not seen as difficult.

2. The concept of attaching a Digital Object Identifier (DOI) to data is becoming well established and accepted, meaning that DataCite and Crossref have achieved success implementing this concept within the science researcher, publisher, and repository communities.

3. The largest gap between importance and ease was around data repositories having reliable funding. The respondents felt that it is very important that repositories have reliable funding, but this need is seen as very difficult.

The survey results are available online (see http://bit.ly/srvy-results).

The Meeting and Follow-Up Work

More than 80 attendees participated in the kickoff meeting, which was aimed at aligning stakeholders and outlining and beginning to develop solutions.

One of the most exciting revelations of the workshop was that the elements needed to effectively share data between repositories and publishers already exist at small scales and that several other international community organizations are already engaged in work to implement parts of the FAIR principles. Thus, adoption across the Earth and space sciences requires, in part, aligning existing activities and ensuring widespread adoption of current standards and recommended practices.

The workshop formed several targeted adoption groups (TAGs) to guide this adoption while aligning with existing groups. Separate TAGs are addressing the following:

- Repository Guidance for Researchers
- Earth and Space Science (ESS) Publishers Aligning Standards (TAG name: Publishers in the ESS team)
- FAIR Resources and Training for Researchers
- Data and DOI Workflows and Handoffs
- Credit for Digital Products (TAG name: Culture Change through Credit)
- Key Elements of Active DMPs (liaison team to existing efforts; a DMP is a data management plan)

These groups are open to any interested participants, and details for joining may be found online (see http://bit.ly/join-info). The goal is to complete the work by spring 2018, test the implementation in early summer, and begin community-wide implementation in midsummer.

For additional information and details on getting involved, contact Shelley Stall (sstall@agu.org), AGU's director of data programs. Status reports and workshops on this project will be offered at the Research Data Alliance Plenary 11 (18 March 2018) and the European Geosciences Union Meeting (10 April 2018).

By **Shelley Stall** (email: sstall@agu.org), Director, Data Programs, AGU; **Erin Robinson,** Earth Science Information Partners, Boulder, Colo.; **Lesley Wyborn,** National Computational Infrastructure, Canberra, Australia; **Lynn Rees Yarmey,** Rensselaer Polytechnic Institute, Troy, N.Y.; also at Research Data Alliance/United States, Troy, N.Y.; **Mark A. Parsons,** Rensselaer Polytechnic Institute, Troy, N.Y.; also at Research Data Alliance, Troy, N.Y.; **Kerstin Lehnert,** Lamont–Doherty Earth Observatory, Columbia University, Palisades, N.Y.; **Joel Cutcher-Gershenfeld,** Heller School for Social Policy and Management, Brandeis University, Waltham, Mass.; **Brian Nosek,** Center for Open Science, University of Virginia, Charlottesville; and **Brooks Hanson,** Executive Vice President, Science, AGU

Reducing Errors in Satellite-Derived Arctic Sea Ice Thicknesses

An illustration of the European Space Agency's CryoSat-2 satellite, launched in 2010. Credit: ESA

Each September, Arctic sea ice melts to a minimum point and then refreezes again over the winter. As a result of climate change, the Arctic is warming at a rate faster than the rest of the globe, causing more sea ice to melt during the summer than freezes in the winter.

The sea ice minimum has been diminishing by about 13% per decade since 1979 (and perhaps long before that) when scientists first started using satellites to track Arctic sea ice. The 2017 Arctic sea ice minimum was the eighth lowest on record, covering roughly 1.8 million square miles of the Earth's surface.

Not only are low sea ice minimums a threat to wildlife, such as polar bears, but also they create a positive feedback loop: Ice is highly reflective, so when there's less of it, sunlight is absorbed at the Earth's surface instead of being reflected back into the atmosphere, causing more warming and thus more melt. Scientists have also found that fewer patches of sea ice are thick enough to survive multiple melt seasons, meaning that ice cover is getting thinner in general and more vulnerable to melting.

In 2010, the European Space Agency launched the CryoSat-2 satellite to estimate changes in the thickness and volume of polar sea ice. An antenna on the satellite transmits microwaves toward the Earth's surface, and a receiver measures the time it takes the signal to be reflected back, determining whether the point below is ice or open water. If it's ice, the microwaves can, in theory, penetrate first through the top of the snow cover to the surface of the ice, where they are reflected back to the satellite's receiver. A bit of math then yields a value for the ice's thickness.

Scientists who use CryoSat-2 data to estimate Arctic sea ice thickness generally assume that these signals are being reflected off of a flat plane of ice; however, it's possible that layers of snow on top of the ice could introduce errors in their measurements. In particular, snow salinity—the amount of salt, traces of which are left behind during the freezing process, contained in the snow—could skew results by reflecting microwaves back to the satellite's receiver from these salty snow layers before they reach the surface of the ice. This would cause the ice's freeboard—the amount of ice above the seawater—to be overestimated.

In a new study, *Nandan et al.* explore the effect of snow salinity on the ability of satellite signals to penetrate through snow to the sea ice's true surface. The team of researchers examined first-year ice measurements collected over the Canadian Arctic in late winter, using a mathematical model to determine the amount and distribution of salt in the snow.

On the basis of their modeling, the researchers found that snow salinity had the potential to throw off sea ice thickness estimates by 11%–25%, depending on sea ice thickness. They recommend that others account for this in the hope that doing so will improve the accuracy of future estimates, especially for first-year ice. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL074506, 2017) **—Sarah Witman, Freelance Writer**

Mapping a Valparaíso Earthquake from Foreshock to Aftershock

A magnitude 7 earthquake struck off the coast of Valparaíso, Chile, in April 2017. A new study uses seismic records of this quake to trace how earthquakes develop. Credit: Ronald Woan, CC BY-NC 2.0 (http://bit.ly/ccbync2-0)

A massive arc of seismic activity, stretching from Australia to Japan, up toward Alaska, and down along the west coast of the Americas, is known among geologists as the Ring of Fire. Roughly 90% of the world's earthquakes occur there.

In April 2017, a swift but powerful magnitude 7 earthquake occurred off the coast of Valparaíso, Chile, near the base of the Ring of Fire. About 2 days before it began, scientists detected intense seismic activity in the region. In a new study, *Ruiz et al.* zeroed in on this earthquake to better understand the formation, or nucleation, of earthquakes, as scientists do not know exactly why or how earthquakes start, become larger, and stop.

Using data collected by a large network of GPS and broadband stations (suites of instruments taking seismic measurements at a broad range of frequencies) along the coast of Chile, the researchers studied the nucleation of the Valparaíso quake in great detail, as well as its rupture dynamic: the movement, deformation, and breakage of rock as an earthquake develops.

The researchers analyzed seismic data from the days leading up to the most intense point of the earthquake, or main shock. They also used a series of GPS readings from before, during, and after the main shock to determine that the earthquake was triggered by a slow-slip event, which is characterized by a slower-velocity rupture in comparison with a regular earthquake. Essentially, the team created a detailed map of the Valparaíso seismic sequence, charting the landscape of seismic movement, from the first foreshocks to the main shock to the final aftershocks.

This study provides the first clear picture of the dynamics of a slow-slip earthquake in the central Chile zone, where the last tsunamigenic megathrust earthquake occurred in 1730. It is also one of the best records in existence of the nucleation phase of an earthquake. This is an important step toward understanding how earthquakes develop and could help scientists predict seismic events with more accuracy. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL075675, 2017) **—Sarah Witman, Freelance Writer**

Searching for Organic Carbon in the Dry Valleys of Antarctica

Few organisms can survive in the upper reaches of the windswept McMurdo Dry Valleys of Antarctica. In the high, desiccated, "ultraxerous zone," ice rarely if ever melts, and life consists mostly of lichens, moss, fungi, and bacteria. A new study finds the first evidence that some microbes perform cellular respiration in this inhospitable zone, which many scientists consider the terrestrial environment closest to that of Mars.

To track the source and distribution of organic matter—possible chemical signatures of life—in the dry, ultraxerous zone, *Faucher et al.* collected 16 icy permafrost cores from the floor of a small glacial valley in Antarctica's Quartermain Mountains. They cut the ice cores into 2-centimeter-thick slices and sealed them in plastic bags in which the samples were allowed to thaw. Then they measured the soils' carbonate, organic carbon, and total nitrogen content.

Organic carbon was scant in the permafrost soils, ranging from 0 to 313 micrograms per gram of soil. Most of the organic carbon and carbonates in the soils were the product of the weathering of higher-elevation sandstone that contains endoliths, organisms that live inside rocks or in pores between mineral grains. However, a very small fraction of the soil carbon content, the team concluded, was likely derived from active microbial respiration in the location where the samples were collected.

The soils the team analyzed have been accreting for the past 200,000 years, yet the chemical composition has not changed much over time, the team found. Although life in the ultraxerous zone has been scant for as long as scientists can measure, the trace amounts of non-endolith-derived carbon reveal that some microbes do respire in those soils. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1002/2017JG004006, 2017) **—Emily Underwood, Freelance Writer**

A small glacial valley in Antarctica's Quartermain Mountains. Here researchers collected cores along the valley floor to better understand the distribution and sources of organic matter in the valley's desiccated soils. Some carbon found in the soils weathered from the sandstone along the valley's walls. Credit: Dale Andersen

Scientists Probe Water in Leaves via Satellite

Sensors on board satellites are able to detect a host of environmental metrics, from Arctic sea ice melt to the reproductive patterns of mule deer to logging and land clearing. One satellite-based measurement, called vegetation optical depth, is often used to track how plant life is responding to changes in climate.

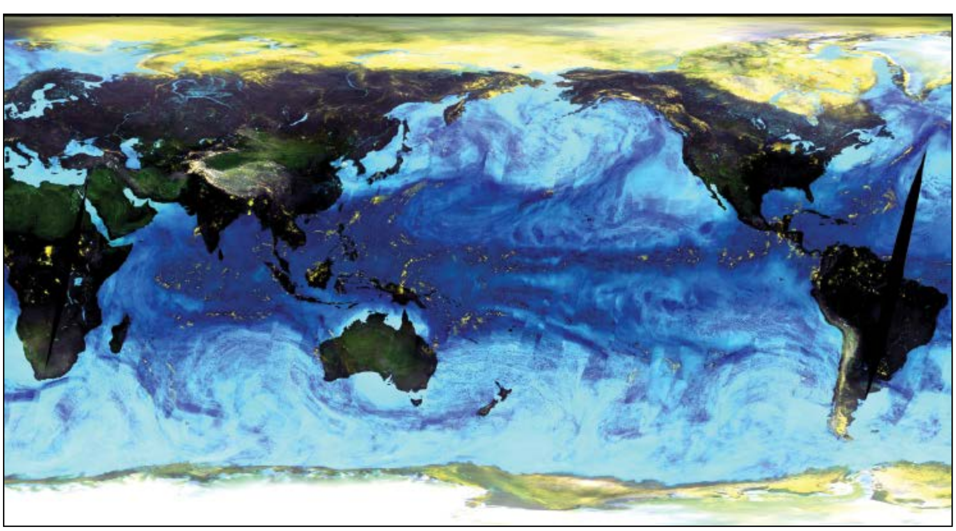
However, scientists have not fully disentangled several other interrelated components of vegetation optical depth, such as biomass (the amount of leafy, versus woody, parts of plants) and water stress (water scarcity due to drought or root damage, affecting a plant's ability to function). In particular, understanding how leaf water potential—the potential energy of water held in a leaf and available to transpire into the atmosphere—affects vegetation optical depth would greatly improve our ability to study how plants respond to water stress and droughts.

Being able to correctly interpret satellite data on vegetation optical depth is becoming increasingly important, as more satellite missions are launched each year, making these data sets more plentiful and accessible to scientists. In a new publication, *Momen et al.* use data collected by the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) satellite instrument to develop a framework for scientists studying vegetation optical depth via satellite.

Using AMSR-E data, the researchers explored the relationships between vegetation water content, leaf area, leaf water potential, and total canopy biomass. They checked these relationships using observations of leaf water potential from three field sites in the United States: an evergreen woodland in New Mexico, a deciduous forest in Missouri, and a deciduous forest in Indiana. Using these relationships and site measurements, the authors estimated vegetation optical depth variations that matched the satellite data well.

The researchers also estimated leaf water potential on a global scale, and they were able to explain about 30% more of the vegetation optical depth signal by taking into account leaf area, and about 15% more by taking into account water potential, suggesting that vegetation optical depth is sensitive to both of these factors on a larger scale. They also found that vegetation optical depth was more highly correlated with leaf area in wetter regions with denser, taller canopies, whereas it was more highly correlated with plant water potential in dry, sparsely vegetated regions.

Using microwave sensors on board satellites to detect water in plants is a capability that was unimaginable mere decades ago. This study is a step toward perfecting this field of study, to provide the best possible information on regional and global climate. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1002/2017JG004145, 2017) **—Sarah Witman, Freelance Writer**



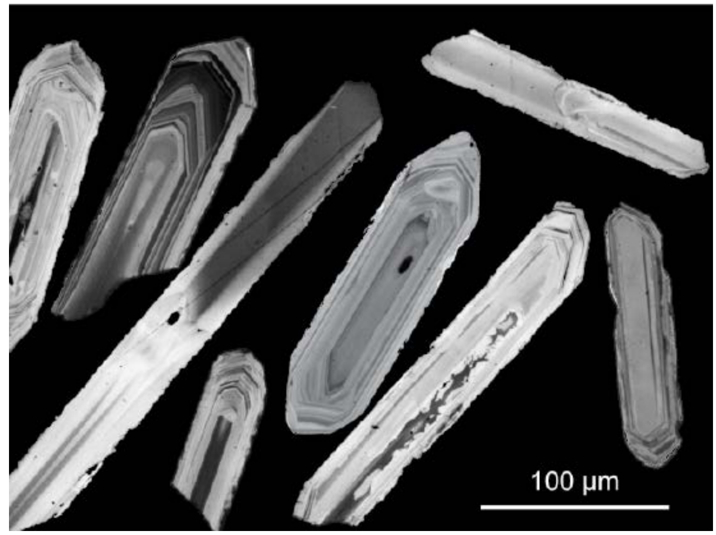
"First light" images from the AMSR-E instrument on board NASA's Aqua satellite. Credit: AMSR-E Science Team, National Space Development Agency of Japan

Resolving a Mystery of the Ages

The transition between the Eocene and Oligocene epochs, which occurred about 34 million years ago, is marked in the geologic record by large-scale extinctions and planetwide cooling that abruptly triggered the growth of the Antarctic ice sheet. However, this dramatic change has not yet been tied to a single event, such as a volcanic eruption, which means that a precise understanding of its timing is necessary to evaluate the potential causes. Despite considerable research, however, there is still a 600,000-year discrepancy between the two principal methods—astronomical tuning and radiometry—used to date this pivotal boundary.

To get a handle on this disparity, *Sahy et al.* used state-of-the-art uranium-lead radiometric techniques to date zircon crystals extracted from 11 volcanic ash layers at three locations in central Italy's Umbria-Marche sedimentary basin, which hosts the global stratotype section that's used as a reference point for this transition. The results indicate that previously published dates from two of these locations, which underpin the Eocene-Oligocene portion of the *Geologic Time Scale 2012*, are up to 500,000 years too old. The new data pinpoint the Eocene-Oligocene boundary at 34.09 ± 0.08 million years, a date that is in good agreement with the astronomically tuned timescale derived from deep-sea sediment cores when magnetic proxies for the transition are taken into account.

This research, which resolves one of the fundamental outstanding questions involving the current Cenozoic era, highlights the importance of integrating the results of multiple techniques to ensure the accuracy of the dates underpinning the geologic timescale. The study's results will have broad implications for researchers in multiple disciplines, including paleoclimatology, paleoceanography, and chronostratigraphy. (*Paleoceanography*, https://doi.org/10.1002/2017PA003197, 2017) **—Terri Cook, Freelance Writer**



Zircon crystals from a volcanic ash layer located about 6 meters above the base of the Massignano section in the Umbria–Marche sedimentary basin, which hosts the global standard of the Eocene–Oligocene boundary. Layers in the crystals are seen here using cathodoluminescence. New radiometric dating indicates that the volcanic ash is 35.47 ± 0.05 million years old. Credit: Diana Sahy

Scientists Simulate a New Mechanism of Fluid Flow in Earth's Crust

Deep in Earth's crust, intense heat and pressure can drive chemical changes in rocks known as metamorphic reactions. These reactions can release fluids that flow through tiny pores between the rock grains. Described mathematically, this flow occurs as a sphere-shaped wave that propagates through the hot, viscous rock.

In a new paper, *Omlin et al.* used 3-D computer modeling to simulate the behavior of reactive porosity waves and compared it with that of viscous porosity waves, another type of fluid transport wave that is relatively well understood. The findings revealed a previously unknown mechanism by which fluids might flow through rock beneath Earth's surface.

This work builds on the researchers' previous work of developing mathematical equations that describe a system in which metamorphic reactions release volatile substances (like water or carbon dioxide) from porous, viscous rock. The released volatile substances become fluid that fills pores between rock grains. Changes in pressure resulting from the reactions cause the fluid to flow with respect to the solid rock.

The research team used these equations to simulate reactive porosity waves via graphic processing unit (GPU) parallel processing. The 3-D simulations revealed how the waves would behave over time.

The scientists found that reactive porosity waves can travel long distances at constant velocity. The waves also behave similarly to viscous porosity waves (which are triggered by rock deformation, not chemical reactions) in that they increase the porosity—the amount of fluid-filled space between grains—of a rock as they pass through.

However, reactive and viscous porosity waves use different mechanisms to travel through rock, the research team found. A viscous porosity wave propagates as changes in fluid pressure compress and decompress the rock. For a reactive porosity wave, chemical reactions that release volatile substances—not rock compaction—drive pressure and porosity changes.

The researchers also simulated what happens when two reactive porosity waves collide. They found that the spherical waves pass through each other before each recovers its own initial shape. Such behavior is characteristic of a soliton, a type of wave that keeps its shape while traveling at constant velocity. This is the first study to show that chemical reactions, and not just rock deformation, can produce solitonlike porosity waves.

These findings could provide new insights into rock veins formed by metamorphic reactions, as well as by fluid release from rocks in subduction zones. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL074293, 2017) **—Sarah Stanley, Freelance Writer**

Atmospheric Sciences

Postdoctoral/Research Scientists, Princeton University

In collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), the Atmospheric and Oceanic Sciences Program at Princeton University solicits applications to its Postdoctoral Research Scientist Program.

The AOS Program and GFDL offer a stimulating environment with significant computational and intellectual resources in which to conduct collaborative or independent research. We primarily seek applications from recent Ph.D.s for postdoctoral positions but will accept applications from more experienced researchers. Appointments are made at the rank of Postdoctoral Research Associate or more senior initially for one year with the possibility of renewal for a second year based on satisfactory performance and continued funding. A competitive salary is offered commensurate with experience and qualifications.

We seek applications in all areas of the climate sciences. This includes research in basic processes in atmospheric and oceanic dynamics; climate dynamics, variability and prediction; atmospheric physics and chemistry; cloud dynamics and convection; boundary layer processes; land-sea-ice dynamics; continental hydrology and land processes; physical oceanography; ocean-atmosphere interaction; climate diagnostics and analysis. Applicants must have a Ph.D. in a relevant discipline.

Further information about the Program may be obtained from:

http://www.princeton.edu/aos/. Applicants are strongly encouraged to contact potential hosts at GFDL and Princeton University prior to application to discuss areas of possible research.

Complete applications, including a CV, copies of recent publications, contact information for at least three references, and a titled research proposal should be submitted by March 1, 2018 for full consideration. Applicants must apply online https://www.princeton.edu/acad-positions/position/5581. We wish to broaden participation in climate-related sciences, and therefore particularly encourage applications from individuals with experience working with groups under-represented in science. These positions are subject to the University's background check policy.

Princeton University is an Equal Opportunity/Affirmative Action employer and all qualified applicants will receive consideration for employment without regard to age, race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Interdisciplinary

Head and Professor, Department of Earth, Atmospheric, and Planetary Sciences, Purdue University

Purdue University invites applications for the position of Head of the Department of Earth, Atmospheric, and Planetary Sciences to start as early as August 2018. We seek a recognized researcher with a proven track record of leadership, vision, and mentoring. The successful candidate will have a clear plan to continue to increase the visibility, stature, and intellectual leadership of the department and the College of Science. The department head will demonstrate a commitment to excellence in teaching. The EAPS department is an interdisciplinary department with 40 faculty whose diverse research topics range from the Earth's mantle through the atmosphere, to the surfaces of other planets, to sustainable communities. We currently have new research initiatives in energy and environment, natural disasters and hazards, and data science. Department faculty are also involved in University-wide multidisciplinary research in planetary science, geochronology, climate change, and environmental science. Further information about the Department can be found at https://www.eaps.purdue.edu/ and additional materials are available upon request.

The Department of Earth, Atmospheric, and Planetary Sciences is one of seven departments in the College of Science with involvement in numerous interdisciplinary programs and centers. Beyond the College, Purdue's strengths in Engineering, Agriculture, Veterinary Medicine, Pharmacy and the Health and Human Sciences contribute to a robust research and educational environment. Further information on the College of Science is available on the website at www.science.purdue.edu.

Qualifications: The successful candidate will have a Ph.D. in Earth, Atmospheric, and Planetary Sciences or a related discipline, an outstanding record of scholarly achievement and a history of extramurally funded research commensurate with the rank of full professor at Purdue, exceptional and proven leadership abilities, a vision for the Department in the university, state, and nation, a commitment to excellence in undergraduate and graduate education, an enthusiasm for engagement, and a dedication to championing diversity and inclusion.

Applications: Interested candidates should submit a cover letter, curriculum vitae with the names and e-mail addresses of three references, a statement of research and teaching accomplishments, and a vision statement for the future of EAPS research and education. Applications should be submitted to http://hiring.science

.purdue.edu. Inquiries should be directed to Ken Ridgway, Chair of EAPS Head Search Committee, ridge@purdue.edu. Review of applications will begin February 15, 2018 and will continue until the position is filled. A background check is required for employment in this position. Purdue University's Department of Earth, Atmospheric, and Planetary Sciences is committed to advancing diversity in all areas of faculty effort, including scholarship, instruction, and engagement. Candidates should address at least one of these areas in their cover letter, indicating their past experiences, current interests or activities, and/or future goals to promote a climate that values diversity and inclusion.

Purdue University is an EOE/AA employer. All individuals, including minorities, women, individuals with disabilities, and veterans are encouraged to apply.

PhD Research Fellowship in Remote Sensing, Virginia Tech

Virginia Tech's Interdisciplinary Graduate Education Program in Remote Sensing has PhD Research Fellowships available for prospective students who have already been admitted to pursue or are currently pursuing a PhD program at Virginia Tech. This program is a collaboration between 5 colleges / 9 departments and offers students an opportunity to study cross-disciplinary applications of Remote Sensing such as Data Analytics, Social/Cultural dimensions, Space Weather, Natural Resources and more. Learn more at: http://rsigep.frec.vt.edu/

Postdoctoral Scholar in Mars Atmospheric Structure, Dynamics, and Aerosols, Jet Propulsion Laboratory

The California Institute of Technology (Caltech), Postdoctoral Scholars Program at the Jet Propulsion Laboratory (JPL) invites applications for a postdoctoral research position in JPL's Planetary and Exoplanetary Atmospheres Group (Requisition ID 2018-9117). Dr. Armin Kleinboehl of JPL's Science Division will serve as postdoctoral advisor to the selected candidate. The appointee will carry out research in collaboration with the JPL advisor and the MCS team, resulting in publications in the open literature.

The research will involve analysis and modeling of data collected by the Mars Climate Sounder (MCS) instrument on board the Mars Reconnaissance Orbiter (MRO) spacecraft. MCS is an advanced limb-sounding infrared radiometer that collects data in one visible and 8 infrared channels to characterize Mars' atmospheric temperature structure and dust and ice distribution with unprecedented vertical resolution. MCS has been collecting data at Mars since September 2006, providing a near-continuous meteorological data set for over 5 Mars years. The successful candidate(s) will work with Level 1B data (measured radiance profiles) and/or Level 2 data (retrieved profiles of atmospheric parameters). Study topics may include the structure of the aphelion cloud belt and its relation to atmospheric dynamics, the distribution and properties of mesospheric clouds, and the distribution of water ice and CO_2 ice in the polar regions.

Candidates should have a recent PhD in planetary atmospheres or a related field with a strong background in the analysis of martian atmospheric data and processes. Experience in programming UNIX systems as well as working with large data sets is highly desirable. Experience with retrieval or radiative transfer at visible or infrared wavelengths is an asset. Candidates who have received their PhD within the past five years since the date of their application are eligible. Postdoctoral Scholar positions are awarded for a minimum of one-year period and may be renewed up to a maximum duration of three years. Applicants should apply through the website https://postdocs-jpl.icims.com/jobs/9117/postdoctoral-scholar-in-mars-atmospheric-structure-dynamics-and-aerosols/job and submit a curriculum vitae and a letter describing their research interests. Applicants must also arrange reference letters from three references to be sent to: armin.kleinboehl@jpl.nasa.gov. Applications will be reviewed starting Feb. 16, 2018.

The Jet Propulsion Laboratory is a federal facility. Due to rules imposed by NASA, JPL will not accept applications from citizens of designated countries unless they are Legal Permanent Residents of the U.S or have other protected status under 8 U.S.C. 1324b(a)(3). The Designated Countries List is available at http://oiir.hq.nasa.gov/nasaecp/.

Research Scientists-Natural Hazards and Structures

FM Global is a leading property insurer of the world's largest businesses, providing more than one-third of FORTUNE 1000-size companies with engineering-based risk management and property insurance solutions. FM Global helps clients maintain continuity in their business operations by drawing upon state-of-the-art loss-prevention engineering and research; risk management skills and support services; tailored risk transfer capabilities; and superior financial strength. To do so, we rely on a dynamic, culturally diverse group of employees, working in more than 100 countries, in a variety of challenging roles.

Responsibilities

Exciting and interesting technical challenges await when you join a world-class research team dedicated to reducing the impact of natural hazards. As a leader in property loss-prevention, FM Global has been on the forefront of innovation since 1835 paving the way for many insurance industry firsts. As part of our research division, you'll work alongside a unique group of scientists across engineering, earth, and atmospheric sciences to protect the value of FM Global's clients' businesses by developing methods to identify hazards, assess risk, and produce loss prevention solutions that are efficient and cost-effective.

Interested in a career with our Structures and Natural Hazards group? We have an opening with

• Hydrological Sciences team studies fluvial and pluvial flood hazards.

o Heavy precipitation: investigate the physical and statistical properties of flood-causing precipitation using rain gauge and remote sensing data, and numerical weather model outputs.

o Hydrologic flood modeling: estimate flood discharges at global to local scales, modeling the water fluxes from precipitation to river overflow.

o Hydrodynamic flood modeling: one and two dimensional, small to large scale, using commercial software and developing in-house models.

The following are some of the areas where we are always seeking specialized research professionals. Please note that there are job openings currently available. By applying to this opportunity, you are expressing interest in a Research Scientist job in Norwood, MA should an opening become available:

• Geological Sciences team studies the hazards and effects of earthquakes and tsunamis.

o Seismology and geology: characterize seismic sources, propagation, and site response for hazard evaluation.

o Ground motion: investigate factors that influence earthquake ground motions; construct site response maps.

o Tsunami: characterize subduction zone earthquakes; model tsunami initiation, propagation, and run-up.

o Shake table: subject specimens to shaking; develop loss prevention solutions to mitigate shaking damage.

• Meteorological Science team studies severe weather, climate change, and other atmospheric perils, and the impacts on building envelope components.

o Hazard: develop hazard maps for extreme weather events including tropical cyclones, thunderstorms, tornadoes, hail, and winter storms.

o Numerical modeling: model weather, climate, and wind-induced coastal storm surge.

o Wind: develop wind load recommendations for building components and cladding using boundary layer

Carleton UNIVERSITY

Canada's Capital University

TIER-2 CANADA RESEARCH CHAIR TENURE-TRACK POSITION AT THE ASSISTANT OR ASSOCIATE PROFESSOR LEVEL

Carleton University's Department of Mechanical & Aerospace Engineering invites applications for a **Tier-2 Canada Research Chair tenure-track position at the Assistant/Associate Professor level**. The successful candidate will have research strength in areas of quantifying and reducing greenhouse gas and other emissions from the energy sector. Applicants will have research expertise strongly aligned with the objectives of environmental sustainability through emissions quantification and reduction, pollutant source identification and attribution, greenhouse gas (GHG) mitigation strategies, or novel combustion technologies.

Applicants must have a Ph.D. in Mechanical engineering or a related field, and a commitment to undergraduate and graduate teaching, research and the engineering profession.

The appointment will be conditional upon the candidate preparing and submitting an application for a Tier-2 Canada Research Chair.

Send your application including a curriculum vitae, the names of three referees, and statements on your teaching and research in one single PDF file.

Email: **Hiring.MAE@carleton.ca**

wind tunnel testing and computational fluid dynamic simulations.

o Mitigation: identify solutions to reduce loss from building envelope failures.

• Structural Mechanics team covers response and damage of structural and non-structural systems, contents and equipment.

o Finite element modeling: model structures, non-structural components, equipment, and fracture mechanics; analysis of commercial and industrial materials and products.

o Loading: evaluate structural vulnerability, damage, and risk under natural hazard and fire loading.

o Material properties: study thermal and mechanical properties of materials used in construction and mechanical equipment.

o Mitigation: identify and develop loss prevention solutions for structural systems, components, and products to reduce the risks associated with natural hazards and fire.

• Qualifications

Qualifications include a Ph.D. degree, strong research record in the area of interest, and excellent written and verbal communication skills. A solid background in probability and statistics, proven technical programming and modeling experience, and knowledge of model physics, principles, setup, calibration, validation and sound analysis practices are highly desired. Senior applicants must have demonstrated project management abilities. The job title and compensation depend on qualifications and experience.

Email Applications: tiara.adducie@fmglobal.com

Planetary Sciences

Tenure-track faculty position in Planetary Science at the California Institute of Technology

The Division of Geological and Planetary Sciences at the California Institute of Technology is seeking outstanding applicants for a tenure-track faculty position in planetary science at the assistant professor level. We are especially interested in individuals whose research complements that in the Division, which covers the full spectrum of the earth and planetary sciences. We are particularly interested in applicants with solar system-focused research programs in planetary geophysics/geology, planetary atmospheric sciences, or small bodies research; but those in other sub-disciplines will be considered.

The initial appointment at the assistant professor level is contingent upon completion of a PhD in a relevant field. Interested applicants should submit an electronic application, which includes a curriculum vitae that includes a list of publications, a statement of proposed research activities, a brief teaching statement, 2–3 select first-author publications (optional), and names and emails of three references. Applications will be accepted until the position is filled and reviews are anticipated to begin on March 16, 2018.

If there are questions regarding this position, please contact us at ps-search@caltech.edu

We are an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, or national origin, disability status, protected veteran status, or any other characteristic protected by law.

Seismology

Hamilton Endowed Professor in Earth Sciences, Southern Methodist University

Position No. 06029. The Roy M. Huffington Department of Earth Sciences at SMU announces a search to fill a named tenure-track or tenured professorship (the rank is open) honoring WB Hamilton. We are seeking applicants with active research programs that are focused on nuclear test monitoring using array seismology, explosion and earthquake source studies, and/or infrasound, with experience in state-of-the art instrumentation and telemetry. The successful applicant will exhibit the ability to (1) maintain active research programs that involve national and international collaborators and to support those programs with external funds obtained from a diverse range of funding agencies, (2) oversee professional staff, and (3) mentor students at both the undergraduate and graduate level. The successful applicant will also have a commitment to full participation in the educational mission of the department, which is to provide professional training in the Earth sciences in a liberal arts environment. As the fourth holder of the chair, which was established in 1921, the successful candidate will extend existing departmental research strengths. These strengths include research on problems in the national interest such as natural hazards; earthquake seismology–including induced seismicity; nuclear test ban monitoring; and natural resources–including geothermal energy. The expected start date is August 1, 2018. Applications can be submitted electronically to: https://apply.interfolio.com/47665 Applicants should include curriculum vitae, statements of research and teaching interests, and contact information for three references. To insure full consideration applications must be received by January 15, 2018, but the committee will continue to accept applications until the position is filled. The committee will notify applicants of its decisions after the position is filled.

Southern Methodist University will not discriminate in any program or activity on the basis of race, color, religion, national origin, sex, age, disability, genetic information, veteran status, sexual orientation, or gender identity and expression. The Executive Director for Access and Equity/Title IX Coordinator is designated to handle inquiries regarding nondiscrimination policies and may be reached at the Perkins Administration Building, Room 204, 6425 Boaz Lane, Dallas, TX 75205, 214-768-3601, accessequity@smu.edu.

Hiring is contingent upon the satisfactory completion of a background check.

Solid Earth Geophysics

Tenure-Track Faculty Position in Geophysics at the California Institute of Technology

The Division of Geological and Planetary Sciences at the California Institute of Technology is seeking outstanding applicants for a tenure-track faculty position in geophysics at the assistant professor level. We invite applicants in any area of geophysics, broadly defined. Preference is for individuals who will lead an innovative research program and are committed to teaching, with the applicant's overall creativity and potential being valued more than their specific area of expertise within geophysics.

The term of the initial appointment at the assistant professor level is normally four years, with appointment contingent upon completion of a PhD in a relevant field. Exceptionally well-qualified candidates may also be considered at the tenured professor level. Initial review of applications will begin on March 1, 2018, but applications will be accepted until the position is filled.

Interested applicants should submit an electronic application that includes a brief cover letter, curriculum vitae, statement of research and teaching plans, up to three representative publications, and contact information for at least three individuals who may be contacted for letters of reference. Please submit applications at the following link: https://applications.caltech.edu/job/geophysics

If there are any questions during the search process, please contact us at: geophysics-search@gps.caltech.edu.

We are an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, or national origin, disability status, protected veteran status, or any other characteristic protected by law.

ASSISTANT/ASSOCIATE/FULL PROFESSORS-
Geophysics, Geodesy, Space Physics, Planetary Sciences

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

SUSTech is a young university at Shenzhen, China (next to Hong Kong) since 2011 which is set to become a world-leading research university, to lead the higher education reform in China, to serve the needs of innovation-oriented national development and the needs of building Shenzhen into a modern, international and innovative metropolitan. These positions are created with a significant development to establish a vigorous research program in Earth and Space Sciences at SUSTech to serve the national call for China's important role in this field.

To apply send a cover letter, complete vitae with list of publications, and three names of references to **hiring@sustc.edu.cn**, or to:

Dr. Xiaofei Chen, Chair Professor at Department of Earth and Space Sciences, Southern University of Science and Technology, No 1088, Xueyuan Rd., Xili, Nanshan District, Shenzhen, Guangdong, China 518055.

Tectonophysics

ASSISTANT OR ASSOCIATE PROFESSOR – TENURE TRACK (Rank Open), Structural/Engineering Geology, broadly defined, DEPARTMENT OF GEOSCIENCES, COLLEGE OF ENGINEERING AND NATURAL SCIENCES

The Department of Geosciences at The University of Tulsa invites applications for a tenure-track position beginning the Fall of 2018. Appointment is expected at the level of Assistant or Associate Professor and preference will be given to candidates interested in leading the department as Department Chairperson.

A Ph.D. in Geology, Geological Engineering or a closely related field is required. Preference will be given to candidates who pursue research and teaching with environmental, engineering and industry applications, and to candidates with specialty in rock mechanics and/or geological engineering. The successful candidate will be expected to teach Structural Geology and other courses of their choosing at the undergraduate and graduate levels, and establish an externally funded research program involving students.

The University of Tulsa is a premier private, doctoral-granting research institution committed to excellence in teaching, creative scholarship, and service. The University offers competitive salary and benefits packages. The Department of Geosciences has strengths in petroleum-related geology and geophysics, tectonics, reservoir characterization and environmental geology. The Department offers BA, BS, MS and PhD degrees in Geosciences and in Geophysics. Students in the Department are high achieving and eager to participate in research. The Department and College are well-equipped for field and laboratory based research in geology and geophysics. Tulsa is home to the international headquarters of the AAPG, SEPM and SEG. Additional information can be found at the department's website: https://engineering.utulsa.edu/academics/geosciences/.

APPLICATION INFORMATION:

The review of applications will begin February 15, 2018 and continue until the position is filled.

The University of Tulsa seeks to recruit and retain talented students, faculty and staff from diverse backgrounds. The University of Tulsa is an affirmative action/equal opportunity employer and encourages qualified candidates across all group demographics to apply. The University does not discriminate on the basis of personal status or group characteristic including, but not limited to race, color, religion, national or ethnic origin, age, sex, disability, veteran status, sexual orientation, gender identity or expression, genetic information, ancestry, or marital status.

Send a letter of application stating research and teaching interests, curriculum vitae, and name and contact information for three references to: jbt@utulsa.edu

Or mail to:
Dr. Bryan Tapp
Department of Geosciences
Keplinger Hall, L103B
The University of Tulsa
800 South Tucker Drive
Tulsa, OK 74104-9700

The University of Tulsa is an Equal Opportunity Employer Disabled/ Veteran.

Volcanology, Geochemistry, and Petrology

Electron Microprobe Operator/ Laboratory Manager, University of Oklahoma

The Office of the Vice President of Research supports an electron microanalysis laboratory built around a Cameca SX100 microprobe as a core research facility of the University (https://ors.ou.edu/Microprobe/OUEMPLHome.html). This includes a fully funded, fullt-time staff position as Electron Microprobe Operator/Laboratory Manager with a starting salary of $55K-$60K. This position is open until filled.

Duties include daily operation of the microprobe and sample preparation for all clients, daily lab maintenance, periodic instrument maintenance (filament, roughing vacuum, etc.), coordinating major service with Cameca engineers, scheduling and bookkeeping of usage by clients, billing and payments, and an annual summary report of laboratory activity. The appointment permits the operator to utilize the electron microprobe for research and personal use. Adjunct professor status and teaching opportunities in the School of Geology & Geophysics are possible for individuals who hold a Ph.D.

Qualifications for the position include (1) a Master's or Ph.D. degree in geosciences or relevant discipline, (2) experience with designing analytical procedures for quantitative EMPA, (3) knowledge of the chemistry of major and minor elements in common rock-forming minerals, and (4) experience with EMP operation including basic maintenance.

Applicants must submit an ONLINE application at https://jobs.ou.edu for requisition number 173902. Computers and personal assistance are available at the Office of Human Resources, 905 Asp, Rm.205, Norman, OK 73069.

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

Postcards from the Field

Hello!

As part of an effort to monitor earthquakes triggered by reservoir loading, we installed two portable seismographs in the neighborhood of La Romaine 3 reservoir in the province of Québec, Canada. The La Romaine hydroelectric complex involves the construction of four dams by Hydro-Québec.

In the photo, the digitizer is located in the black container and is connected to three short-period seismometers to the left. The backdrop of the picture is the 95-meter-high La Romaine 3 dam (located at 51.12°N, −63.42°W). The 38-square-kilometer reservoir filled very quickly following snowmelt in early May 2017. As of 1 February 2018, only a few small reservoir-triggered earthquakes have been recorded at La Romaine 3, but La Romaine 2 has been more active.

—**Maurice Lamontagne,** Earth Sciences Sector, Natural Resources Canada, Ottawa, Ont.

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