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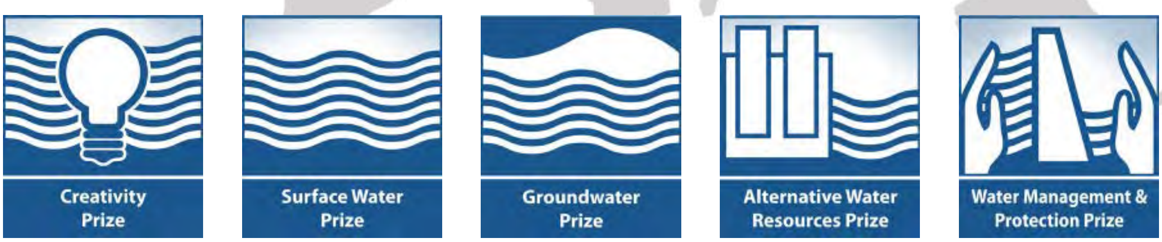

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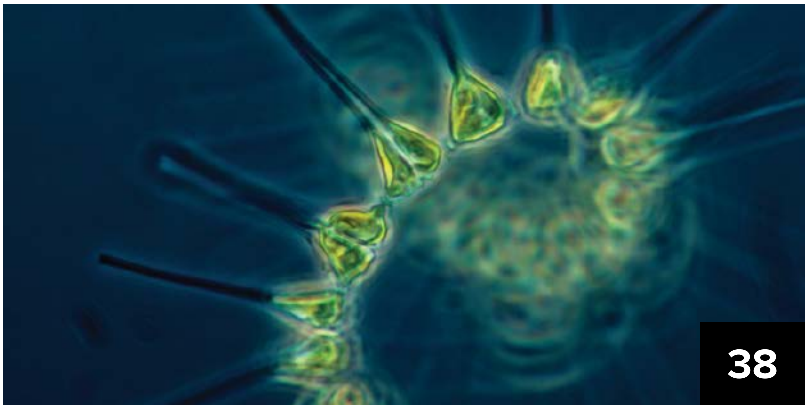

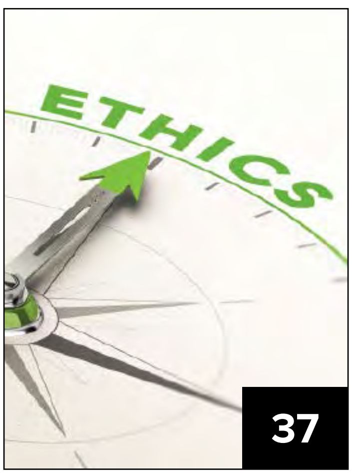

On the Cover

Italy's Stromboli volcano, spewing fountains of lava. Credit: demarfa/iStock/Getty Images Plus

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Volcano Woes May Have Contributed to Ancient Egypt's Fall

This Landsat 8 satellite image captures a stunning contrast between the Nile floodplains (green) and the surrounding arid desert. Ancient Egyptians relied on the Nile River's annual floods to water their crops through the summer. When the Nile's banks failed to flood because of climatic effects of volcanic eruptions, the subsequent food shortages could have contributed to societal unrest. Credit: USGS/NASA

Imagine that it's 245 BCE. You're Ptolemy III, a Macedonian king ruling Egypt, and you're leading an army against Egypt's biggest rival, the Seleucid Empire. But there's a revolt back home, and you must return to the people that your dynasty will rule until 30 CE.

Sometime in the 3rd century CE, the Roman historian Justin will write that if you had "not been recalled to Egypt by disturbances at home, [you] would have made [yourself] master of all Seleucus's dominions." Other writings declare that you did what you had to do to relieve a famine in Egypt. The summer was unusually dry that year, wrote a priest, and the Nile didn't flood like it usually did. You imported grain from rainier territories—gaining you a priestly commendation in 238 BCE about the sacrifices you made for "salvation for the population."

Fast-forward to the present day: A team of 21st-century scientists and historians is offering a new look at something that might have indirectly caused the upheaval that changed Ptolemy III's fortunes as well as other unrest that beset the Ptolemaic empire: large volcanic eruptions.

> Scientists and historians are offering a new look at something that might have indirectly caused the upheaval that changed Ptolemy III's fortunes.

In a paper published this fall in *Nature Communications,* the researchers present a raft of evidence—from climate modeling and ice core and Nile River hydrological records to ancient Egyptian chronicles—indicating that a series of eruptions may have caused sharp drop-offs in the summer rainfall usually brought by the African monsoon (http://bit.ly/Manning-etal-2017).

The loss of monsoon precipitation would have depleted the headwaters of the Nile River and deprived Egyptian civilization of the annual Nile flooding that it depended on to sustain its agriculture. As food became scarce, insurrections may have followed, including one known as the Theban revolt, which rose against the ruling Macedonian Ptolemies starting in 207 BCE.

"The Ptolemies lost control over huge areas of Egypt for almost 2 decades" during the Theban revolt, said Francis Ludlow, a coauthor of the study and a climate historian at Trinity College in Dublin, Ireland. It "was a very destructive revolt, with damage to temples and huge losses of tax revenues for the state."

Volcanoes and the Nile

Researchers know well the climatic effects of volcanic eruptions. Major eruptions spew sulfur dioxide, among other substances, into the atmosphere, which reacts to form aerosol particles. These particles reflect sunlight back into space, cooling the atmosphere.

Generally, this cooling decreases evaporation, and less evaporation means less water in the atmosphere for rain. The summer floods along the 6,800-kilometer-long Nile got their water mainly from rainfall in the Ethiopian highlands, and that rainfall comes from the African monsoon, which is driven by summer heating of the atmosphere. A cooler atmosphere supplies less water for the monsoon and thus less water for the Nile.

This effect has been documented. Writings from 1788, for example, describe a low-flowing Nile in the summers of 1783 and 1784—during and after Iceland's Laki eruption—which caused a food shortage that killed many people. Recently, other scientists have used models to show how the Laki eruption and its 80 megatons of sulfur aerosols could have indirectly wiped out those monsoons so integral to the Egyptian population's well-being.

Some possible factors didn't make it into this research, however, according to Kevin Anchukaitis, a paleoclimatologist at the University of Arizona in Tucson. He told the *New York Times* that the study didn't account for weather influences on the Nile like El Niño.

Islamic Nilometer

To investigate a possible connection between volcanic eruptions and a Nile flood failure, the researchers on the new paper turned to one of the longest hydrological records on Earth: the Islamic Nilometer, an ancient structure built in 622 CE that people used to track water levels on the Nile. The researchers studied eruptions that occurred from 622 to 1902 CE and compared the dates of those eruptions—like Laki in 1783 and Tambora in 1815—with dates of Nile failures recorded by operators of the Nilometer. In summers during eruption years, the researchers found, floodwaters averaged 22 centimeters lower than in noneruption years.

Although these eruptions occurred long after the end of the Egyptian empire, the researchers assume that they would have affected the African monsoon similarly. "It would be surprising if the climate system operated completely differently in the Ptolemaic era," Ludlow said.

The researchers then looked back in time by way of ice cores from Greenland and Antarctica to find evidence, like the presence of sulfur, that would point to volcanic eruptions. They counted the layers in the ice cores like tree rings to date those eruptions and compared those dates with dates of major societal challenges like famine, disease, and land abandonment.

It turns out there was a major eruption in 209 BCE, just 2 years before the Theban revolt began. Other major eruptions occurred in 247 and 244 BCE, just as Ptolemy III clashed with Seleucus II in the east. "[We observed] in historical records a dynamic societal response" to the climate changes, said Joseph Manning, a historian at Yale and lead author of the new paper.

The mix of different records "is an important part of putting together the effects of the eruptions," Heli Huhtamaa, a climate historian at Utrecht University in the Netherlands, told *Science*. She said that she found the team's analysis very convincing.

Climate and Society

The researchers stress that their claim is not that volcanic eruptions caused social unrest or that regional climate change alone brought down an empire.

"Environmental pressures don't act in a vacuum," Ludlow said. More likely, "pressures from poor flooding coalesced at certain points in time with political and economic factors" like tensions between warring regions and high state-levied taxes. Food shortages resulting from a lack of Nile flooding could have added the heat needed to boil an already simmering pot of unrest.

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

How to Trigger a Massive Earthquake

A *Los Angeles Times* article published on 11 June 1952 tells of a successful new oil well at Wheeler Ridge in Kern County in California. The well operated for 98 days, but then, on 21 July at 4:52 a.m. local time, a magnitude 7.5 earthquake let loose beneath the well along the White Wolf fault. It was the second-largest earthquake in California in the 20th century, and it killed 12 people.

A team of seismologists, reporting new research, thinks the oil drilling triggered the event. The work is the first to give a detailed explanation for how industrial activity could cause such a big earthquake, the researchers said.

Taking oil out of the ground likely destabilized the White Wolf fault, triggering the Kern County quake, explained Susan Hough, a seismologist at the U.S. Geological Survey in Pasadena, Calif., and lead author of a study published 2 October in the *Journal of Seismology* (http://bit.ly/Hough-etal-2017).

The work follows a 2016 *Bulletin of the Seismological Society of America* study in which Hough and a colleague suggest that oil drilling played a role in other historic southern California earthquakes, like the deadly 1933 magnitude 6.4 Long Beach earthquake that killed 120 people. That study, however, lacked an explanation for how drilling could trigger such large quakes when modern experience shows that induced quakes rarely exceed a magnitude of even 5. This time, Hough and her colleagues propose a mechanism.

Putting the Pieces Together

Hough told *Eos* how she stumbled across old California state reports that give detailed accounts of oil drilling activity in southern California. The reports revealed evidence for a spatial and temporal association between oil

Oil wells line the Huntington Beach shoreline in southern California in 1926. In 1933, the magnitude 6.3 Long Beach earthquake struck, and according to seismologists, the temblor was likely due to oil drilling in the Huntington Beach region. Credit: Orange County Archives

A school in Kern County in California destroyed by the 1952 earthquake. A new study suggests that this earthquake could have been set off by nearby oil drilling activities, and it explains how that might have happened. Credit: NOAA National Geophysical Data Center

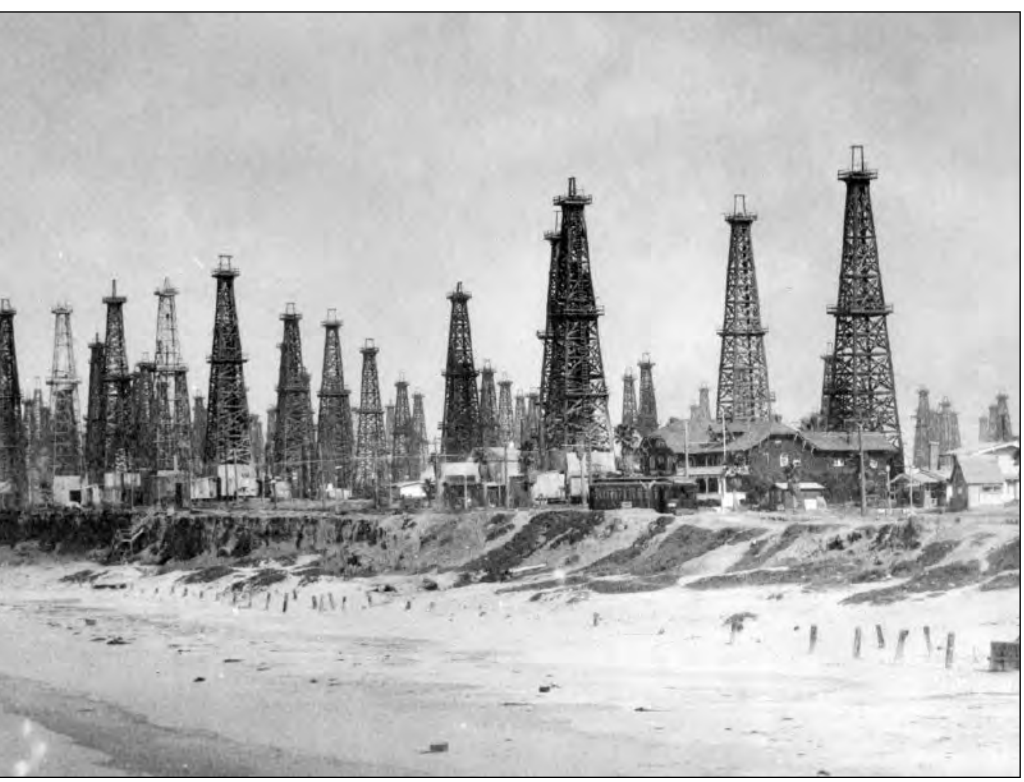
industry activity and earthquakes. "From the industry data for the [oil] production volumes and the location of the well and the location of the [White Wolf] fault, we can show that the stress change on the fault would've been potentially significant," she said.

The stress change Hough refers to happened as the well pumped oil out of the ground. This likely triggered the quake by "unclamping" the underlying fault, Hough explained. In this case, picture the fault as a fracture along an inclined plane where crustal blocks on opposite sides stall as they try to move past each other. "The fault is locked because there's friction on the fault, and part of the reason for that is there's the weight of the overlying crust on the fault plane," said Hough. "But if you take some of that weight off, it shifts; it's going to reduce the confining pressure…depending on the faults that are there, that could just destabilize what had been a locked fault."

Liquids like oil, however, typically lubricate faults, making them more prone to slipping. So how could removing oil help trigger an earthquake? The answer lies in the structure of the rock layers beneath the well, which, Hough explained, prevented the oil's lubricating effects from reaching the White Wolf fault. This means that removing the oily overburden led to the fault destabilization.

According to the team's calculations, the amount of oil removed from above the fault generated a stress change of about 1 bar of pressure, a value that seismologists generally think of as the amount of stress change required to set an earthquake in motion, Hough explained. "After 80 days of drilling, the stress change was right at and exceeding that magic number that we think is significant," she said.

"They've developed a very plausible geologic scenario for how the Kern County earthquake could've been induced," said Gillian Foulger, a geophysicist at Durham University in the United Kingdom, who was not involved in the work. "They're really putting flesh on the bones for this particular earthquake."



Foulger also agrees that a modest change in the overlying weight could have been enough to set off the quake. "Earthquakes are a little bit like snow avalanches," she said. "You can have a massive amount of snow pile up on a mountainside, and then you have a skier who skis across it and that's just enough to trigger the disturbance that causes the whole lot to fall off."

Unlikely Recurrence

Hough, a member of the *Eos* Editorial Advisory Board, presents a model for initiating a large earthquake based on just one case example, although she thinks her work can apply to induced earthquakes in general: "It highlights the possibility that inducing any initial [earthquake] nucleation in proximity to a major fault could be the spark that detonates a larger rupture," she said.

Nucleation refers to the small change in stress needed to destabilize a fault—a stress change that could happen in oil-producing regions today. But the chances of producing another temblor in the manner of the Kern County earthquake are slim, according to Hough, mostly because oil fields tend not to sit above major fault lines. In addition, oil producers long ago changed to a standard practice of injecting water into the ground after oil removal, something that was not done at the Wheeler Ridge oil field and that could have restored much of the otherwise lost weight locking the fault.

Most induced earthquakes are small—usually no bigger than a magnitude 4—although there is no reason to suspect that humans cannot induce a big quake, explained Hough. The reason most induced quakes tend to be relatively small, she added, is that most earthquakes, in general, tend to be small. "One school of thought argues that the size distribution is the same for induced and natural earthquakes," she said. But whether there is a maximum size limit for induced earthquakes, seismologists still do not know, she added.

An important aspect of the new work, Foulger said, is that Hough presents a model that other scientists can test, which is a first for a large induced event like the Kern County earthquake. For Seth Stein, a geophysicist at Northwestern University in Evanston, Ill., who also had no part in the study, "the take-home is that for one of the largest earthquakes that we know of in the last hundred years in California, a reasonable case can be made that it was induced."

By **Lucas Joel** (email: lucasvjoel@gmail.com), Freelance Writer

Administration Sets Moon as Destination

Vice President Mike Pence promised the Moon during the first meeting of the reconstituted U.S. National Space Council.

"We will return American astronauts to the Moon, not only to leave behind footprints and flags, but to build the foundation we need to send Americans to Mars and beyond," Pence said at the 5 October meeting at the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Center in Chantilly, Va.

"The Moon will be a stepping-stone, a training ground, a venue to strengthen our commercial and international partnerships as we refocus America's space program toward human space exploration," he said.

Pence, who chairs the council, said that the Trump administration wants to ensure America's continued leadership in space; stressed the importance of space for civil, commercial, and national security activities; and castigated previous administrations for a national space program that "has suffered from apathy and neglect."

Under the president's leadership and the guidance of the space council, "the United States will usher in a new era of space leadership for our nation that will benefit every facet of our national life," he said. "The truth is that America entered this new millennium without a coherent policy, a coherent vision for outer space. And in the absence of American leadership, other nations have seized the opportunity to stake their claim in the infinite frontier. Rather than lead in space, too often we have chosen to drift." Pence called for the council to provide recommendations about space policy to the president within 45 days.

Some analysts, however, questioned some of Pence's conclusions. In a 5 October analysis by Casey Dreier and Jason Davis of the Planetary Society, they said that "human spaceflight has lacked clear and consistent direction." Nonetheless, they noted that "as far as civil space is concerned, NASA already leads in every conceivable metric" (http://bit.ly/Dreier-Davis-2017).

The Council's Role

In a 30 June executive order, President Donald Trump revived the space council to review U.S. government space policy; develop recommendations on space policy and space-related issues; and foster coordination among civil, national security, and commercial space sectors, among other tasks. Council members, in addition to Pence, include seven other cabinet members, the NASA administrator, the chairman of the Joint Chiefs of Staff, and other officials.

U.S. vice president Mike Pence delivers opening remarks during the revitalized National Space Council's first meeting on 5 October at the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Center in Chantilly, Va. Credit: NASA/Joel Kowsky

The council, established in 1989 under President George H. W. Bush, had never dissolved but went dormant in 1993. An earlier version of the council had been established in 1958 near the beginning of the space race.

National Security Concerns

At the half-day October meeting, Pence said that the country struggled to define the direction and purpose of its space program following the triumphant Apollo missions to the Moon. The results of that "drift" include not having sent an American astronaut beyond low-Earth orbit in 45 years, continuing to rely on Russia to shuttle American astronauts to and from the International Space Station, and facing potential threats from other countries that "are aggressively developing jamming, hacking, and other technologies" that could damage military surveillance, navigation, and communication systems, he said.

Pence said that according to the U.S. intelligence community, "Russia and China are pursuing a full range of anti-satellite technology to reduce U.S. military effectiveness, and they are increasingly considering attacks against satellite systems as part of their future warfare doctrine."

Council member and national intelligence director Dan Coats said that U.S. dominance in space is being threatened by adversaries. "As wonderful as it is to hear about the vision and the future for space and what it can provide commercially, what it can provide for human exploration," we end up "sobered" by the fact that "there's a dark side" to space endeavors by adversaries, he said. "One of the important things this council can do is to ensure that we achieve the dominance in space necessary for us to protect our people, to keep our adversaries in a position where they can't provide the dominance that can do us wrong."

Expert Testimony

During the meeting, the council also heard panels of experts speak about civil, commercial, and security issues related to space. In response to a question from Pence about the public concern to not militarize space, James Ellis, former commander of the U.S. Strategic Command and a speaker on the security panel, reminded the council that in 1962 President John F. Kennedy "said it is up to us to define whether the space domain becomes an ocean of peace, as he called it, or an area of conflict. We have that choice along with our allies."

The council also heard from speakers on the civil space panel about the need to support and bolster commercial space activities. Marillyn Hewson, president and CEO of Lockheed Martin, said that to secure American leadership in space, the country needs clear and strong government leadership, visionary programs, and stable, sustained investment. "By taking these positive actions, we will enable industry to plan, invest, and innovate over the long term," she said.

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

Playing with Water: Humans Are Altering Risk of Nuisance Floods

Nuisance flooding—the kind of sunny-day, nonfatal flooding that closes roads, seeps into basements, and generally causes, well, a nuisance—is on the rise along southern stretches of the U.S. East Coast and on the decline farther north. The ways in which humans are altering the natural flow of water in and on the Earth are partly responsible for these changes, according to a team of international researchers.

"In some of our past work, we showed that there is a high rate of subsidence along the U.S. East Coast," said Makan Karegar of the University of South Florida in Tampa and the University of Bonn in Bonn, Germany. "We asked ourselves, 'What comes next? How does this relate to human life, and what are the implications?'" Karegar is lead author on a paper describing this research that was published in *Scientific Reports* on 11 September (http://bit.ly/Karegar-etal-2017).

Karegar and his colleagues measured vertical land motion along the U.S. East Coast using data from the past 2 decades. They found that coastal latitudes that include Virginia, North Carolina, and South Carolina—regions that extract groundwater faster than nature replenishes it—are sinking significantly faster than geologic average. As a consequence, they are experiencing increased nuisance flood rates.

In contrast, the coastlines of Maine and New Hampshire are actually rising, and nuisance flooding in northern U.S. coastal cities has decreased. These regions are ascending in response to water building up behind Canadian dams hundreds of kilometers away, the weight of which presses down on the land directly beneath the reservoirs and pushes peripheral land upward, according to this study. Human-induced changes to local water loads, said Karegar, have altered the natural risk of nuisance floods along the coast.

"We are nowadays able to measure such small rates [of vertical land motion]," said Riccardo Riva of Technische Universiteit Delft in Delft, Netherlands, who did not participate in the project. "This is highly relevant for urban and infrastructure planning."

Although this research does not consider potentially fatal floods due to severe weather, like the recent hurricane-induced flooding in Texas, Florida, and Puerto Rico, frequent nuisance flooding can indicate areas that may be at risk for catastrophic flooding in the face of future storms.

A Southern Sink and a Northern Rise

On average, the U.S. East Coast is slowly sinking at a rate of about 1.5 millimeters per year, with some variation based on latitude.

*High tides can flood streets and homes, like this 2015 incident in Charleston, S.C., even on perfectly sunny days. Credit: Grace Beahm/*Post and Courier *via Associated Press*

As northern glaciers melt, they release the pressure they had been exerting on Earth's crust, which had created a temporary bulge along the coastline. This coastal bulge is now subsiding back to its previous elevation, Riva said, a fact that is well known to geologists.

Karegar's team, however, used GPS data from 1990 to the present to estimate vertical land motion above or below this average rate. They discovered two regions where elevation changes are significantly different than the geologic average for those latitudes: a southern anomaly spanning Virginia, North Carolina, and South Carolina and a northern anomaly that encompasses the Maine and New Hampshire coasts.

GPS data for the southern anomaly show areas where land is sinking at nearly twice the geologic rate. Not coincidentally, Karegar said, this area has also experienced an increase in nuisance floods over the past 2 decades. The authors suggest that humans have been removing groundwater from this region at a rate faster than nature replaces it, making that section of crust denser and less buoyant and causing it to sink faster.

The modern records also show a lot more variation in the rate of subsidence in this region than in other areas of the coast, which the researchers attribute to differences in local groundwater management policies.

In the north, however, the researchers found that the land is rising, not sinking, and that the change does not appear to be related to a shift in groundwater usage like in the southern anomaly. The team tested whether something else human-made could be shifting enough weight around to counterbalance the glacier's slow retreat.

They realized that the northern anomaly sits approximately 800 kilometers from the James Bay hydroelectric project in Quebec, Canada, which has drastically shifted the regional water load with dams around James Bay, Hudson Bay, and the Gulf of St. Lawrence that power hydroelectric stations. Karegar's team tested how the lithosphere responded to the extra weight using theoretical models, which indicated that the shift in weight from displaced water was likely just right to cause a peripheral bulge near Maine and New Hampshire and reduce the frequency of nuisance floods in those states.

"They have highlighted the importance of vertical land motion in coastal areas," Riva said. He added that the team has demonstrated that the human contribution to this motion is a critical factor in some coastal regions and that "even a moderate [relative] sea level rise could be enough to largely increase the frequency of nuisance flooding."

Nuisance flooding is increasingly common in Charleston, S.C., as increased groundwater extraction in the region accelerates the natural land subsidence rate. Credit: National Oceanic and Atmospheric Administration

"Even a moderate [relative] sea level rise could be enough to largely increase the frequency of nuisance flooding."

Reducing the Nuisance

The frequency of nuisance flooding has increased 925% in some areas since the 1960s. Frequent nuisance flooding can be an early indicator of regions that will eventually see accelerated land loss and increased catastrophic flooding from hurricanes and tropical storms. The researchers suggest in their paper that their work may help identify regions that will be at risk for increased nuisance flooding, which could lead to more conscientious municipal planning and water management policies.

Karegar plans to conduct a similar investigation into the rate of nuisance flooding in southeastern Texas and the Mississippi River delta, two regions that have seen increased nuisance flood rates in the past decade.

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

World's Heavy Dependence on Fossil Fuels Projected to Continue

The International Energy Outlook report says that natural gas will be the world's fastest growing fossil fuel in the period 2015–2040. In the United States, gas from shale will increase to nearly 70% of the nation's natural gas production by 2040, with advances in horizontal drilling and hydraulic fracturing techniques. Pictured is natural gas fracking on the Haynesville Shale near Shreveport, La., in 2013. Credit: Daniel Foster, CC BY-NC-SA 2.0 (http://bit.ly/ccbyncsa2-0)

Global energy consumption will increase 28% between 2015 and 2040, with fossil fuels still providing the bulk, 77%, of the consumption by 2040, according to a report (http://bit.ly/EIA-2017) by the U.S. Department of Energy's Energy Information Administration (EIA). That's a slight decrease from EIA's 2016 report, which modeled fossil fuels as accounting for 78% of energy consumption by 2040.

The increased energy use will be matched by a 16% increase in energy-related carbon dioxide (CO_2) emissions over that same time period, with annual emissions rising from 33.9 billion metric tons in 2015 to 39.3 billion metric tons in 2040, according to EIA's report, "International Energy Outlook 2017," released on 14 September. That energy usage, increasing from 575 quadrillion British thermal units (Btu) (607 exajoules) per year in 2015 to 663 quadrillion Btu (700 exajoules) in 2040, assumes an annual 1.7% gross domestic product growth in Organisation for Economic Co-operation and Development (OECD) countries—including the United States and many European nations—and a 3.8% growth in non-OECD countries.

The projected 16% increase in emissions noted in the new report differs significantly from the projected 34% increase stated in EIA's 2016 report, which projected emissions rising from 32 billion metric tons in 2012 to 43 billion metric tons in 2040.

The new report, which provides long-term modeled projections of energy production and consumption, states that energy consumption could be up to 40 quadrillion Btu (42 exajoules) higher or 29 quadrillion Btu (31 exajoules) lower annually, depending on what rates of economic growth actually occur and other factors.

Reduction Expected in the Growth Rate of Emissions

The growth rate of energy-related CO_2 emissions is expected to ease, with an average 0.6% increase per year between 2015 and 2040, according to the report. That's a sizable drop from a 1.3% annual growth rate from 1990 to 2015. EIA attributes that anticipated slowdown to increases in energy efficiency and a gradual shift from coal to natural gas and renewable energy sources.

The report, which Ian Mead, EIA's assistant administrator for energy analysis, presented at the briefing, also forecasts a 2.8% annual increase in renewable energy, including hydropower. "By 2040, generation from renewable energy sources surpasses generation from coal on a worldwide basis," the report states.

EIA's projections find renewables to be the most rapidly growing energy source for electricity generation. Still, the agency may be underestimating the contributions from renewables, according to some economists, including Rachel Cleetus, lead economist and climate policy manager for the Union of Concerned Scientists.

The report also forecasts a continued decrease in carbon intensity, the amount of energy used per unit of economic growth. EIA attributes that decrease to the decline of coal use in China and to global growth in the use of non-CO_2-emitting sources of energy.

The industrial sector continues to account for the largest share of energy consumption through 2040, with a 0.7% annual increase in energy use between 2015 and 2040. However, other sectors grow faster, with energy use for the transportation and building sectors increasing 1% and 1.1% annually, respectively.

An Increase in Nuclear Power

Amid concerns about greenhouse gas emissions and energy security, nuclear power for electricity generation will increase from 2.5 trillion kilowatt hours in 2015 to 3.7 trillion kilowatt hours in 2040, with much of that increased capacity occurring in China, according to the report.

With the Paris accord on climate change having come into force in November 2016, EIA attempted to incorporate some details about country-specific plans to meet emissions targets. However, the report notes that a great deal of uncertainty remains about the full implementation of policies and how countries will meet their goals. It also mentions that the Paris accord covers more than energy-related CO_2 emissions.

"Without pointing fingers at any particular countries, there are some regions where we don't assume that [country targets are] a binding constraint," Mead said at the briefing.

Fossil Fuels Continue to Dominate

The report projects that natural gas will be the world's fastest growing fossil fuel, increasing by 1.4% annually, whereas petroleum and other liquids will increase 0.7% and coal will see just a 0.1% increase, with declined usage in China and OECD regions offset by growth in India and other non-OECD countries.

Fossil fuel dependence will continue because "a lot of it just has to do with the base that you are starting with," Mead told *Eos*. "So it may take a while for some of those [other] sources to move in."

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

Ancient Maya May Have Foreseen Meteor Showers

The ruins of the Temple of the Jaguar (Temple I) and the North Acropolis loom over what remains of the ancient Mayan city of Tikal in El Petén, Guatemala. Two major events in the city, the coronation of the 6-year-old Lady of Tikal in 511 CE and a defeat by the city-state Caracol in the 562 CE "Star War," took place in approximate synchrony with meteor outbursts. Recently published research suggests that the Maya may have linked the timings of events such as royal accessions and wars to astronomical predictions of meteor showers. Credit: Jon G. Fuller/VWPics/Alamy Stock Photo

Using state-of-the-art computer models, an amateur historian and a professional astronomer have found evidence that many important societal events recorded in Mayan hieroglyphic inscriptions may coincide with outbursts of meteor showers related to Halley's Comet.

In recently published results, the two-person research team has found more than a dozen instances of hieroglyphic records from the Mayan Classic Period (250–909 CE) indicating that important events occurred within just a few days of an outburst of Eta Aquariid meteor showers, one of the celestial displays tied to the comet.

No Mayan astronomical records from that period survived the Spanish invasion, and the four surviving Mayan codices from later eras do not mention meteor showers. However, the researchers suspect that many significant historical events that coincided with meteor showers, like a ruler's assumption of power or a declaration of war recorded in the codices and carved in stone monuments, are not chance overlaps.

Instead, the Maya most likely predicted meteor showers, the researchers argue in a paper that was published in the 15 September issue of *Planetary and Space Science* (http://bit.ly/Kinsman-2017). What's more, the ancient civilization might have purposefully timed significant occasions to coincide with portentous celestial events.

If this new research is validated by further computational tests, it would help address a long-standing puzzle, said David Asher, an astronomy research fellow at Armagh Observatory in Northern Ireland: How did the ancient Maya, a civilization that meticulously recorded astronomical information about Venus, eclipses, and seasonal patterns, fail to note meteor showers in their astronomical studies? They likely did record meteor showers, assert Asher and his colleague Hutch Kinsman, who has been an independent scholar of Mayan history and hieroglyphics for nearly 25 years. However, the records were lost to us.

Modern Science Answers Puzzles from Ancient Times

Experts in Mayan hieroglyphic astronomy widely acknowledge that the Maya observed and recorded three types of common astronomical events during the Classic Period: phases of the Moon, solar and lunar eclipses, and the movement of Venus. Kinsman and other historians have wondered whether the Maya overlooked meteor showers or whether they noted them.

Although mentions of the meteor showers themselves are missing from Mayan codices, Kinsman and Asher used computer models that track the motions and interactions of orbiting objects to calculate dates when the Eta Aquariid meteor shower, born from remnants of Halley's Comet, would have been visible to the Maya during the Classic Period. They checked their calculated meteor shower dates against Chinese astronomical records of meteor showers from the same time period.

Halley's Comet leaves behind a trail of would-be meteors when it passes by Earth about every 75 years. The comet debris can remain in orbit for hundreds or thousands of years before entering Earth's atmosphere, or it may never cross paths with Earth at all. Asher, an expert in solar system dynamics, explained that when modern astronomers try to predict the positions of small chunks of rock and ice hundreds of years after they break off from a parent comet, they "need a comet whose orbit was well known before the time when you hypothesize that the Maya might have observed the meteor outburst. Halley's Comet fits the bill quite nicely," he added.

The comet's remnants produce a few very predictable and large meteor showers, including the Eta Aquariid shower, which is typically observable from April to May across northern to southern midlatitudes. "The Eta Aquariids were the natural choice for research," Kinsman said.

Meteor Outbursts Coincide with Ascents to Power

After the researchers predicted dates during the Classic Period when Eta Aquariid outbursts likely occurred, they then searched for significant events recorded in Mayan hieroglyphics that took place on or near those dates, attempting to see whether the Maya, like other ancient civilizations, used meteor showers as portents of greatness.

"The approach we've taken is to look for coinciding dates," Asher explained. "There are dates on the Maya[n] inscriptions, and Mayanist experts can tell us what they are….

The oldest surviving Maya codex, the Dresden Codex, dating to circa 1200 CE, contains astronomical almanacs. These sheets from the Dresden Codex depict eclipses (sheets 55–57; left three), multiplication tables (sheets 58–59; second and third from the right), and a flood (sheet 74; right). For a larger version see https://bit.ly/dresden-codex. Credit: Saxon State Library, Dresden, Germany

Orbital computations give dates when meteor outbursts occur[ed]."

The researchers' models suggested 18 different Eta Aquariid meteor outbursts that were likely visible to the ancient Maya during the Classic Period. A third of those meteor showers occurred within 4 days of a ruler ascending the throne, and other showers correlated with declarations of war, important people traveling between cities, or agricultural or industrial activities. "With coinciding dates, we start to have evidence rather than (interesting) speculation," Asher said.

The strongest meteor outburst that Kinsman and Asher pinned down to a particular date occurred on 10 April 531 CE, when three different comet trails entered Earth's atmosphere at the same time. They indicate in their paper that this extreme outburst was "likely the most intense that the Maya would have seen during the Classic Period." Four days after the 531 CE Eta Aquariid outburst, the ruler K'an I ascended to power in Caracol (in modern Belize).

Ruins of the Maya temple designated "Structure A6" at the center of the Mayan ruins in Caracol, Belize, photographed on 7 May. The ancient city was the site of a royal accession in 531 CE, 4 days after an extremely bright outburst of the Eta Aquariid meteor shower likely occurred. Credit: Hutch Kinsman

Archaeoastronomy: Two Research Fields, One Idea

Kinsman began investigating whether the Maya had observed comets or meteors back in 2011. He met Asher at the Meteoroids 2013 conference in Poznań, Poland, where Kinsman was presenting preliminary work on the Maya and meteors.

"It captures the imagination," Asher said. "I was so fascinated to hear Hutch's lecture four years ago…I thought, 'Oh, that sounds interesting!'"

The two began collaborating in early 2015 and completed most of their work when Kinsman was invited to visit Armagh Observatory that summer. This research was a departure from the norm for Kinsman and Asher, their first steps into the collaborative field of archaeoastronomy.

The fruit of this first venture is producing mixed reactions from other experts in Mayan history and hieroglyphics.

Their work "is a valid beginning toward the study of an important and likely historical insight into the timing of Maya[n] ceremonial events," Mark Van Stone, a professor and art historian at Southwestern College in Chula Vista, Calif., told *Eos*.

However, John Henderson, a professor of anthropology at Cornell University in Ithaca, N.Y., cautioned that the researchers' results merely imply a statistical correlation between meteor outbursts and meaningful events; the team made no attempt to identify a Maya logic for the connections or reanalyze Maya codices, he noted.

Perhaps if the correlations all applied to a single kind of event or if the celestial events occurred more closely in time to the terrestrial ones, he would find the results more persuasive, Henderson added.

Expanding to Other Meteor Showers

No other researchers have conducted a comprehensive search before for possible meteor events across the entire Mayan Classic Period, Kinsman said. Previous attempts to connect meteor activity and historical events in pre-Hispanic Western civilizations have focused on only one or two meteor events at a time.

He and Asher plan to continue their Mayan archaeoastronomy investigation by analyzing other prominent meteor showers like the Orionids and Perseids, Kinsman said. He is already running their computer model to predict Orionid outbursts during the Mayan Classic Period.

"That's what makes [this idea] exciting," Asher explained, "when it draws together two topics which are on the face of it very different but realizing that there's actually a connection."

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

Understanding Mountain Lakes in a Changing World

Mountain Lakes and Global Change Workshop
Fort Collins, Colorado, 6–8 March 2017

A hiker reaches Sky Pond in Loch Vale in Colorado's Rocky Mountain National Park. The Loch Vale watershed program, established in 1982 by Jill Baron (U.S. Geological Survey), is one of the longest-running alpine ecological research programs in the United States. At a workshop earlier this year, participants discussed the ways that changes in the amount and type of precipitation and deposition of atmospheric contaminants complicate efforts to understand the consequences of global climate change on mountain lakes like Sky Pond. Credit: Isabella Oleksy

Alpine zones in many mountainous regions are warming faster than the global average. Recently observed changes in mountain lakes, including warming and increased algal growth, make it more urgent for scientists to understand the fundamental processes and properties of these lakes and to anticipate their future responses to global change.

Alpine and subalpine mountain lakes of the Northern Hemisphere are important witnesses to global change because of their rapid response to climate and atmospheric deposition and their relatively undisturbed catchments compared with lakes at lower elevations. These water bodies naturally contain low levels of organic matter and nutrients, making them ideal sites to better understand the effects of climate warming on lakes in general.

However, the combined changes in the amount and type of precipitation, along with atmospheric deposition of nitrogen, phosphorus, and contaminants, complicate our efforts to understand the immediate and long-term consequences of global climate change on these sensitive water bodies.

To discuss these changes, researchers and resource managers from North America and Europe held a workshop earlier this year. Attendees discussed how extreme climate events and changes in precipitation influence biogeochemical cycling, especially the cycling of key nutrients essential for life. They considered whether mountainous regions are experiencing increases in extreme events and, if so, whether local watershed characteristics moderate climate-driven influences on lakes.

A warmer climate could increase the probability of rain-on-snow events, exacerbate glacier retreat, and induce permafrost thaw, all of which alter the timing and quantity of runoff and quality of nutrient delivery to lakes. Climate change may lead to shorter winters and warmer summers. So workshop attendees wondered, What will be the ramifications on lake dynamics, particularly algal productivity and photosynthesis? Changing climatic regimes may interact with atmospheric pollution and nonnative species introductions to cause profound biological changes in mountain lakes. These stressors could have implications for downstream water quality and energy movement through food webs.

Workshop participants developed a conceptual framework unique to mountain ecosystems. This framework takes advantage of elevation gradients, long-term measurements, and experiments to develop a comprehensive understanding of ecosystem change.

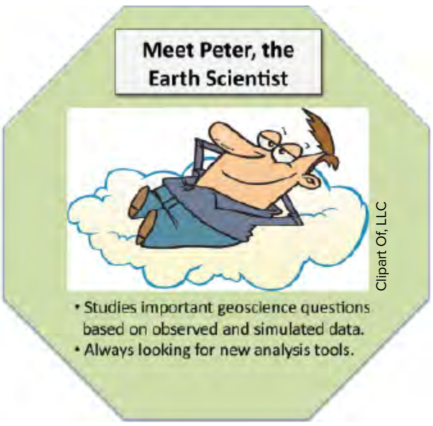
The group developed a template for a growing and comprehensive database that will address many other research questions raised at the workshop, such as whether the species assemblages and food webs of mountain lakes are resilient to climate perturbations due to the highly variable environment in which they reside. In addition, are winter conditions changing in mountain ecosystems? Efforts are already under way to evaluate factors that determine the sensitivity of mountain lakes to species turnover, using data from this growing database of dozens of lakes in the Northern Hemisphere. In addition, attendees reported that several national parks in the western United States will coordinate targeted sampling efforts to better understand interactive effects between temperature and nutrients in regulating algal growth.

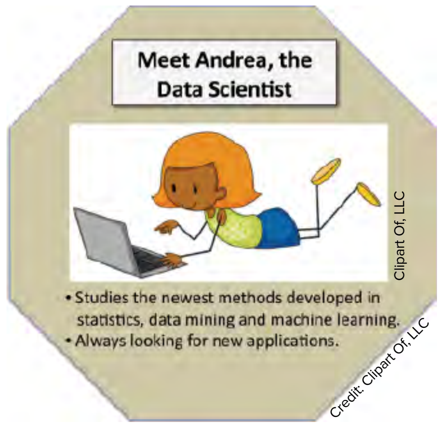
Although the workshop organizers and participants were primarily limnologists, we welcome the participation of other disciplines, including hydrology, atmospheric science, and climatology. We aim to continue building a comprehensive network of data that increases the probability of understanding lake processes and anticipating system changes to mountain lakes worldwide.

Readers who would like to help document the extent of algal growth in mountain lakes can download WATR2016, a citizen science app for iPhones available from iTunes (see http://apple.co/2gfgtCP). Register for the program through the app, and follow the instructions for taking and uploading pictures of mountain lake algal growth. All data will be compiled in the Alpine Algal Bloom Monitoring database on CitSci.org (see http://bit.ly/alpine-algae).

By **Isabella Oleksy** (email: isabella.oleksy@colostate.edu), Natural Resource Ecology Laboratory, Colorado State University, Fort Collins; and **Joshua Culpepper,** Division of Hydrologic Sciences, Desert Research Institute, Reno, Nev.

Three Steps to Successful Collaboration with Data Scientists





Credit: Clipart Of, LLC

The vast and rapidly increasing supply of new data in the Earth sciences creates many opportunities to gain scientific insights and to answer important questions. Data analysis has always been an integral component of research and education in the Earth sciences, but mainstream Earth scientists may not yet be fully aware of many recently developed methods in computer science, statistics, and math.

The fastest way to put these new methods of data analysis to use in the Earth sciences is for Earth scientists and data scientists to collaborate. However, those collaborations can be difficult to initiate and even more difficult to maintain and to guide to successful outcomes. Here we break down the collaboration process into steps and provide some guidelines that we have found useful for efficient collaboration between Earth scientists and data scientists. We base our structure on discussions with many researchers working in similar areas and on our own experience, gained from more than 6 years of collaboration on related topics.

Knowledge Discovery from Data

The data analysis methods we are concerned with are those that seek to identify new knowledge: discovering patterns, revealing interactions between different processes, or yielding other types of insights that can be interpreted by Earth scientists and eventually attributed to some physical effect. We refer to these types of methods as knowledge discovery from data.

Some of these new methods come from the fields of deep learning (using artificial neural networks), causal discovery (using probabilistic cause-and-effect relationships), and self-organizing maps. Artificial neural networks, for example, have been used to predict air quality and the occurrence of severe weather. These networks have been used to derive nonlinear transfer functions that convert observations to important geophysical parameters. Causal discovery has been used to identify information flow (the pathways between cause and effect) in the atmosphere around the globe. Self-organizing maps are becoming a preferred tool for classifying recurring atmospheric flow features such as jet streams.

Meet the Scientists

How do Earth scientists and data scientists get acquainted and begin to work together? Meet Peter and Andrea, our two companions in this article. Peter is an Earth scientist. He studies important geoscience questions, often based on data from observations and computer model simulations. Andrea is a data scientist. She studies the newest data analysis methods developed in statistics, data mining, and machine learning. Let's follow Peter and Andrea as they meet and move through the three major phases of their collaboration experience.

How did Peter and Andrea find each other? They might have run into each other on campus. Maybe one of them attended a talk given by the other. Or maybe a mutual colleague connected them. If they were actively looking for such collaboration, they might have met at an activity designed to establish new collaborations between Earth and data scientists, such as the annual Climate Informatics workshop (see http://www.climateinformatics.org) or the Intelligent Systems for Geosciences Research Coordination Network (IS-GEO; https://is-geo.org).

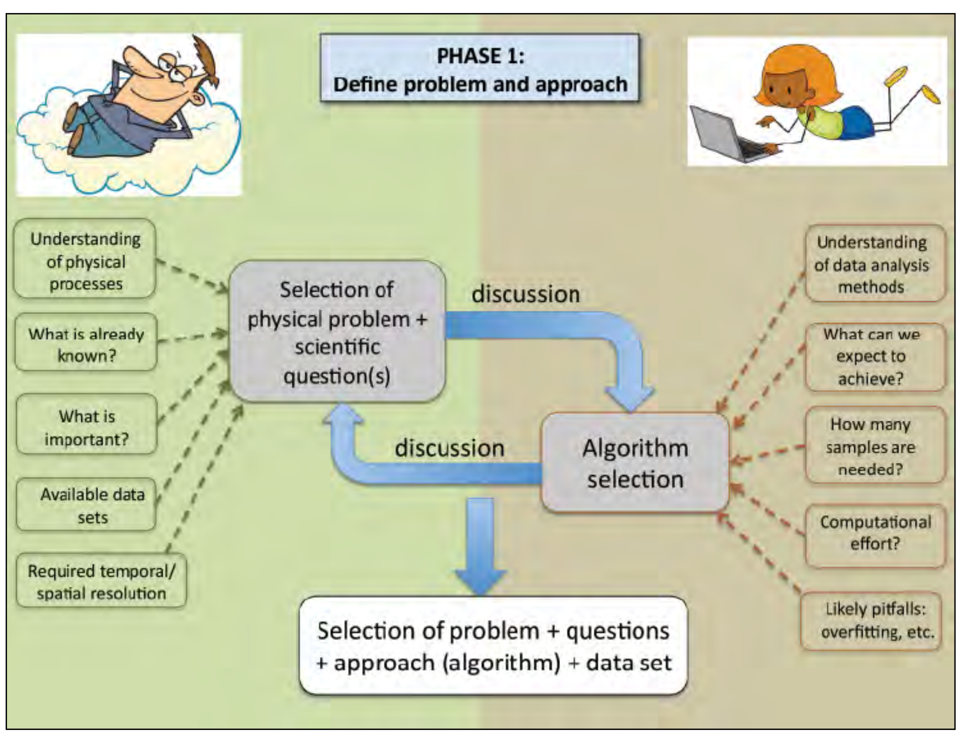


Fig. 1. Peter and Andrea followed an iterative process. In Phase 1, they defined the problem and approach. Credit: Cartoon figures from Clipart Of, LLC

Once they met, they briefly talked one on one about the methods for data analysis that Andrea is using and about science questions that Peter is interested in. A 15-minute in-person meeting may have been all that was needed for them to discover some common interest and to set up a longer meeting to discuss potential collaboration.

Would it have been better for Andrea to just read papers from the Earth sciences to identify science questions that might be a good match and then to contact the authors for potential collaboration? She could find a good collaborator that way. However, Andrea's chances for success would be small, unless she already has a solid background in Earth sciences, because of the complexity of identifying problems to work on.

Research Phase 1: Defining the Research Problem and Approach

Peter and Andrea begin their research collaboration by defining a problem and choosing an approach to solving it (Figure 1). This first phase is an iterative process that must take into account many different and inherently coupled aspects.

On the Earth science side, this task requires knowledge of which science questions are important and not yet fully understood and knowledge of available data sets. It also requires a deep understanding of the physical processes and interactions being investigated, the temporal and spatial scales at which these interactions take place, and most important, intuition of what aspect of a science question might benefit significantly from "mining" large amounts of data with innovative approaches.

On the data science side, this task requires a solid understanding of available data analysis methods and what insights can realistically be gained from them. The task also requires knowing the associated data requirements (minimal sample size and distribution assumptions) and computational effort, as well as common pitfalls and how to avoid them.

The aspects from both sides are inherently coupled. For example, to figure out which algorithm to use, our collaborators first need to understand the properties of the available data and the types of insights they want to gain. Thus, neither Peter nor Andrea can define the research problem in isolation. To define a feasible and meaningful research project, they must work closely together and have frequent conversations. They need to be open-minded and willing to learn the basic vocabulary and way of thinking of each other's disciplines.

Research Phase 2: Conducting Experiments on the Data

In the second phase, the researchers conduct experiments on the data, such as trying different data analysis methods (Figure 2). This step sounds like a job mainly for Andrea, but if Andrea works in isolation, there is a good chance that she will take many unnecessary detours that might even cause her to get lost and give up on the project altogether. Only Peter knows what kind of preprocessing or other modifications might help to expose the signals or patterns in the data that they seek to discover.

Therefore, this step also requires constant communication between Peter and Andrea. Every time Andrea tries a new approach, Peter needs to look closely at the results and provide suggestions on how additional preprocessing of the data, focusing on a different spatial or temporal resolution, focusing on a specific geographical area, or rephrasing the scientific question may get the team closer to useful results.

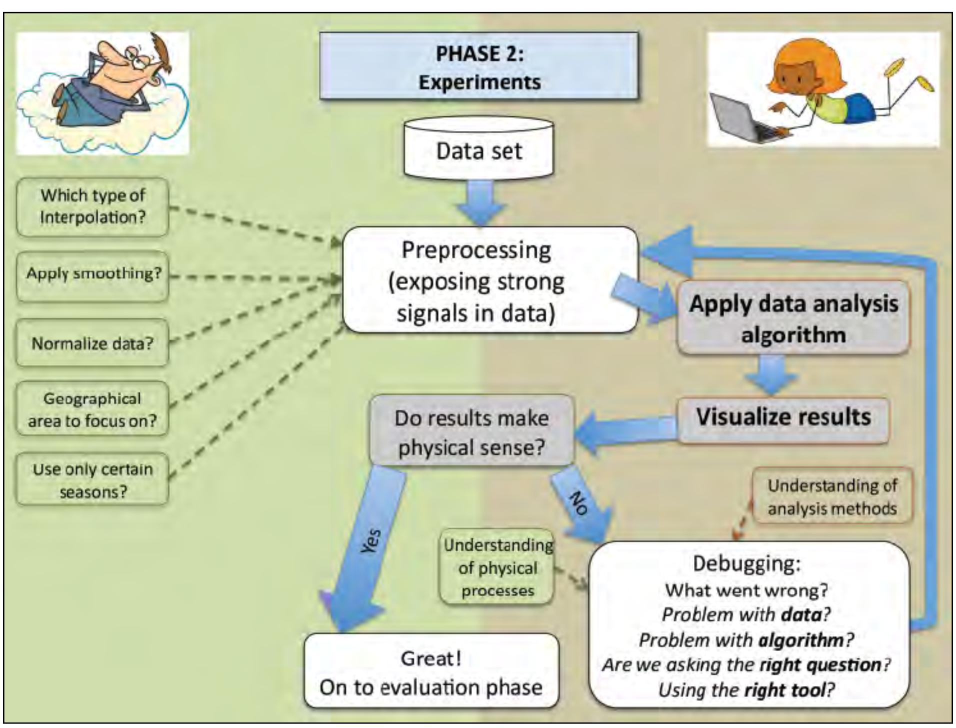


Fig. 2. In Phase 2, Andrea and Peter conducted experiments. Credit: Cartoon figures from Clipart Of, LLC

Research Phase 3: Evaluation and Interpretation

Once Peter and Andrea obtain promising results, they need to evaluate them (Figure 3). Do the results represent a real physical phenomenon, or are they merely an unforeseen by-product of the data collection or analysis method? Economist and Nobel laureate Ronald Coase once said, "If you torture the data long enough, it will confess" (see http://bit.ly/Coase-quote).

Thus, before presenting the results as facts of the actual physical processes they studied, Peter and Andrea need to verify that the patterns are, indeed, properties of the underlying system, not just artifacts of the specific data set and analysis method. Ultimately, Peter needs to check whether the results are robust, make physical sense, and can be explained by known or hypothesized interactions in the considered Earth system.

What Does It All Mean?

The last tasks of phase 3 lead us to the final step of the project, namely, to fully understand what the results mean in the context of the science question they set out to address. Do Peter and Andrea's results answer the original question they asked? What exactly did they learn?

Only if Peter and Andrea take the time to translate the research results back into the real world of physics, dyn amics, chemistry, and geosciences and spell out all the implications for the considered Earth system will anyone in the Earth science community care about the results. Peter obviously plays the bigger role in this last step, but he still needs continuous feedback from Andrea to help him interpret the results correctly because only she knows about weaknesses or limitations of the method.

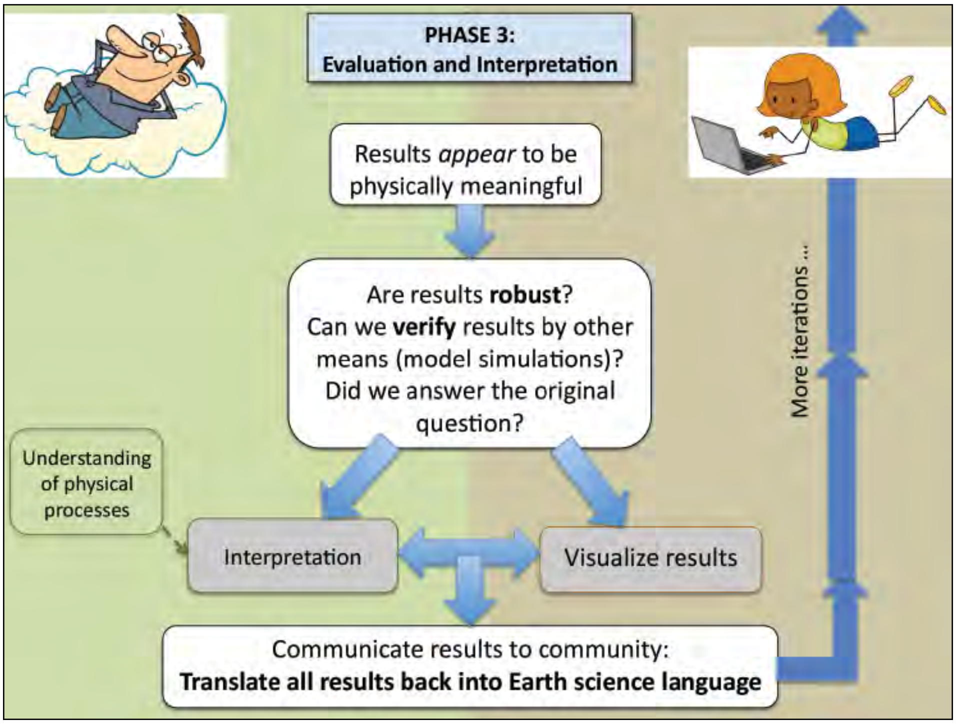


Fig. 3. In Phase 3, Peter and Andrea evaluated the results of their experiments and translated them back into Earth science language. Credit: Cartoon figures from Clipart Of, LLC

Peter and Andrea learned that they have to work together very closely at every step of their joint project because all their decisions require a deep understanding of both Earth science and data analysis disciplines. Each of them had to be curious about the other's discipline and also be willing to teach some basic skills or knowledge of their own discipline to the other person. Through this process, they each gained at least some basic understanding of the nature of the other's discipline, including its way of thinking, relevant concepts, and terminology.

Working closely together and learning about the other's field not only made Peter and Andrea's current collaboration run much more smoothly than it otherwise would have; it also created ideas for future projects. Through close collaboration, Peter and Andrea learned about each other's fields even as they were contributing to them.

By **Imme Ebert-Uphoff** (email: iebert@colostate.edu), Department of Electrical and Computer Engineering, Colorado State University, Fort Collins; and **Yi Deng,** School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta

DRONE PEERS INTO OPEN

VOLCANIC VENTS

An unmanned aerial vehicle provided high-resolution data that allowed scientists to construct their first detailed map of erupting vents at Stromboli, one of the world's most active volcanoes

By Nicolas Turner, Bruce Houghton, Jacopo Taddeucci, Jost von der Lieth, Ullrich Kueppers, Damien Gaudin, Tullio Ricci, Karl Kim, and Piergiorgio Scalato

Volcanoes that erupt frequently give researchers special opportunities to make repeated high-resolution observations of rapid eruption processes. At explosive volcanoes like Stromboli, situated just off the southwestern coast of Italy, "normal" explosive eruptions take place every few minutes to tens of minutes. However, the rainout of hot volcanic bombs, some as large as a meter across, makes it hazardous for scientists and their instruments to get close enough to Stromboli's active vents to collect some forms of essential data.

At volcanoes like Stromboli, we can make many key observations from safe locations, hundreds of meters from the erupting vents. Other key observations must be made from locations beside or immediately above the vents. These underrecorded observations include the exact locations of vents, their dimensions, and the depth to the magma's free surface. These observations generally have not been feasible because explosions

Credit: AZ68/iStock/Getty Images Plus

occur at irregular frequencies, and they seldom provide warning; our inability to make these observations has been a major impediment to our models of the eruption process.

Fortunately, robotic technology can go where humans cannot. Unmanned aerial vehicles (UAVs), also called drones, have become cheaper and more accessible, and they now have the ability to carry lightweight optical sensors for mapping and for aerial observations of volcanic activity.

We used a UAV in a May 2016 pilot survey campaign at Stromboli to map detailed features of the active crater terrace and produce a high-resolution digital elevation model, with details as small as about 5 centimeters. Different vent areas within this crater terrace host active and inactive vents as well as fumaroles, and the UAV helped us determine their locations and dimensions.

What We Do Know

There are many things scientists can observe from volcanoes without using drones. For example, remote observations from closely positioned cameras and sensors can record initial velocities for the erupted particles (bombs and ash) [*Patrick et al.,* 2007; *Gaudin et al.,* 2016], event durations and mass eruption rates [*Taddeucci et al.,* 2012; *Rosi et al.,* 2013; *Gaudin et al.,* 2014], temperature and flux of gas species [*Burton et al.,* 2007], and the sizes of the ejected bombs [*Gurioli et al.,* 2013; *Harris et al.,* 2013; *Bombrun et al.,* 2015].

Through recent field campaigns at Stromboli, scientists have gathered excellent time-synchronized databases of geophysical data and observations of eruption timings, pulsations, and mass flux derived from seismometers, high-speed cameras, webcams, Doppler radar, and infrasound sensors [e.g., *Scarlato et al.,* 2014]. MultiGAS instruments (which combine optical and electrochemical sensors), Fourier transform infrared spectrometers, and ultraviolet and thermal infrared cameras have captured the nature and flux of key magmatic gases (water, carbon dioxide, and sulfur gases) associated with the activity.

These sensors, however, have their limits. UAVs can push data collection beyond these limits.

Soaring Above the Danger

Over the past 2 decades, Stromboli has been surveyed with lidar technology, but because of the high costs involved with lidar surveys, they are not conducted frequently enough to capture rapid changes at the summit of Stromboli.

UAV-based mapping can supplement or replace lidar surveys. UAVs were first used at Stromboli in 2007 to col-

Team members launch their UAV from the summit of Stromboli volcano in preparation for gathering data and images of Stromboli's active vents. An automated flight plan guides the UAV for accurate mapping, and team members use a tablet to monitor the flight status remotely. Credit: Bruce Houghton

lect ash samples [*Taddeucci et al.,* 2007]. Since that time, they have become cheaper, smarter, and able to carry higher-quality imaging sensors, such as the X5 camera mounted on the DJI Inspire 1 quadcopter used in our 2016 study.

Advances in the field of computer vision have also yielded software capable of extracting 3-D topography from multiple 2-D images in a process called structure from motion. Pairing this practical technique with UAVs has resulted in its widespread adoption across multiple fields in science, and volcanology is no exception [*James and Robson,* 2012].

UAVs, in combination with the live webcams deployed around the crater terrace [*Fornaciai et al.,* 2010; *Calvari et al.,* 2016], provide an unprecedented level of monitoring via imaging and sampling of eruption plumes. UAVs could even be used to deploy sensors near or inside the vent.

What's more, with an extended range, UAVs could allow observations when human access to the summit is forbidden and dangerous. This capability would be especially useful, for example, during the rare paroxysmal phases, which can last several months.

Given this potential, we decided to put the utility of UAVs to the test.

First Results

Even UAVs face challenges like constant gas emissions, high and gusting winds, and unpredictable explosions when mapping volcanic environments like Stromboli. In the worst case, UAVs may be severely damaged, or their data may be lost.

During our 2016 campaign, explosions proved the most challenging to cope with. On more than one occasion, the UAV was almost engulfed by a rising ash plume while it was mapping directly above an active vent. Active fumaroles constantly sent up clouds of gas, condensed water vapor, and ash particles, making it difficult for the onboard camera to get clear images of these vents for use in mapping the interior of the source craters. Fortunately, shifts in wind would briefly clear the craters, providing the camera with an occasional clear view (see video at http://bit.ly/Eos_volcanic_vents).

We constructed the final maps of the crater terrace (Figure 1) by selecting the highest-quality images from more than a dozen mapping flights over 2 days. We processed the images with structure from motion software to construct a relatively gas free orthomosaic (aerial map corrected for distortions) and accompanying digital elevation model.

We mapped a total of 4 active vents, 11 inactive vents, and 33 fumaroles in the southwestern and northeastern vent areas present in May 2016 (Figure 1). There is no clear pattern to vent distribution within the larger structures on the crater terrace. Inactive vents, particularly fumaroles, tend to occur in clusters without a single, consistent orientation. The two principal northeastern vents are aligned approximately east-west and are 69 meters apart. The two principal southwestern vents are 55 meters apart and aligned roughly north to south.

Overall, the northeastern active vents were similar to each other in depth and diameter (Figure 2), but the southwestern active vents were significantly deeper. Inactive

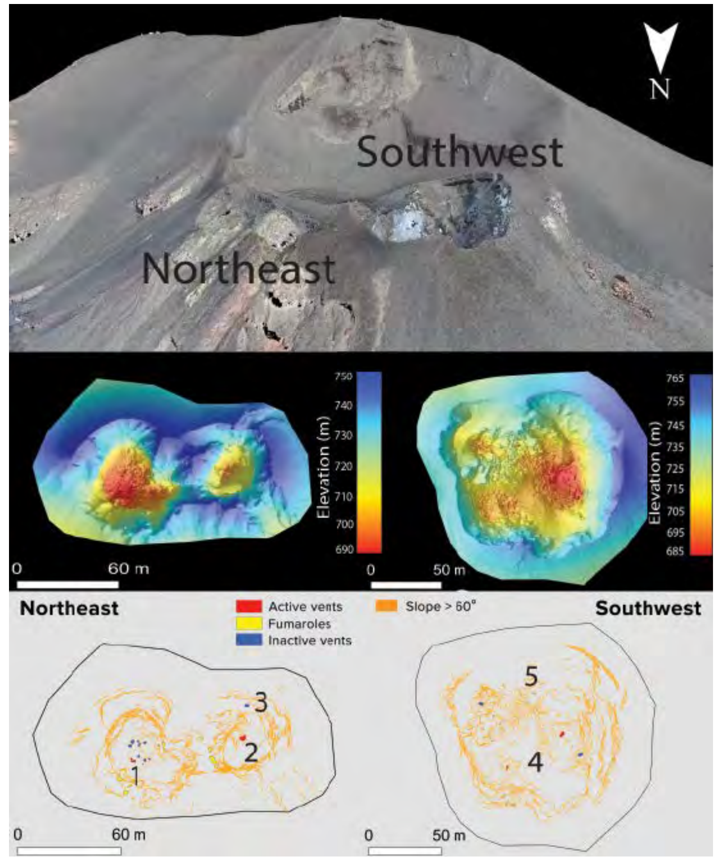


Fig. 1. (top) Digital point cloud model of Stromboli crater terrace showing the two vent areas of the crater terrace. (middle) Digital elevation models (DEMs) of the northeastern and southwestern vent areas showing morphology. (bottom) Classification maps of active vents, inactive vents, and fumaroles from the high-resolution DEMs, aerial imagery, and low-altitude video observations of activity for active vents and fumaroles. Inactive vents were identified by examining the DEMs for features with morphology similar to that of the active vents.

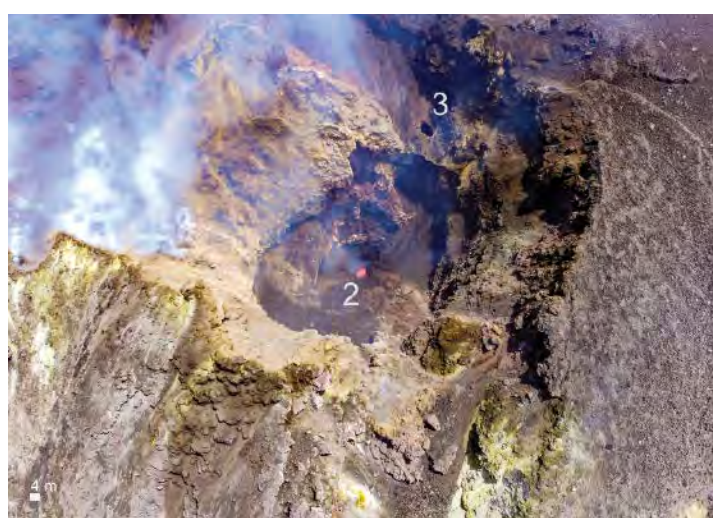


Fig. 2. A sudden shift in wind direction momentarily sweeps away a gas cloud, giving the UAV a clear view of the interior of the crater and revealing an active vent (2) and an inactive vent (3). Active vent 1 is obscured, but it lies directly behind the bluish gas plume to the left of vent 2.

Fig. 3. The UAV captured this visible-light still frame of an expanding ash-rich explosion from the dominant vent 4. The ash plume is more than 300 meters tall.

vents were much shallower than active vents. During a week of observations, the southwestern vents produced the larger and more powerful explosions. Explosions from vent 4 (see Figure 1) were typically ash charged, and the free surface was generally covered by debris between successive explosions. These plumes often reached heights of several hundred meters (Figure 3).

In contrast, an incandescent free surface was often visible in vent 5 and the active northeastern vents (see Figure 4), and spattering and outgassing were clearly visible in vent 2 during a repose interval (Figure 5).

Implications for Eruption Processes and Volcano Monitoring

This pilot survey yielded useful data, and it serves as a guide for future, more ambitious and repeated deployments. The data we gathered—the precise source locations of explosions, for example—can potentially help us reduce the uncertainty in geophysical model inputs for seismic and acoustic arrays and gravity measurements.

We hope to establish precise correlations of changing eruption style and intensity with time for single vents, along with synchronous observations of depths to the free surface of magma in the parent vents. This and future deployments will help us to monitor abrupt and progressive changes in the diameter of single vents over time and the influence of these changes on eruptive behavior.

Our data will assist in making comparisons of how differences in vent width and depth to the free surface, the orientation and inclination of the conduit, and the extent of debris covering the free surface all influence contrasting eruption behavior at adjacent vents.

The ability to capture such detail at an active volcano offers the opportunity to greatly enhance programs for short-term and long-term volcano monitoring. Scientists modeling Strombolian eruptions can use these new data to reduce the uncertainty in numerical model input parameters (e.g., conduit and acoustic modeling).

The low cost and safety of UAV operations allow small-scale changes to be captured and UAV surveys to be launched as frequently as necessary. These benefits make UAVs a critical complement to other remote sensing and geophysical techniques.

Acknowledgments

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Fig. 4. The UAV captured this image of vents 2 and 5 in the northeastern and southwestern regions, respectively, between explosions.

Fig. 5. Close-up view of vent 2 showing weak, discontinuous spattering activity that continued between explosions.

Capturing detail at an active volcano offers the opportunity to greatly enhance programs for short-term and long-term volcano monitoring.

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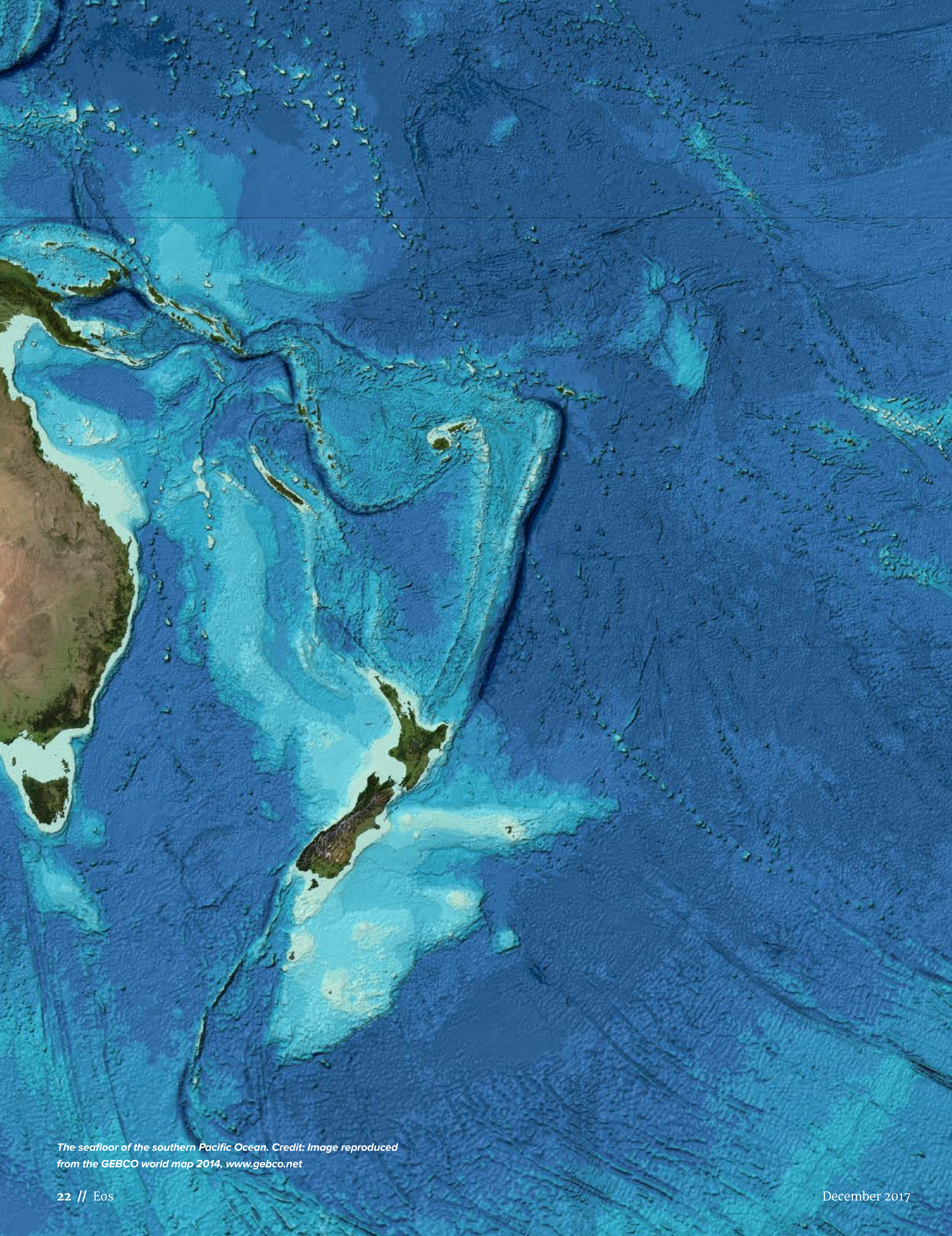

The seafloor of the southern Pacific Ocean. Credit: Image reproduced from the GEBCO world map 2014, www.gebco.net

A GRAND TOUR OF THE OCEAN BASINS

A new teaching resource facilitates plate tectonics studies using a virtual guided tour of ocean basins around the world.

By Declan G. De Paor

Students, especially those at the beginner levels, are often presented with simplistic visualizations of plate tectonics that lack the rich detail and recent science available to researchers. Yet the ability of plate tectonics to explain fine details of the continental and oceanic lithosphere is the strongest available verification of this theory. Presenting more of this detail in a real-world setting can help motivate students to study the processes that mold Earth's oceans and continents.

Google Earth allows instructors and students to explore Earth's oceans and continents in considerable detail. The images in this open-access, online resource provide a striking portrait of the planet's continents and oceans. A user can browse this virtual globe's features and explore in fine detail mountain ranges, geological faults, ocean basins, and much more.

Properly annotated, Google Earth can also provide insights into the geophysical processes that created the world that we experience today. It can serve as an informative tool for students and instructors in their study of tectonic plates, bringing to life the geological significance of such features as the famous Ring of Fire, which girdles the Pacific Ocean.

Our project, Google Earth for Onsite and Distance Education (GEODE), has now added a Grand Tour of the Ocean Basins to its website to provide such help (see http://bit.ly/GEODE-ocean-tour). This tour gives instructors a way to become familiar with details of Earth's tectonic story and to stay up to date about new insights into tectonic processes. They can then better respond to, and provide context for, on-the-spot questions from students as they become caught up in the images they view on Google Earth.

The tour was designed for geoscience majors, but an instructor could edit it to suit general education or high school courses. Students can use the documentation as a self-study tool, even if they do not have extensive prior knowledge of tectonic processes.

A Teaching Sequence

The tour is organized in a teaching sequence, beginning with the East African Rift, continuing through the Red Sea and Gulf of Aden into the Arabian Sea. The tour proceeds to the passive margins of Antarctica, which lead tourists to the South Atlantic, North Atlantic, and Arctic oceans. En route, students visit thinned continental shelves and abandoned ocean basins (where seafloor spreading no longer occurs). The Lesser Antilles Arc and the Scotia Arc serve as an introduction to Pacific continental arcs, transform boundaries, island arcs, and marginal basins. The tour ends with ophiolites—slivers of ocean thrust onto land—in Oman.

The tour uses a series of Google Earth placemarks (map pin icons), with descriptions and illustrations in a separate PDF file. We provide plate tectonic context by combining two superb resources: ocean floor ages from the Age of the Lithosphere for Google Earth website (based on work by *Müller et al.* [2008]; see http://bit.ly/lithosphere-age) and the plate boundary model from Laurel Goodell's Science Education Resource Center page (based on work by *Bird* [2003]; see http://bit.ly/explore-tectonics).

Not Your Grandmother's Plate Tectonics

Our virtual tour of ocean basins includes lots of up-to-date local details, thanks largely to recent research that takes advantage of precise data provided by satellite-based GPS. Just as your car's GPS receiver tells you how fast you are traveling and in what direction, highly sensitive GPS devices record plate velocities, even though plates move only at about the rate your fingernails grow. Researchers no longer regard plates as absolutely rigid: Internal plate deformation was first documented in the Indian Ocean [*Wiens et al.*, 1985].

GPS surveys and seismic records reveal large regions of deformation along diffuse boundaries between tectonic plates, where the movement is not along one well-defined plane. Instead, movement involves microplates, relatively rigid parts of plates that move with significantly differing velocities. For example, tour stop 9, the eastern Indian Ocean, shows the presence of widespread diffuse deformation in the Indian, Australian, and Capricorn plates (Figure 1). For mechanical reasons, these microplates tend to pivot about points separating regions of diffuse extension from compression, represented by white circle icons in the Google Earth tour.

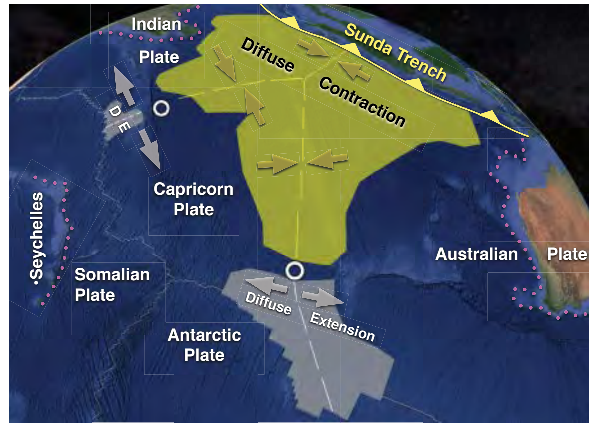

Fig. 1. This image from the grand tour illustrates diffuse deformation on the Indian, Australian, and Capricorn plates. Areas of extension are shaded gray; areas of contraction are yellow. Bold dashed lines mark the median lines of the zones of diffuse deformation. They define a diffuse triple junction. Open circles are poles of relative rotation of pairs of plates (a third pole may already be subducted under the Sunda plate). These poles occupy regions of little deformation between the extensional and contractional zones. Purple dotted lines outline continental shelves. Credit: Based on data from Royer and Gordon *[1997]. All figures are based on Google Earth, ©2017, Google, Inc. Images: PGC/NASA, Landsat/Copernicus, USGS. Data: SIO, NOAA, U.S. Navy, NGA, GEBC, USGS*

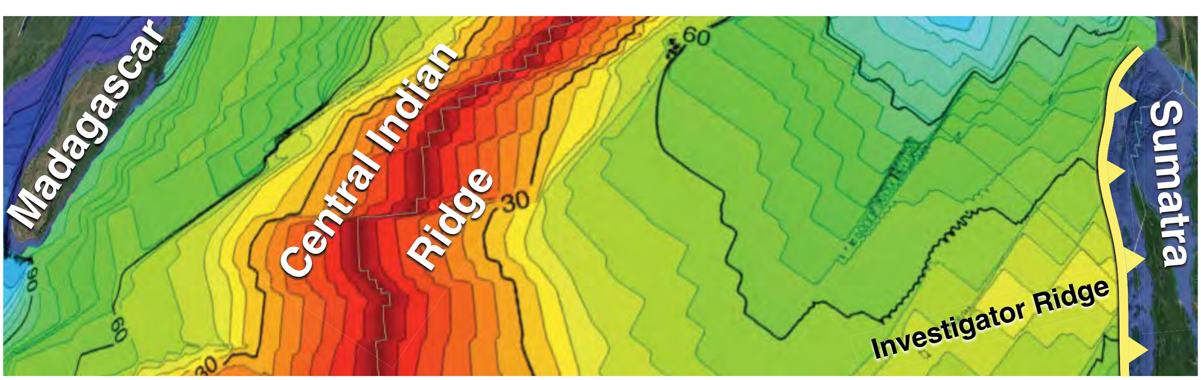

Fig. 2. An ocean can be bounded by a passive continental margin on one side and an active plate boundary on the other. In such cases, the spreading ridge is never in the middle of the ocean. A traverse from Madagascar in the west to Sumatra in the east, shown here, serves as a modern-day analogue for the evolution of the Iapetus Ocean, which was consumed in the Appalachian–Caledonian Orogeny.

Beyond Atlantic Style and Pacific Style

Our Google Earth tour also allows us to address misconceptions about the boundaries between tectonic plates and between oceans and continents. Some of the most persistent misconceptions concern the differences between active plate boundaries and passive continental margins.

A bit of background first: Active plate boundaries can be divergent (mid-ocean ridges), convergent (subduction and collision zones), or transform (e.g., the San Andreas Fault). At passive continental margins, oceanic lithosphere and continental lithosphere are welded together along the fossilized line of initial continental rifting. A person in our Google Earth tour will encounter numerous examples of both active plate boundaries and passive continental margins.

Misconceptions arise from the introductory level on, where teachers present students with two basic cross sections of ocean basins: Atlantic style with two passive continental margins and Pacific style with two active plate boundaries. Students commonly draw cross sections with two symmetrical active convergent plate boundaries even though there is no such ocean basin on Earth.

Symmetrical passive margins do exist, however; they border large regions of oceanic crust, including, for example, the North and South Atlantic oceans, the western portion of the Indian Ocean within the Arabian Sea, and the Southern Ocean between Australia and Antarctica, as well as between Africa and Antarctica. But active basins are always asymmetrical, with ridges often far from the middle of the ocean basin. Seafloor spreading is generally symmetrical about ocean ridges (except for local instances of ridge jump), but there is no reason for subduction to occur at the same rate on either side of an ocean basin; hence, ridges migrate as they spread, and in places they reach a trench and are subducted.

Our grand tour presents lithospheric cross sections of the Pacific crust to scale, with its eastern 4,000-kilometer-wide Nazca plate and western 12,000-kilometer-wide Pacific plate. It also highlights the eastern Indian Ocean, with its passive margin against Madagascar and active plate boundary against Burma-Sumatra, the scene of the devastating, tsunami-generating earthquake of 26 December 2004 (Figure 2).

This combination of passive continental margin and active plate boundary serves as a good modern analogue for the Iapetus Ocean, the ocean that separated paleo–North America from paleo-Europe and paleo-Africa before the collisions that created the Appalachians, Caledonides, and associated mountains. Models of those mountain-building events involve, at times, a collision of active and passive sides of the ocean basin as Iapetus was consumed.

Sampling Diversity in Ocean Basins

The grand tour also visits many of the diverse features of Earth's ocean basins. A significant amount of oceanic crust resides in failed or abandoned basins bounded by passive margins. Such regions include the Gulf of Mexico, the Labrador Sea and Baffin Bay between Canada and Greenland, the Bay of Biscay between France and Spain, the western Mediterranean, and the Tasman and Coral seas east of Australia, all of which are visited on the tour.

Many offshore regions are underlain by oceanic crust that developed in marginal basins behind such island arcs as Japan and the Mariana Islands, and the tour visits these regions as well. Because the west side of the Pacific's oceanic crust is so much older than the east, it is colder and denser and subducts steeply and rapidly. Consequently, trenches marking the initiation of subduction roll back eastward, like a Michael Jackson moonwalk. The resultant "trench suction" forces open multiple back-arc basins to the west of the main Pacific basin, with their own miniature spreading ridges.

A third type of minor ocean basin is created by side-stepping transform fault arrays as in the Gulf of California and on the northern border of the Caribbean plate. In such locations, transform faults are long and spreading ridge segments are short.

Finally, there are numerous oceanic plateaus with relatively thick crust derived from large igneous provinces or small submerged continental fragments. Examples of all of the above are included in our tour.

Triple Junctions and Hot Spots

The tour makes stops at triple junctions, where three major plates meet. At some locations, triangular microplates without any bounding continental margins grow, as exemplified by the Galápagos microplate (Figure 3, tour stop 38).

Researchers have found strong evidence that one such paleomicroplate grew to become the Pacific plate [*Boschman and van Hinsbergen*, 2016]. The Pacific oceanic crust never had passive continental margins. It was born at sea!

Oceans are also home to mantle hot spot trails unrelated to plate boundaries. The grand tour visits the well-known Hawaiian Islands–Emperor Seamount trail. Numerous other trails are easily recognizable in Google Earth.

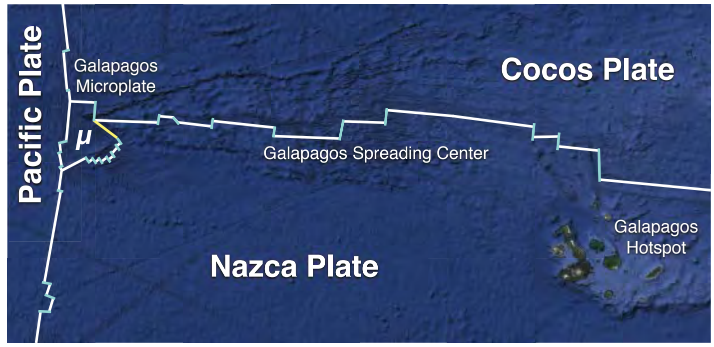

Fig. 3. Stop 38 on the Grand Tour of the Ocean Basins focuses on the Galápagos microplate (designated μ in the image) on the East Pacific Rise. It sits at a triple junction where three large plates meet. The Galápagos hot spot to the east was probably instrumental in the location of the triple junction. Credit: Based on data from Schouten et al. *[2008]*

File Formats and System Requirements

The tour is presented in two file formats: Keyhole Markup Language (KML)—the format of Google Earth custom content—and an associated PDF file. Google Earth puts descriptive text and imagery into placemark balloons, which can obscure the surface of the map. Because these balloons cannot be dragged to one side, simultaneous viewing of KML maps and PDF descriptive documents is the solution. Dual monitors, twin projectors, or pairs of laptops make for the best viewing for personal study, lecture presentation, and student collaboration.

The PDF document is laid out in frames suited to reading on digital devices. Each frame contains a block of text and associated imagery. Instructors may omit or rearrange tour stops to suit the needs of their courses. Because KML is human-readable, such rearrangements can be done in a text editor. Note that the KML file must be viewed on a desktop or laptop computer (Mac, Windows, or Linux) because Google Earth for mobile devices is highly limited.

Trying It Out for Yourself

The KML and PDF files are available for download. The KML download contains a simple network link to an online KML document so that updates occur automatically whenever the document is opened in Google Earth.

The author invites suggestions for continuously improving this resource.

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(Top) A photograph taken near the town of Popoyo, Nicaragua, during a post-tsunami survey following a M_w = 7.7 earthquake that struck Nicaragua's Pacific coast on 1 September 1992. Here sedimentologist Jody Bourgeois, part of the first ever International Tsunami Survey Team (ITST), takes notes 3 weeks after the event at a house destroyed by the tsunami. Tsunami wave height reached almost 6 meters in this coastal town; most houses were washed away. Credit: Harry Yeh/NCEI. (middle left) Destruction seen in the town of Masachapa, Nicaragua, the morning after the tsunami. Credit: Wilfried Strauch/INETER. (middle right) Three weeks after the 1 September 1992 tsunami in Nicaragua, ITST members document two houses in Popoyo that survived—all the others were washed away. Credit: Harry Yeh/NCEI. (bottom left) A lone wall stands on a foundation in Popoyo 3 weeks after the 1 September 1992 tsunami. Credit: Harry Yeh/NCEI. (bottom right) A boat perches on the ruins of a structure in the town of El Tránsito, Nicaragua. Run-ups here reached a height of nearly 10 meters. Credit: Harry Yeh/NCEI

THE LEGACY OF THE 1992 NICARAGUA TSUNAMI

A powerful tsunami struck Nicaragua's Pacific coast 25 years ago. In its wake emerged the first coordinated collaboration among international tsunami scientists.

By Nicolas Arcos, Paula Dunbar, Kelly Stroker, and Laura Kong

On the night of 1 September 1992, a deadly tsunami struck the Pacific coast of Nicaragua with little or no warning, triggered by a nearby earthquake. Early newspaper reports indicated that waves almost 15 meters high swept away houses, boats, vehicles, and anything in their path [*Globe and Mail,* 1992].

The earthquake and tsunami left at least 170 people dead, approximately 500 injured, and more than 13,500 homeless. The tsunami caused most of the damage.

Following the earthquake, the National Oceanic and Atmospheric Administration (NOAA) Pacific Tsunami Warning Center (PTWC) did not issue a tsunami warning. That's because the earthquake's initial surface wave magnitude (M_S) was only 6.8, lower than the warning threshold. However, analysis of seismic signatures would later show that the earthquake's moment magnitude (M_W), a better representation of the total energy radiated by the earthquake, was 7.7.

Close to the source, many people also underestimated the magnitude of the earthquake on the basis of the shaking. Often, strong earthquake ground shaking serves as a natural warning sign of an impending tsunami, so that coastal communities can evacuate. But in this case, the ground shaking was weak or soft. The source was only about 100 kilometers away, so why didn't many coastal residents feel the earthquake, and why was the ensuing tsunami so high?

The unusual earthquake source characteristics and growing interest in tsunamis in the United States led to the organization of the first International Tsunami Survey Team (ITST) to document the tsunami's effects. For the 25th anniversary of this event, we interviewed several Japanese and U.S. scientists involved with assessing the tsunami that followed this earthquake. From their accounts, we learned that ascertaining why coastal residents didn't feel the earthquake greatly improved the ways scientists study tsunami generation and coordinate post-tsunami surveys today.

A Slowly Unrolling Earthquake

In a typical earthquake tsunami sequence, communities near the source feel the earthquake and, if properly alerted to its hazards, brace for the possibility of a tsunami. But the 1992 Nicaragua earthquake, which occurred on 2 September at 00:16 coordinated universal time (1 September at 7:16 p.m. local time), did not follow this typical pattern.

"We found only about half the coastal residents actually felt the ground shaking," recalled Kenji Satake, then a seismologist at

Following the 1992 ITST, Bourgeois returned to Nicaragua twice to study tsunami deposits. This photograph from March 1995 shows Bourgeois (left) in Nicaragua with then University of Southern California researchers José Borrero (middle) and Paul Merculief (right). The scientists are taking a core of coastal sediments to look for tsunami deposits. Credit: Costas Synolakis and ITIC

the University of Michigan, who participated in the post-tsunami survey.

To understand what happened, one needs to look to a paper published 20 years prior to the events that preceded the 1992 Nicaragua tsunami. In 1972, Hiroo Kanamori, then at Japan's Earthquake Research Institute of the University of Tokyo, proposed the term "tsunami earthquake" [*Kanamori,* 1972]. In such earthquakes, fault rupture occurs more slowly and gradually than it would during a typical tectonic earthquake. Measurements of just the short-period seismic waves will not adequately capture this slow release of energy, so a tsunami triggered by such an earthquake is larger and runs up higher than one would expect from quick calculations of M_S.

Prior to 1992, scientists knew about tsunami earthquakes, but they hadn't really observed seismograms of one unfolding or developed methods for quickly calculating a reliable magnitude when the largest energy is released later. The 1992 earthquake in Nicaragua changed that.

Newly developed broadband seismometers with digital acquisition systems enabled the tracking of the Nicaragua earthquake over multiple frequencies. The seismometers told an intriguing story: "We knew from our seismogram analysis that the source process was unusual, characterized by long duration," Satake noted.

There it was: the first tsunami earthquake ever recorded by broadband seismometers [*Kanamori and Kikuchi,* 1993].

In this context, it made sense that many residents didn't feel the ground shaking. The earthquake was slow, but it packed a big punch that triggered a destructive tsunami where none was expected [*Satake,* 1994].

The First International Tsunami Survey Team

The gradual release of energy during the 1992 Nicaragua earthquake resulted in underestimated early magnitude assessments because much of the energy was contained in longer-period waves. In 1992, PTWC calculated magnitudes using the 1-second short-period *P* waves and 20-second-period surface waves. Thus, scientists did not know the M_S until 30–40 minutes after the earthquake, and when determined, it was below the tsunami warning threshold, recalled Laura Kong, who was on duty at PTWC for the event. As a result, the initial earthquake magnitude calculated did not tip off the scientific community about the possibility of a destructive tsunami.

Because scientists were not tipped off, most of the world outside of Nicaragua heard about the tsunami through news media. Inside the country, however, Wilfried Strauch, a geophysicist at Nicaragua's Instituto Nicaragüense de Estudios Territoriales (INETER), felt the long earthquake. After hearing on the radio about inundations along the coast, Strauch gathered his equipment and immediately left for the coast. Accompanied by the military, Strauch was among the first scientists and officials to confirm the tsunami's destruction at sunrise.

Fumihiko Imamura, an engineering professor at Tohoku University, was in Japan when he learned of the tsunami from news broadcasts. He had also noted a 7-centimeter



(Top left) A view near the coast in Masachapa, Nicaragua, on 2 September 1992; the tsunami struck the night before. Credit: Wilfried Strauch/INETER. (right) A photograph taken near the town of Popoyo, Nicaragua, during the first ITST. Bourgeois stands next to a large rock that the 1 September 1992 tsunami carried 50 meters inland and deposited 1.85 meters above sea level. Credit: Harry Yeh/NCEI. (bottom left) The ruins of a building in Poneloya, Nicaragua, seen a few days after the tsunami. Credit: Wilfried Strauch/INETER

rise in a tide gauge moored near Kesennuma, Japan. This blip was the event's tele-tsunami, observed more than 12,000 kilometers from its Nicaraguan source. Working backward, far-field tide gauge observations were inverted to estimate the magnitude of the source. These calculations indicated a higher-magnitude earthquake than was initially reported [*Satake et al.,* 1993].

Intrigued, Imamura led one of the survey teams in Nicaragua's affected areas. His team and others joined a larger survey effort initiated by Kuniaki Abe (from Nippon Dental University College in Niigata, Japan) and Katsuaki Abe and Yoshinobu Tsuji (from the University of Tokyo's Earthquake Research Institute, also in Japan). Upon hearing of the survey efforts, Satake contacted the U.S. National Science Foundation (NSF) to request permission to use grant funds to join the survey team in documenting this unusual tsunami. This request led Jody Bourgeois, a program officer at NSF at the time, to link up with the post-tsunami survey teams.

Through this coordination, the first ITST began to take shape. Scientists and engineers from Japan and the United States, aided by local Nicaraguan scientists and engineers, surveyed the affected areas within 3 weeks of the event.

International Collaboration

Japan has a long history of tsunami events, and Japanese scientists had done extensive research on tsunami effects before the 1992 Nicaragua event. For instance, Satake was part of a post-tsunami survey team that documented the 1983 Sea of Japan earthquake and tsunami.

Japanese team members had a great deal of post-tsunami survey experience. In contrast, U.S. team members had little such experience. Although U.S. scientists surveyed the effects of the 28 March 1964 Alaska earthquake and tsunami, few destructive tsunamis had hit U.S. coasts in the decade leading up to the Nicaragua event. However, when the Nicaragua tsunami struck, there was growing interest in tsunamis among many U.S. scientists. Recent discoveries in the Cascadia subduction zone had revealed a tsunami that we now know struck in 1700, and many scientists were focused on reconstructing that event [*Atwater,* 1987].

Thus, leadership of the first ITST fell largely to Japanese scientists, given their prior tsunami experience in Japan. The Japanese members handled initial communications with Nicaraguans at INETER and benefited from previously established local connections.

However, as Frank Gonzalez, then an oceanographer at the NOAA Pacific Marine Environmental Laboratory (PMEL), recalled, the level of collaboration "was a first for everyone, so there was a lot of winging it and improvisation."

One tricky problem to navigate was the availability and accuracy of baseline maps of the coastline. "The Nicaraguans supplied the Japanese team members with maps produced with the help of the Soviet Union," Bourgeois recalled. "I had a set of maps produced by the U.S. government. The Nicaraguan set was more up to date from on-the-ground data because of cooperation between the Sandinista government and the USSR. We joked that the two sets were 'KGB' and 'CIA.'"

Nonetheless, she noted that both sets of maps ultimately had issues with accuracy. One survey team member did have a GPS: It "was not very accurate, but then, neither were the maps," Bourgeois said.

Results from the First ITST Survey

The ITST conducted its survey along more than 250 kilometers of the Nicaraguan coast. It determined the largest wave runups to be along the coast of central Nicaragua. The tsunami reached a height of 9.9 meters at El Tránsito (not 15 meters as reported in newspapers), decreasing to the north and remaining at 6–8 meters south to Bahía Marsella (Figure 1). These runup locations are stored in the NOAA National Centers for Environmental Information (NCEI)/World Data Service (WDS) Global Historical Tsunami Database [*NCEI/WDS*, 2017].

At El Tránsito, 80% of the buildings were swept away. Walls of water were reported at Masachapa, Pochomil, and San Juan del Sur, all of which have shallow ocean depths near the coast. "I was floored by the damage," reflects Bourgeois. "I was impressed with how building structure had a lot to do with tsunami resilience. Open lower floors and houses with breezeways perpendicular to the beach could survive where other houses were obliterated. It wasn't until I returned in February 1993, though, that I realized that some places where I had seen foundations had actually been standing houses before the tsunami."

Costa Rica also experienced some tsunami damage, and the ITST sent a small group to survey the area. The group faced many challenges, including transport and border

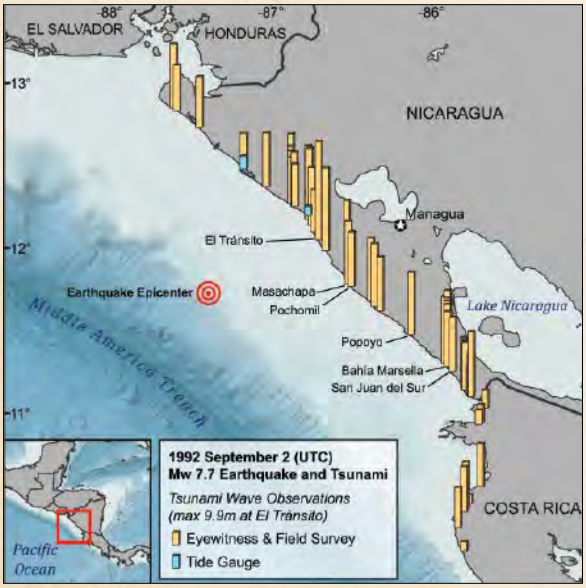

Fig. 1. Tsunami wave observations from the 1 September 1992 Nicaragua earthquake and tsunami along the coasts of Nicaragua and Costa Rica. The length of bars indicates the relative runup height of the tsunami, with the maximum height of nearly 10 meters observed at El Tránsito, Nicaragua. Data were pulled from the NCEI/WDS Global Historical Tsunami Database. Credit: NCEI

It was the beginning of communication among tsunami scientists through the Internet.

crossings that were open irregularly, but they managed to collect and report the data.

An Early Example of a Listserv

After the tsunami, Gonzalez and his team at PMEL developed what is now considered an Internet listserv. The forum, then called the Nicaragua Bulletin Board (or Tsu-Nica), was used to exchange data and manuscripts.

Although these forums are common today, such a listserv was groundbreaking at the time. "It was the beginning of communication among tsunami scientists through the Internet," Satake said.

This listserv continues today, now called the Tsunami Bulletin Board (TBB). Since 1995, the service has been hosted by the NOAA International Tsunami Information Center (ITIC). The TBB continues to be the main platform for sharing tsunami event information and coordinating post-tsunami surveys. Of course, Tsu-Nica did not solve all coordination and data-sharing problems, but it was an important first step.

Development of a Post-Tsunami Survey Field Guide

Three years later, in June 1995, tsunami scientists from 10 countries participated in an International Tsunami Measurements workshop in Estes Park, Colo. This workshop started the development of a post-tsunami survey manual to provide guidance on conducting a survey, including logistics, techniques, and challenges.

In 1998, ITIC and the United Nations Educational, Scientific and Cultural Organization's Intergovernmental Oceanographic Commission (IOC) published the first edition of the *Post-Tsunami Survey Field Guide* using experience gained from the Nicaragua ITST [*IOC*, 1998]. Much of the guidance included was based on the work of the first ITST in Nicaragua. For example, Japanese scientists "had a questionnaire which became the basis for future questionnaires," noted Bourgeois, who attended the 1995 workshop.

As the years passed, many scientists contributed to updating the guide, using their experiences from many events. These events include the 2004 Indian Ocean, 2007 Solomon Islands, 2009 Samoa, 2010 Chile, and 2011 Japan tsunamis.

The Legacy of the First Survey

The 1992 ITST focused on collecting water height, maximum inundation, and runup data. In the 25 years since that first survey, much has evolved. Bourgeois was the only sedimentary geologist on the 1992 ITST, but now post-tsunami surveys regularly survey geologic effects (e.g., deposits and erosion) of tsunamis. Social scientists, economists, ecologists, and engineers are now commonly involved in ITSTs. In addition, scientists are gathering eyewitness accounts from those who remember tsunamis that occurred in their childhoods, before modern instrumentation. All these efforts help communities better understand their long-term hazards.

Reflecting on surveys then and now, Gonzalez remarked, “the tsunami community is now much more professionally diverse: not only engineers and oceanographers, but biologists, social scientists, etc. This is as it should be. Tsunamis know no borders, and no single profession can span all tsunami causes and effects.”

Since 1992, ITSTs have documented a total of 33 tsunami events in the Pacific and Indian oceans and the Caribbean and Mediterranean seas (Figure 2) [*IOC*, 2014]. To ensure easy access to data, the number of deaths, injuries, economic losses, and buildings damaged reported by ITSTs are now collected in the NCEI/WDS Global Historical Tsunami Database.

In short, from scrappy beginnings, a robust, coordinated post-tsunami survey system has emerged.

From Tragedy to Inspiration

The 1992 Nicaragua earthquake and tsunami were tragic events for the people of this Central American country. They brought to focus research on tsunami earthquakes, which remain a “blind spot on local tsunami warnings,” Satake noted. Through the earthquake’s analysis and first ever ITST, scientists took the first steps toward understanding these dangerous events.

From this tragedy, many new systems have grown. The event led to the creation of a national tsunami warning system in Nicaragua, and it planted the seeds of the new Central American Tsunami Advisory Centre (CATAC), a project under development with Japanese support and hosted by Nicaragua’s INETER.

But perhaps the most enduring legacy of the 1992 Nicaragua earthquake and tsunami is their impact on how we now survey tsunamis. Post-tsunami surveys are now coordinated, interdisciplinary, international efforts. In some cases, the affected country may even request that IOC and ITIC assist coordination efforts. The collection of perishable tsunami data has benefited from improved measurement capabilities (e.g., differential GPS and integrated laser range finders), leading to a better understanding of tsunamis. Moreover, the ITSTs have underscored to researchers the importance and duty of sharing data with one another through emerging technologies.

Better hazard management stems from coordinated scientific focus. The events 25 years ago in Nicaragua demonstrate this and serve as an enduring example of how collaboration yields information that may ultimately save lives.

A resident assesses damage in San Juan del Sur, Nicaragua, days after the 1 September 1992 tsunami. Credit: Wilfried Strauch/INETER

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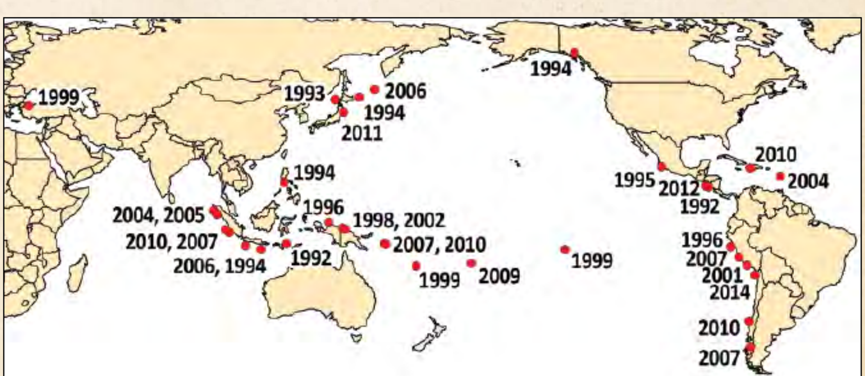

Fig. 2. Spatial distribution and dates of ITSTs. Credit: NCEI

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Diversifying the Reviewer Pool

Since the publication this past January of a study showing underrepresentation of women as reviewers of papers submitted to AGU journals, our organization has taken multiple steps to address issues of diversity and bias in peer review. AGU has been striving to deepen its understanding of disparities in its review process related to such factors as gender, age, and geographic location and to explore ways to counteract those biases.

The conclusions of the study, conducted by the authors of this article and published in *Nature*, were that women were being used less as reviewers in nearly all age groups compared to expectations based on their higher success rates as authors and their distribution with age in the AGU membership (see http://bit.ly/invite-too-few). This bias began with author suggestions and persisted through invitations from editors. It was exacerbated by a higher decline rate among women in the younger age cohorts.

Along with those findings of gender bias in peer review, overall data clearly show that AGU needs to engage more younger scientists and more scientists from Asia and Africa in reviewing. AGU recruits a large proportion of its reviewers from the United States, Canada, and Europe, whereas accepted authors reside roughly equally in North America, Europe, and Asia.

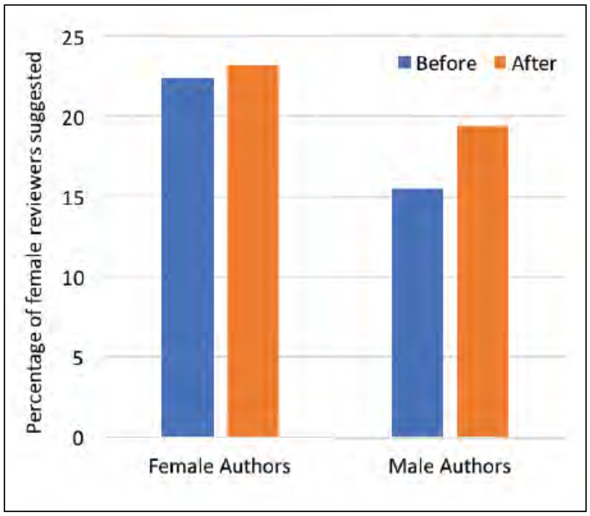


Fig. 1. Change in gender distribution of reviewers suggested by corresponding authors (male and female) who submitted papers to Geophysical Research Letters *(*GRL*) before and after 1 April 2017. On that date,* GRL *introduced its reminder statement regarding diversity. The before data are from 2,893 matched reviewers; the after data are from 2,732 matched reviewers.*

Action and Results

Since we began to analyze the data for the *Nature* study, we have been discussing these issues with AGU journal editors and editorial boards. In turn, the society's editors in chief have worked to expand diversity on their teams (both editors and associate editors) and to discuss the larger bias among peer reviewers.

This past spring, we also conducted an experiment in explicitly encouraging authors to recommend diverse reviewers. On 1 April 2017, with the support of the editors of our largest journal, *Geophysical Research Letters* (*GRL*), we added a note to the *GRL* submission form that asked authors to help the journal improve the diversity of its reviewer pool by including women, young scientists, and members of other underrepresented groups in their lists of suggested reviewers.

We have now analyzed the results from that experiment and found that with regard to gender diversity, this simple step had a salutary effect.

Figure 1, which shows the percentage of female reviewers suggested by authors in the 3 months before and after this note was included, reveals that gender diversity increased significantly. A comparison with data across all other AGU journals rules out other factors in producing this change, such as awareness of our study published in January 2017.

Given the success of the recent test, we will now be including the statement, which is quoted in its entirety below, across all our journals, not only in the instructions for authors but also as a reminder to the editors when they select reviewers.

The statement will read as follows (as it did on the *GRL* site):

Evaluation of our journals' peer review practices suggests that women were less likely than men to be asked to review. Please help us improve the diversity of our reviewer pool by including women, young scientists, and members of other underrepresented groups in your suggested reviewers (e.g., age, ethnic, and international diversity).

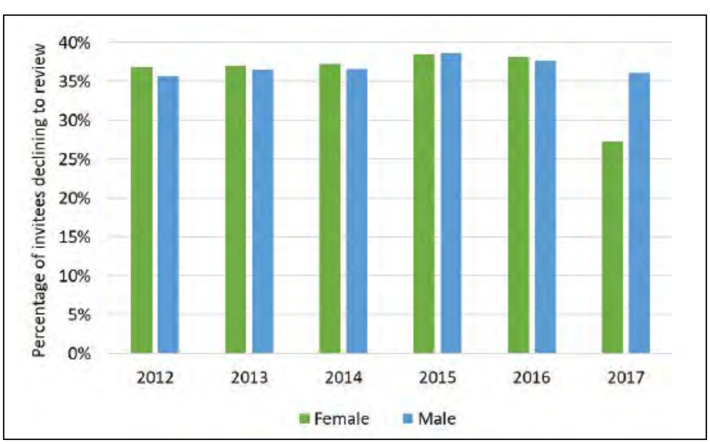


Fig. 2. Percentage of researchers by gender declining an invitation to review a paper in an AGU journal from January 2012 through June 2017.

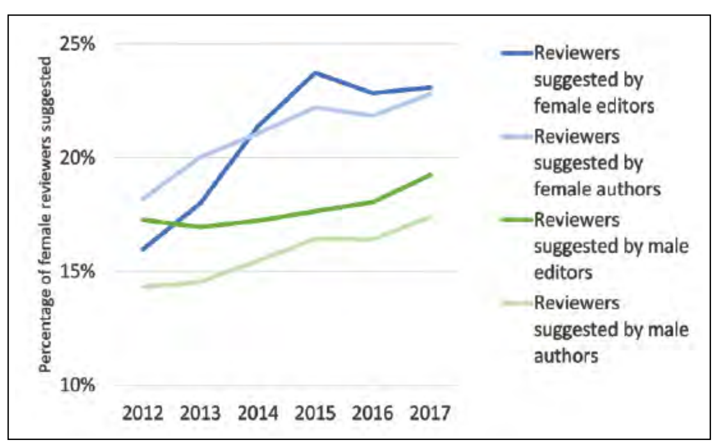


Fig. 3. Percentage of female reviewers suggested by four different author or editor cohorts for all papers submitted to all AGU journals from January 2012 through June 2017.

Other data show a marked increase in the acceptance of the invitation to review, especially by women in 2017 to date, as shown in Figure 2. This increase likely reflects a broader awareness of this issue prompted by our *Nature* paper, as well as our conference presentations about that study and other coverage of its findings. In that study, we merged information on age and gender from AGU membership data with editorial data on authors and reviewers. This provided a large sample of activities and allowed accounting for age in exploring bias.

AGU journals continue to expand the gender diversity of our reviewer pool.

More Work to Do

As shown in Figure 3, AGU journals continue overall to expand the gender diversity of our reviewer pool.

Although the gender diversity of reviewers has improved, the data for 2017 indicate that the *GRL* reminder statement so far has not led to a significant change in recruiting reviewers for that journal who are younger or from countries outside North America and western Europe. Thus, there is more work to do.

To help, AGU editors have been conducting international workshops on reviewing, including recently at the International Geological Congress meeting in Cape Town, South Africa, and the Japan Geoscience Union–AGU meeting in Chiba, outside of Tokyo, and in visits to universities and research institutions in China. AGU Publications has also conducted several webinars on reviewing, including the most recent one, "How to Write Effective Reviews (and Improve Your Own Manuscript)," and will expand these efforts further. (Watch the webinar at http://bit.ly/reviewing-webinar.)

AGU will continue to collect and report data on reviewer diversity in its scientific publishing and provide regular updates. We hope that these results encourage other journals and publishers to take more direct efforts to expand and diversify the reviewer pool.

By **Brooks Hanson** (email: bhanson@agu.org), Senior Vice President, Publications, AGU; and **Jory Lerback,** Data Analyst, Publications, AGU; now at Department of Geology and Geophysics, University of Utah, Salt Lake City

New Earth and Space Science Preprint Server to Be Launched

AGU and Atypon, a developer of online scholarly publishing tools, have announced a joint initiative to develop a community server for the open dissemination of Earth and space science preprints and conference presentations. The partners have named this new server the Earth and Space Science Open Archive (ESSOAr).

Research results can quickly gain broad distribution and peer feedback prior to formal publication through preprint servers. The upcoming debut of a new server aims to make these benefits available to the Earth and space science community. Credit: Fabian Irsara

Preprint servers allow researchers to receive peer feedback prior to formal publication of results. They also facilitate faster, more open dissemination of research. More than 50,000 posters are presented each year across Earth and space science conferences, including about 17,000 at the AGU Fall Meeting. Preserving them will greatly increase scientific transparency.

"Our interest and involvement in the ESSOAr initiative reflects our corporate commitment to open science," said Georgios Papadopoulos, Atypon's founder and CEO. "Offering preprint capabilities to support researchers' editorial needs is a natural extension of our core platform."

The ESSOAr effort, including development of the server, community engagement, and policies and practices, will be guided by an international advisory board, which currently includes representatives of the Association for the Sciences of Limnology and Oceanography, Earth Science Information Partners, European Geosciences Union, Geochemical Society, Geological Society of America (GSA), Japan Geoscience Union (JpGU), and Society of Exploration Geophysicists. Initial development will be supported by AGU's publishing partner, Wiley, which owns Atypon. AGU hopes that other Earth and space science societies and scholarly publishers will join this effort.

Researchers can preserve and make citable content from scientific conferences on preprint servers, thus extending the traditional role of archiving manuscripts.

Research outputs posted on preprint servers are fully citable via a digital object identifier (DOI) and are freely accessible. Researchers can preserve and make citable presentations, posters, and related multimedia content from scientific conferences on preprint servers, thus extending the traditional role of archiving manuscripts.

"GSA is pleased to participate in this advisory group to explore all the options for preprint publications," said Vicki McConnell, executive director of GSA.

Kiyoshi Suyehiro, international program coordinator at JpGU, added, "We appreciate the opportunity to learn about and guide a larger effort around developing preprint options for our community."

The ESSOAr preprint server will begin accepting content in 2018.

By **Chris McEntee** (email: agu_execdirector@agu.org), Executive Director/CEO, AGU

AGU Revises Its Integrity and Ethics Policy

Olivier Le Moal/iStock/Getty Images Plus

The AGU Board of Directors has approved changes to the AGU Scientific Integrity and Professional Ethics Policy. The revisions adopted on 14 September were made in response to a June 2016 decision by AGU leadership, under then AGU president Margaret Leinen, to form a task force to review the organization's ethics policy and practices in the wake of high-profile cases alleging sexual harassment in science.

The updated policy is intended to address ongoing issues within the Earth and space science community that have a profound impact in the workplace and on scientists' individual lives and careers. It is the result of the 18-member task force's efforts over the past year.

New Standards and Expectations

Most notable, changes to the policy include identifying as scientific misconduct harassment, discrimination, and bullying in scientific endeavors. The previous ethics policy was silent on code of conduct expectations for AGU members related to the issue of harassment.

Further, the new policy extends to all AGU members, as well as staff, volunteers, contractors, and nonmembers who participate in AGU programs. The policy is aspirational in setting standards for scientific integrity and professional ethics in the Earth and space science community, but it also establishes mechanisms that allow for the imposition of sanctions to deal with breaches of the AGU ethics policy. As the updated policy states, "When an allegation of misconduct involves activity that is against the U.S. code of law, or code of law in other respective regions, AGU will work with all appropriate authorities as needed and required to resolve the allegation."

Changes to the policy include identifying as scientific misconduct harassment, discrimination, and bullying in scientific endeavors.

Key provisions of this updated policy include

- AGU leadership's affirmation of the international principle that the free, open, and responsible practice of science is fundamental to scientific advancement and human and environmental well-being
- a definition of scientific misconduct that includes conduct toward others
- definitions of discrimination, harassment (including sexual harassment), and bullying
- a higher standard for AGU volunteer leader conduct
- the extension of the AGU ethics policy to cover participants in all AGU program activities, including honors and awards and AGU governance
- self-reporting requirements for recipients of AGU awards and honors and for candidates for AGU's elected positions
- ethical guidelines for publication of scientific research
- ethical guidelines for student-adviser relationships
- a clear and detailed process for reporting and investigating scientific misconduct
- a description of support mechanisms for issues that may not rise to the level of a formal ethics complaint

The initial draft of the ethics policy revisions was open for AGU member review and comment in March 2017. During the comment period, many constructive responses were received and incorporated into the final version.

A Stepping-Stone Toward Further Efforts

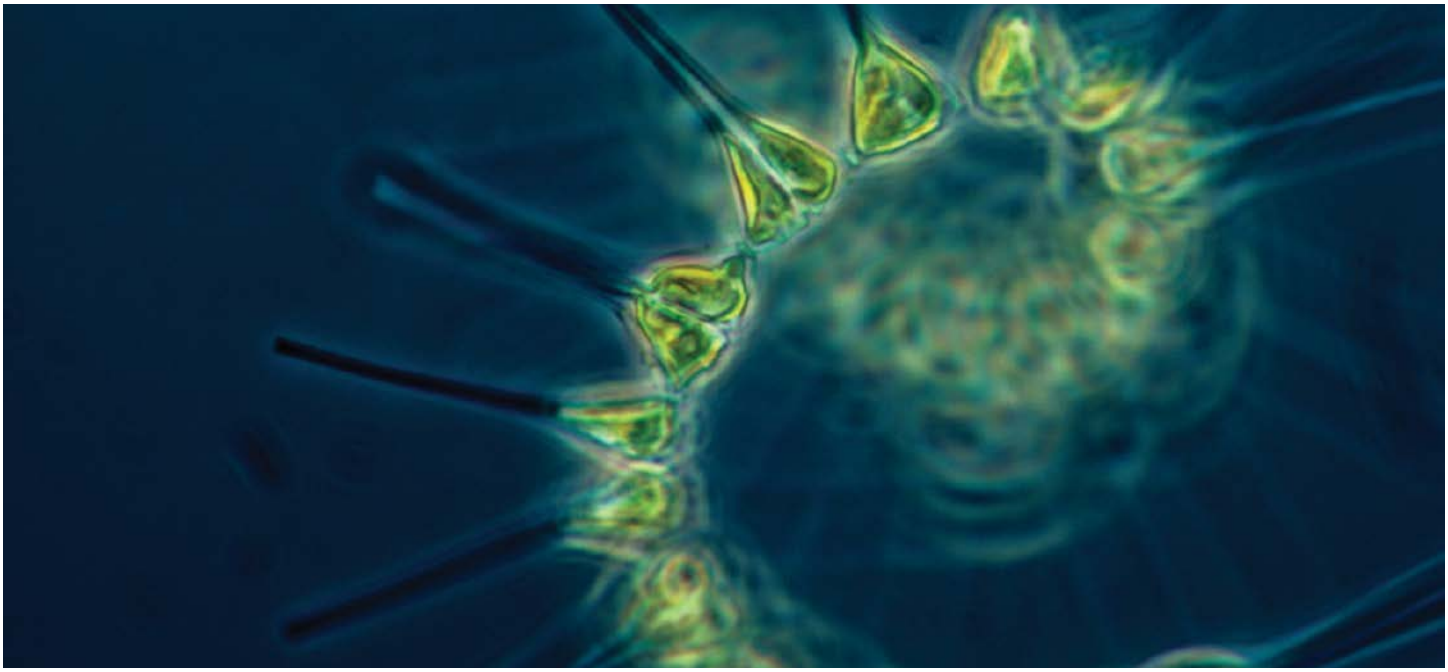
AGU is not alone in its efforts to expand research misconduct to include harassment. In September 2016, Celeste Rohlfing, chief operating officer of the American Association for the Advancement of Science (AAAS), proposed that federal agencies do the same. That same month, AGU was joined by cosponsoring organizations, including AAAS, the American Chemical Society, the American Geosciences Institute, the Association for Women Geoscientists, and the Earth Science Women's Network, in hosting a workshop entitled "Sexual Harassment in the Sciences: A Call to Respond." The National Science Foundation funded the event.

As it rolls out the new policy, AGU is providing additional educational resources to help foster the change in culture needed to eliminate harassment in the Earth and space science community.

For further information regarding the revised ethics policy, please read the 15 September *From the Prow* blog post by AGU's president, Eric Davidson; president-elect, Robin Bell; and immediate past president, Margaret Leinen (see http://bit.ly/FTP-post). You can review the updated policy and associated AGU antiharassment educational resources at http://bit.ly/harass-site.

By **Michael J. McPhaden** (email: ethics@agu.org), Chair, Task Force on Scientific Ethics, AGU; **Linda Gundersen,** Member, Task Force on Scientific Ethics, AGU; and **Billy M. Williams,** Vice President, Ethics, Diversity, and Inclusion, AGU

World's Greatest Oxygen Producers Living in Swirling Ocean Waters



Phytoplankton, including the Asterionellopsis glacialis *seen here, are microscopic marine plants that produce roughly 80% of the world's oxygen. Credit: NOAA*

Plankton are not just one species of sea creature but, rather, a large variety of tiny organisms. Algae, bacteria, crustaceans, mollusks, and more are all considered plankton. What sets them apart from other organisms is how they move. Their extremely small size precludes them from swimming against ocean currents, so they drift.

Plankton may be small, but these tiny drifters play a huge role in aquatic ecosystems. Many animals, including whales, rely on them for food. Plankton that are plants, known as phytoplankton, grow and get their own energy through photosynthesis and are responsible for producing an estimated 80% of the world's oxygen. Climate scientists are interested in learning more about phytoplankton because of the role they play in oxygen production, as well as in carbon sequestration.

A recent study conducted by *Bosse et al.* demonstrated how powerful winter storms create oceanic structures that can affect the distribution of nutrients to phytoplankton communities, as well as the organisms' ability to produce and store carbon. These oceanic structures, called submesoscale coherent vortices, or SCVs, are isolated, long-lasting types of eddies (swirling seawater) that typically flow in the direction opposite of Earth's rotation.

In June 2013, the researchers examined an SCV in the Ligurian Sea, a basin of the Mediterranean touching both Italy and France, that was formed several months earlier by a major winter mixing event caused by severe storms. They used an autonomous glider—a drone—equipped with sensors to detect oxygen and fluorescence, a stealthy property of many underwater creatures that allows them to absorb light at one wavelength, or color, and re-emit it at another wavelength to avoid detection.

They then supplemented the glider's measurements with data from an instrument, lowered from a ship, called a CTD, named after the properties its sensors detect: conductivity, temperature, and depth. They also collected water samples from within and outside the SCV, measuring levels of nutrients and phytoplankton pigments.

The team found that the core of the SCV (which traps and transports nutrients, plankton, and other living things) stretched vertically about half a kilometer to more than a kilometer across, below the sea surface. Consisting of highly uniform, oxygenated water, the core would have formed during the winter that preceded its summertime observation. The overall radius of the SCV, they found, was nearly 6.5 kilometers wide.

A kilometers-wide, swirling body of seawater might sound intimidating, but the SCV's radius was actually unusually small, considering it had a relatively high Rossby number (the measurement of a fluid's flow intensity). The researchers think that rotation sets up dynamical barriers, which control the transport and mixing of water properties within eddies. These barriers hampered the ability of water to spread out from the SCV's core to the surrounding ocean.

Although the core of the SCV was fairly depleted of such nutrients as nitrate, phosphate, and silicate (13%–18% lower than the nutrient-rich surrounding waters), there were more than enough to keep phytoplankton well fed, especially toward the sea surface. The team's measurements show that phytoplankton, and even the tiniest nanoplankton, not only were plentiful inside the SCV but also were producing more carbon than ever.

By diving into the dynamics of this SCV, the researchers were able to show how these meteorological phenomena provide a place for phytoplankton to thrive. Such information helps scientists better understand the tiny critters that play a critical role in Earth's changing climate. (*Journal of Geophysical Research: Oceans*, https://doi.org/10.1002/2016JC012634, 2017) **—Sarah Witman, Freelance Writer**

Improving Water Resources Management from the Ground Up

We might not always think about it, but the water that quenches our thirst, flushes away our waste, waters our lawns—and so much more—first flows through a complex system designed to be as efficient, sustainable, and useful as possible. To manage water resources effectively, urban planners must have the best available data.

These days, satellites can provide a wealth of hydrologic data by remotely sensing conditions on Earth's surface. However, this technology has not yet replaced data collected on the ground using rain and stream gauges. Although data from ground-based sensors cover much smaller areas, they are often highly accurate and can be used to verify satellite data.

The World Meteorological Organization has provided a set of brief guidelines for the minimum number of stations needed to shield ground-based hydrologic data collection from the most serious gaps. In a new study, *Keum and Coulibaly* expand upon these guidelines in a major way by developing an algorithm that determines the optimal locations of rain and stream gauges simultaneously, in part to help preserve a shrinking pool of available funds for science worldwide.

In nature, rainfall has a major impact on the amount of water flowing in a stream at a given time, known as streamflow. However, rainfall and streamflow measurements are often considered independent of one another. To more accurately reflect the natural environment, the team's algorithm seamlessly bridges the gap between the two monitoring networks.

A stream gauge along the Merced River in Yosemite National Park in California measures the daily discharge of water. Credit: Alex Demas, USGS

The researchers also developed a theoretical framework to better examine each set of data and to precisely understand the information that the rain gauge data are providing about streamflow.

This study is a major leap forward for the field of hydrology, as it will allow scientists to identify the most needed rain and stream gauges and pinpoint where additional gauges should be added. This information will help optimize funds and lead to more effective water resources management. (*Water Resources Research,* https://doi.org/10.1002/2016WR019981, 2017) **—Sarah Witman, Freelance Writer**

Revising an Innovative Way to Study Cascadia Megaquakes

Along the west coast of North America, the Cascadia subduction zone stretches more than 1,000 kilometers from Vancouver Island to Cape Mendocino, Calif. It produced a magnitude 9 megathrust earthquake about 300 years ago, one of the biggest quakes in world history.

Scientists know that Cascadia will produce another earthquake at some point in the future; the question is how soon. The odds of it happening in the next 50 years are 1 in 3. The Federal Emergency Management Agency projects that Cascadia's next megathrust earthquake will cause thousands of deaths and injuries and leave millions in need of shelter, food, and water.

To better understand subduction zones, scientists often study the thermal environments of material that has been pushed up onto the surface during past earthquakes. This buildup of material, called an accretionary wedge, might consist of rock, soil, sand, shells, or any other kind of debris. These wedges also sport subtly different average temperatures at various depths, compared with material located off the wedge.

In a recent study, *Salmi et al.* examined the thermal environment of the Cascadia subduction zone's accretionary wedge, which stretches for about 97 kilometers along the coast of the state of Washington. Their goal was to find out more about the physical changes of fluids and solids within the wedge, with the hope that the knowledge will help them better anticipate future earthquakes.

Using data collected on a cruise by the R/V *Marcus G. Langseth*, the researchers found significant variations in temperature within this section of the Cascadia subduction zone, as well as signs of gas hydrates (icelike deposits that form from natural gas at the bottom of the ocean) throughout the region. They also detected that most fluids from the deep move upward through the accretionary wedge instead of through the crust, which is different than in most other subduction zones. This change in fluid pathway prevents the plate from cooling and reduces the area where an earthquake might rupture along the two plates to completely within the accretionary wedge rather than under the continental plate.

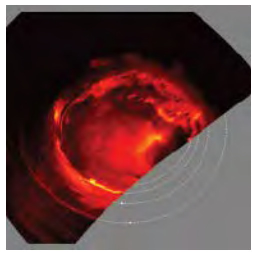
This is the first study to concentrate on the southern Washington margin alone, rather than the subduction zone as a whole, revealing the influence of fluid distribution on local, small-scale temperature variability. This insight opens the door to further research into how local temperature variability might interact with other factors, like stress or fault roughness, to affect earthquake hazards. Overall, this study provides a revised method for probing the thermal environment of an accretionary wedge, a crucial link to the cause of ruptures in Earth's crust that can lead to earthquakes and tsunamis.

By understanding these mechanisms more fully, scientists can tell us more about how to prepare for the smallest of tremors and the largest of megaquakes. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2016JB013839, 2017) **—Sarah Witman, Freelance Writer**

Juno Gets Spectacular View of Jupiter's Aurora

Since arriving at Jupiter in the summer of 2016, NASA's Juno probe has been exploring the giant planet's environment, capturing amazing vistas of its swirling bands and taking measurements of its atmosphere, interior, and magnetic field.

Now *Mura et al.* have published an analysis of infrared images of Jupiter's impressive auroras, captured by Juno as it made its first flyby of the planet on 27 August 2016. These images reveal that the auroral ovals ringing the poles are made up of multiple intense arcs within, giving clues about the structure of currents running through Jupiter's magnetosphere. They also capture a long auroral "tail" caused by Jupiter's moon Io and its unique magnetic influence within the Jovian system.



Infrared emission from the southern aurora taken on 27 August 2016. White dashed lines are the projection of the trajectories of moons along the magnetic field lines ("footprints"), from which additional signal is emitted. Credit: Mura et al. *[2017]*

Like those at Earth, Jupiter's auroras are caused by energetic charged particles being channeled along the planet's magnetic field to the poles. When struck by the charged particles, atmospheric molecules glow, forming a dynamic oval around the planet's poles. But unlike at Earth, where the most spectacular auroral displays are driven by particles from the solar wind streaming into Earth's magnetic field, Jupiter has its own local source of plasma: the volcanic moon Io, which spews sulfur dioxide gas into space.

As Io moves with respect to Jupiter, it acts as an obstacle to the plasma and magnetic field flow; this disturbance propagates back to Jupiter, traveling along the magnetic field lines as Alfvén waves. This propagation generates an additional auroral signature—a glowing spot called a "footprint" at the point where it enters the planet's atmosphere. As the planet rotates, the tube's end point drags across the surface of Jupiter, creating an auroral tail. The same thing happens at the moons Ganymede and Europa, but in a much weaker fashion because the source of the plasma is not volcanic activity but ice sublimating off the moons' surfaces.

These observations were carried out by an instrument on Juno called the Jovian Infrared Auroral Mapper (JIRAM), specifically designed to image the infrared auroral glow given off by molecular hydrogen. The mapper has captured dramatic images of Io's tail on Jupiter, 500 kilometers thick and extending a quarter of the way around the planet in longitude. Europa's and Ganymede's tails were also visible. The instantaneous footprints of Io and Europa were beyond the horizon, but future flybys should image them. That should prove helpful; because the footprints are magnetically connected via the flux tubes back to the moons, they can help map out the geometry of the planet's magnetic field.

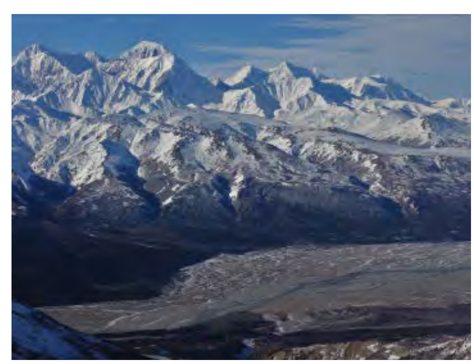
JIRAM's images also captured a detailed view of the main auroral oval, revealing that its structure is not uniform but banded, made up of several thin, nested arcs. This structure suggests that instead of one loop of current connecting the planet to its magnetic field, there may be several ribbons of current in a filamentary structure.

Juno also carries an ultraviolet spectrometer that has returned images published separately. Future studies will compare the imagery to learn more about the structure of the aurora in Jupiter's atmosphere. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL072954, 2017) **—Mark Zastrow, Freelance Writer**

Why Are Arctic Rivers Rising in Winter?

Alaska's glacier-fed, braided Tanana River is home to some of the world's highest-quality salmon fisheries, which have provided sustenance for humans for nearly 12,000 years. Like many Arctic rivers, however, the Tanana and its tributaries are changing because of rising global temperatures. One prominent change in recent decades is a steady rise in Arctic rivers' winter flow, which has long puzzled researchers because there is no commensurate increase in precipitation in the Tanana River watershed. Now a new study suggests that melting glaciers may drive this increased flow by amplifying headwater runoff, the water that drains the mountain region, which is partly lost to the underlying aquifer. In turn, the aquifer feeds the Tanana River year-round. Increased aquifer recharge due to glacier-fed stream corridors may also degrade permafrost from below, further amplifying the seasonal aquifer storage capacity and therefore lowland winter flows.

Liljedahl et al. conducted their study on Jarvis Creek, one of the Tanana's headwater streams. First, they obtained long-term meteorological records from the National Oceanic and Atmospheric Administration dating from 1947 to 2016, as well as more recent glacier mass balance, runoff, and groundwater levels for the watershed over time. The authors compared recent and historical glacier coverage maps of the area and found that glacier coverage in the Tanana River watershed had decreased by 12% during the 60-year period between 1950 and 2010. Glacier melt accounted for more than 15% of Jarvis Creek's total annual streamflow, with roughly 46% of that water seeping into the ground and refilling the aquifer below as determined by runoff measurements located 55 kilometers apart. Of note was that the size of the glacier cover was not linearly related to how much runoff it produces. In nearby Phelan Creek, for example, which had 20 times more glacial coverage in its watershed than Jarvis Creek, the glaciers contributed about 47% of annual mean runoff. The nonlinear relationship between glacier cover and runoff has been noted in previous studies of watersheds in the Alps, but the drier Arctic climate may make this disconnect more significant.



The Delta River on the north slope of the eastern Alaska Range. The river is fed by the Jarvis Creek watershed and drains into the Tanana River. Credit: Tiffany Gatesman

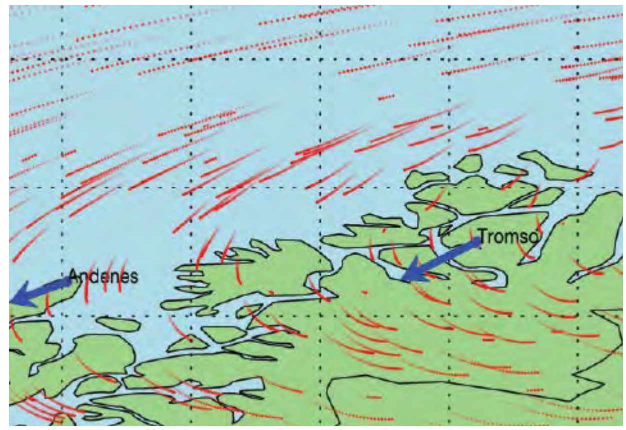
Increased glacier-derived groundwater recharge via the headwater stream corridors could explain why winter flows are up in other glacierized Arctic rivers as well, according to the authors. A natural next step would be to explore the role of shrinkage in other large Arctic glaciers. Understanding the role of mountain glaciers and long-term glacier loss is important because even small increases in freshwater runoff could affect sea ice growth, ocean circulation, river ice thinning, and the development of salmon eggs and embryos. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL073834, 2017) **—Emily Underwood, Freelance Writer**

Tracking Meteor Trails to Study the Mesosphere

The mesosphere is one of the most mysterious layers of our planet's atmosphere. Hovering between 50 and 85 kilometers above Earth, it is too high for aircraft to reach and too low for satellites to orbit in. To study its cold, thin air, scientists usually launch sounding rockets that take a sample, then fall back to Earth. Now, however, researchers have achieved the first on-the-ground measurement of mesospheric wind fields, using radar that detects falling meteor trails.

Most meteors burn up when they hit the mesosphere, creating the streaks of light we call shooting stars. They also leave a trail of vaporized atoms and free electrons that move with the wind. To learn more about mesospheric wind field patterns, *Chau et al.* used a new approach, combining a technology called specular meteor radar—which bounces high-frequency waves off the comet trails—with a tomographic approach.

Scientists have been using specular meteor radar to study movements in the mesosphere for more than a decade but without identifying the small-scale variations within the relatively large volume of air. The new study combines 12 years of data from the Andenes and Tromsø radar instruments, located 130 kilometers apart in northern Norway. Their combined radar data encompass a region roughly 400 kilometers across and 20 kilometers in altitude.



Sketch of wind fields (in red) derived from meteors hitting the mesosphere over northern Norway. Mean winds obtained with previous techniques are shown in blue for comparison. Credit: Jorge Chau

The data revealed a previously undetected pattern. During summer, the large, swirling vortices that form in the mesosphere reversed their clockwise direction at an altitude of roughly 86 kilometers. The researchers also saw that these vortices are accompanied by pattern changes in the horizontal divergence—the extent to which air draws together or converges—and started spreading out around that altitude. The results suggest a fresh approach to measuring large-scale phenomena in this little-studied layer of the atmosphere. (*Radio Science*, https://doi.org/10.1002/2016RS006225, 2017) **—Emily Underwood, Freelance Writer**

A New Baseline to Monitor Earth's Dynamic Surface

Volcanic eruptions, continental drift, rising sea levels, earthquakes, floods, and other natural processes are ceaselessly reshaping Earth's surface. To measure these changes, scientists rely on a terrestrial reference frame—a collection of defined points around the globe that function as landmarks to help monitor the position of Earth's features.

The International Terrestrial Reference Frame (ITRF) serves as a standard for researchers around the globe, and it is updated every few years with newer, more precise details on how the reference points themselves are expected to drift. Meanwhile, scientists develop alternative terrestrial reference frames to try out and learn from new approaches.

In a new study, *Abbondanza et al.* present an alternative terrestrial reference frame called JTRF2014 (the J is for the Jet Propulsion Laboratory in Pasadena, Calif.) and compare it with ITRF2014, the most recent version of ITRF. To develop JTRF2014, the research team used the same four types of space- and ground-based observations that underpin ITRF2014.

These four observation types come from four sources. In very long baseline interferometry, ground-based stations use signals from distant quasars to monitor Earth's orientation. Satellite laser ranging uses lasers to calculate the precise distance between a ground station and a satellite. The Doppler Orbitography and Radiopositioning Integrated by Satellite system makes similar measurements using radio signals. The Global Navigation Satellite Systems use ground receivers to determine location on the basis of signals from satellites, including GPS satellites.

The mathematical approach used to combine data from these four sources is what sets JTRF2014 apart from ITRF2014. ITRF2014 catalogs the initial positions of ground stations and the velocities at which they move from those points. In contrast, JTRF2014 provides successive measurements—time series—of ground station positions, as determined by combining data from the four sources on a weekly basis.

JTRF2014 relies on a new tool developed by the researchers, known as the Kalman Filter for Terrestrial Reference Frame (KALREF) realization. KALREF incorporates a Kalman filter, an algorithm often used to produce estimates based on time series data that contain some inaccuracies. Such an approach is well suited to the sometimes messy data provided by the four sources used here.

After developing JTRF2014, the team showed that its prediction estimates closely agree with ITRF2014. It also used JTRF2014 to predict how Earth's center of mass changes position as other features change, showing that these predictions align very closely with those made using other methods and data sources. Now the team is working to improve the performance of its KALREF tool. (*Journal of Geophysical Research: Solid Earth*, https://doi.org/10.1002/2017JB014360, 2017) **—Sarah Stanley, Freelance Writer**

Lightning Strikes May Leave Traces Like Those of Meteorites

Amid a summer storm, a powerful lightning bolt strikes Mellieħa, Malta. Billions of lightning strikes occur annually on land, leaving fulgurites on sands, soils, rocks, and sometimes human-made monuments. Credit: Owen Zammit, CC BY-SA 2.0 (http://bit.ly/ccbysa2-0)

When a meteorite strikes a rock, it triggers rapid changes in pressure and temperature that alter the rock's structure. Scientists traditionally have treated microscopic planar deformation features in quartz crystals as a telltale sign of past meteorite impacts. However, recent research has demonstrated that lightning strikes can also leave similar signatures of shock.

In a new paper, *Chen et al.* mathematically simulate a lightning strike on a granite surface. They demonstrate that the resulting changes in the rock are a fingerprint of the energy and intensity levels of the lightning that caused them. More specifically, they demonstrate that shock features in quartz are created by the intense shock wave associated with the lightning strike. The results suggest that shocked quartz should not be interpreted as certain evidence of past meteorite impacts.

Scientists have known for decades that lightning can rapidly heat rock to more than 2,000 K near the strike point. Organic material on the surface burns off, and part of the rock itself melts almost instantaneously, later cooling to form a glassy surface layer called a fulgurite. It wasn't until 2015 that researchers discovered shocked quartz in the granite substrate of a fulgurite.

In the new study, the research team developed a mathematical model to estimate the pressure exerted by a lightning strike on a granite surface, as well as the rapid heating and cooling of the rock. The model incorporated physical characteristics of lightning and granite, such as the typical temperature of lightning, the melting temperature of granite, and the temperature at which organic material on the granite surface would likely burn.

The simulations showed that a lightning strike can impart more than 7 gigapascals of pressure on the granite surface, enough to trigger the formation of shocked quartz. The strike creates a roughly circular layer of fulgurite about 18 centimeters across within a slightly wider region of burned organic material about 22 centimeters across.

These results are consistent with observations of fulgurite samples collected from field sites. For example, fulgurites collected from Mount Mottarone in Italy have regions of burned organic matter that are of similar size, roughly 20 centimeters across. Fulgurites from Les Pradals in France feature shocked quartz in a surficial layer less than 3 micrometers thick, consistent with the pressure calculations in the lightning strike model.

With this discovery, additional evidence will likely now be needed to convince impact geologists that shocked quartz indicates a past meteorite impact. Furthermore, these findings could help explain confusing occurrences of higher than expected impact rates, according to evidence for shocked quartz, in some regions. (*Geophysical Research Letters*, https://doi.org/10.1002/2017GL073843, 2017)

—Sarah Stanley, Freelance Writer

Geochemistry

Geochemistry Specialist (368953), Aramco Services Company

Aramco Services Company is seeking a Geochemistry Specialist to conduct research and technology development in the area of inorganic and/or organic geochemistry. Located at the Aramco Research Center in Houston, the candidate will use their broad knowledge and experience in geochemistry to guide and perform research related to areas including but not limited to: quantitative reservoir quality assessment, diagenesis, source rocks and hydrocarbon system evaluation. Qualified candidates will have 3-5 years related work experience, including geochemistry applications in clastic and carbonate settings. They will have expertise in laboratory procedures and be competent in quantitative geochemical analyses as well as geochemical modeling software. Knowledge of established industry practices and current, leading-edge research in geochemistry is expected. Supplementary knowledge of computer programming, 3D printing methods and materials science is strongly desired. Research accomplishments will be supported by engagement across multidisciplinary teams delivering forefront technology for the upstream of Saudi Aramco while shaping future geochemistry research programs. As such, the position offers an excellent avenue for an early career geochemist to grow as a technical leader with strong opportunities to publish while broadening industry experience.

Apply here: http://www.aramcoservices.com/Careers

Global Environmental Change

Tenure-Track Faculty Position in Climate Change and Earth System Modeling – Vanderbilt University

Vanderbilt University and the Department of Earth and Environmental Sciences has a strong institutional commitment to recruiting and retaining an academically and culturally diverse community of faculty. Minorities, women, individuals with disabilities, and members of other underrepresented groups, in particular, are encouraged to apply. Vanderbilt is an Equal Opportunity/Affirmative Action employer.

This faculty position presents an opportunity to join a productive and collegial department at a highly-ranked R1-research university. We seek an individual aimed at the highest standards of scholarship in research and teaching at both the undergraduate and graduate (MS, PhD) levels, and who would be drawn to interact with a diverse, interdisciplinary faculty and student body in the Earth and Environmental Sciences and related fields. The position is effective for the Fall 2018 semester at the Assistant Professor level. The successful candidate will have completed the PhD by August 16, 2018.

The desired concentration of study centers on climate change and/or internal modes of climate variability that operate at inter-annual to millennial time scales and at synoptic to planetary spatial scales. Study areas could also involve related biogeochemical cycles and/or the water cycle. A strong foundation in climate modeling or earth system modeling is preferred, as well as interest or experience with both modern and ancient systems.

Applications should include a vita, a statement of research and teaching interests specific to our program, and names of at least three references (including mail and e-mail addresses and phone numbers). Select applicants will later be asked to provide student evaluations of teaching, if available. Applications should be submitted online via Interfolio at http://apply.interfolio.com/44162. Contact FacultySearchVU_EES@vanderbilt.edu for more information. Applicants can meet with VU Faculty at Exhibit Both # 909. The review of files will begin in middle December, 2017 with a final closing date of January 7, 2018.

Vanderbilt University is located in Nashville, Tennessee, a thriving state-capital city that enjoys a moderate climate, excellent parks and natural areas, a strong and varied economy, ample, and diverse food, music, and cultural opportunities.

Hydrology

Hydrology and Water Resources, Assistant/Associate Professor

The University of Nevada, Las Vegas Geoscience Department seeks to recruit an Assistant or Associate Professor in the field of Hydrology and Water Resources [18545] as a tenure-track or tenured appointment. The successful candidate is expected to develop (Assistant-level), or expand upon (Associate-level) a rigorous, externally funded research program, supervise graduate students at both the master's and doctoral levels, and teach both graduate and undergraduate classes. Preference will be given to applicants with research interests in one or more of the following sub-disciplines: hydroclimatology; interactions among groundwater, surface water and atmosphere; hydrogeochemistry; innovative means of characterizing water resources; and/or ecohydrology and geobiologic impacts on water resources. Research approaches may include analytical, numerical, field, remote sensing and/

Columbia University
in the City of New York

Faculty Position in Experimental Earth Science

The Department of Earth and Environmental Sciences at Columbia University seeks applicants for a tenure-track Assistant Professor position with expertise in experimental laboratory approaches to understanding Earth materials and processes. We are open to a broad set of research topics relating to the application of chemical thermodynamics and reaction kinetics over a wide range of conditions, from the Earth's surface to its interior. The ideal candidate will conduct research that complements existing and strategic priorities of the Department of Earth and Environmental Sciences, Lamont Doherty Earth Observatory, and Columbia University, including but not exclusive to: carbon capture and storage and other climate solutions, magmatic and volcanic processes, hydrothermal systems, marine and environmental geochemistry, fluid-rock interaction, climate-life-solid-earth interactions, and natural resources.

The successful applicant is expected to develop a high-impact research program at LDEO, Palisades, NY, and demonstrate potential for strong teaching abilities at undergraduate and graduate levels. Applicants should submit a cover letter, CV, statements of teaching and research interests, and names of at least 3 references using our online site:

https://academicjobs.columbia.edu/applicants/Central?quickFind=65446

Review of applications will commence on December 18, 2017 and continue until the position is filled. Columbia University is an Equal Opportunity/Affirmative Action employer, dedicated to the goal of teaching and working in a diverse environment. We strongly encourage applications from women and underrepresented groups.

CLUSTER HIRING IN
GEO-BIOINFORMATICS/ENVIRONMENTAL
GENOMICS AND ORGANIC BIOGEOCHEMISTRY

The Southern University of Science and Technology (SUSTech) was founded in 2011 with public funding from Shenzhen, a dynamic city that has been viewed as the vanguard of China's development in science and technology. The goal of SUSTech is to become a top-tier international university that excels in interdisciplinary research, talent development and knowledge discovery.

We seek highly qualified candidates who are able to apply bioinformatics techniques to analyze data from the next-generation sequencing and other high-throughput sequence profiling to address fundamental questions mentioned above, and highly qualified candidates with strong skills in mass spectrometry and isotope geochemistry.

Applicants are required to have a Ph.D. degree in related disciplines. Candidates must have a proven and consistent track record of high-quality scientific publications and good communication skills.

To apply, please submit the application electronically to **wangy9@sustc.edu.cn.**

or experimental techniques. The position requires a Ph.D. in an appropriate earth science discipline from a regionally accredited college or university. Salary will be competitive with those at similarly situated institutions. Position is contingent upon funding.

Application materials must include a cover letter, curriculum vitae, proposed research plans (five page limit), statement of teaching philosophy and interests (two page limit), and contact information for at least five referees. Review of candidates' materials will begin on January 10, 2018. Materials should be addressed to Dr. Elisabeth Hausrath, Search Committee Chair, and submitted at https://hrsearch.unlv.edu. For assistance with UNLV's on-line applicant portal, contact UNLV Employment Services at (702) 895-3504 or applicant.inquiry@unlv.edu.

EEO/AA/Vet/Disability Employer

Interdisciplinary

Assistant Professor of Earth System Science (tenure track): Humans in the Earth System

The Department of Earth System Science (ESS) at The University of California Irvine seeks to hire an Assistant Professor with expertise in the coupling of human and natural systems, with the goal of strengthening the department's commitment to understanding and teaching how Earth system change interacts with human systems. The department is particularly interested in interdisciplinary researchers who integrate methods of the natural and social sciences to assess the connections between the global environment and human activities. Research areas might include, for example, pathways of sustainable development, the future of global fisheries, integrated assessment modeling, quantification of regional- to global-scale ecosystem services, econometric analyses of climate change impacts, and the drivers and consequences of land use change.

The ESS vision at UC Irvine began in in 1992 with a focus on global environmental changes that occur on human time scales. Currently the department has twenty-five full time faculty with research and teaching in climate dynamics, biogeochemistry of oceans and atmospheres, atmospheric chemistry, cryosphere, ecohydrology, food security, and global energy systems (see http://www.ess.uci.edu/). We seek a new colleague who will build on these core strengths. The new hire will be at the assistant professor level and in the UC tenure track. Candidates must have a Ph.D. in a suitable discipline. Apply online at https://recruit.ap.uci.edu/apply/JPF04234 or contact facultysearch@ess.uci.edu. The selection process begins 1 Oct. 2017, and the position will remain open until filled.

The University of California, Irvine is an Equal Opportunity/Affirmative Action Employer advancing inclusive excellence. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability, age, protected veteran status, or other protected categories covered by the UC nondiscrimination policy.

Graduate Research Opportunities at Purdue University

The Department of Earth, Atmospheric, and Planetary Sciences

The Department of Civil and Environmental Engineering at Michigan State University invites applications for two tenure-system faculty positions in the general area of risk and reliability. These are open-rank positions and the successful candidate(s) will possess a strong background in risk assessment and risk management related to critical contemporary issues in civil or environmental engineering.

Interested individuals should submit an application for these positions through **www.careers.msu.edu** and refer to job #**470022**.

MICHIGAN STATE UNIVERSITY

MSU is committed to achieving excellence through cultural diversity. The University actively encourages applications and/or nominations of women, persons of color, veterans and persons with disabilities.

MSU is an Affirmative Action, Equal Opportunity Employer.

(EAPS) at Purdue University is looking for enthusiastic and self-motivated graduate students for a variety of research projects in Geology and Geophysics, and Planetary, Environmental, and Atmospheric Sciences. As a multidisciplinary department within the College of Science, EAPS draws students from a variety of STEM backgrounds. We offer 4 years of guaranteed financial support and a variety of fellowships. Students with demonstrated academic and research excellence are invited to explore funded graduate opportunities at http://www.eaps.purdue.edu/gradresearch. Come see our booth (905) at AGU.

Graduate Student Opportunities at Case Western Reserve University.

Students with backgrounds in geology, physics, chemistry, biology, engineering, and related fields are encouraged to apply for our Ph.D. and MS programs in Earth, Environmental, and Planetary Sciences. Areas of active research in the Department include planetary geology and geodynamics, planetary materials, high-pressure mineral physics and geochemistry, core and mantle processes, sedimentary geology, and sediment transport. For more information, please visit http://eeps.case.edu or write to eeps-gradinfo@case.edu. Financial assistance is available. Application deadline: 1/15/2018.

Postdoctoral Positions in Ocean, Atmosphere and Climate Dynamics, Yale University

One or two postdoctoral positions in Ocean, Atmosphere and Climate Dynamics will be available at Yale University, Department of Geology and Geophysics (http://people.earth.yale.edu/profile/alexey-fedorov/about). General fields of research include ocean and atmosphere circulation, ocean-atmosphere interactions, the role of ocean in climate, climate variability and change, paleoclimate. Two particular topics of interest are (1) El Niño and mean tropical climate, and (2) stability, variability and predictability of the Atlantic meridional overturning circulation (AMOC). The work will involve numerical modeling, analyses of observational and GCM data, and analytical approaches. A PhD in physical oceanography, atmospheric sciences or related disciplines is required. Previous experience with ocean, atmospheric or climate GCMs is highly desirable. Funding is currently available for two to three years. Successful candidates can begin their program at Yale in winter-spring of 2018; later starting dates can also be discussed. The applicants should email his/her CV, a statement of research interests, one reprint or preprint, and the names of three referees to Professor Alexey Fedorov (alexey.fedorov@yale.edu; subject: postdoctoral search). Shortlisted candidates will be contacted. Yale University is an affirmative action/equal opportunity employer. Yale values diversity in its faculty, staff, and students and strongly encourages applications from women and members of underrepresented minority groups.

Program Directors, Division of Earth Sciences, National Science Foundation, 2415 Eisenhower Ave, Alexandria, VA 22314

The Division of Earth Science (EAR) at the National Science Foundation is seeking candidates for program directors in Education and Human Resources, Geoinformatics, Geophysics, Geomorphology and Land-use Dynamics, Geobiology and Low-Temperature Geochemistry,

DIRECTOR OF THE PACIFIC NORTHWEST SEISMIC NETWORK

The University of Washington seeks an energetic and visionary leader to become Director of the Pacific Northwest Seismic Network (PNSN). A tenured faculty position within the Department of Earth & Space Sciences, the Director will advance the mission of the PNSN (**https://pnsn.org/about/mission**) through scientific research, advocacy, and effective leadership.

Part of the Advanced National Seismic System, the PNSN is a collaboration of the UW, the University of Oregon, and the US Geological Survey. PNSN operates more than 300 seismic stations in the Pacific Northwest, makes and distributes earthquake alerts, earthquake catalogs, ground motion maps, and earthquake early warnings (ShakeAlert).

For more information and to submit an application, please visit **http://bit.ly/2wzLMen**

1867 THAYER SCHOOL OF ENGINEERING AT DARTMOUTH

EVANS FAMILY PROFESSORSHIP IN ARCTIC ENGINEERING

The Thayer School of Engineering at Dartmouth seeks an outstanding candidate to be the inaugural holder of the Evans Family Professorship, which will be filled at the **Assistant, Associate or Full Professor level**. The Thayer School of Engineering is undertaking a significant expansion of faculty and programs: this position is the first of three new hires at Dartmouth in an interdisciplinary cluster focused on "Ice, Climate, and Energy" The successful candidate, who will have a doctorate in engineering or a related field, will contribute to Dartmouth's well-established research effort in cold regions science and engineering by leading a strong externally-funded research program in engineering related to the Arctic, including but not limited to: the behavior of ice, snow and permafrost, and developing Arctic-related technologies. The successful candidate will also be a gifted teacher with motivation and expertise that complements the Thayer School's interdisciplinary approach to engineering education. Facilities include Thayer School's long-established Ice Research Laboratory, and there is strong potential for collaborations with Dartmouth's Arthur L. Irving Institute for Energy and Society, Dartmouth's Institute for Arctic Studies, and with the nearby U.S. Army's Cold Regions Research and Engineering Laboratory. Dartmouth is part of the University of the Arctic.

Review of applications will begin on **January 1st, 2018** and will continue until the position is filled. Interested candidates should submit a cover letter, complete CV, statement of research and teaching interests, and contact information for three references via Interfolio at: **apply.interfolio.com/45797.** Inquiries about the position should be directed to Professor Ian Baker, **Ian.Baker@Dartmouth.edu.**

icdp

The International Continental Scientific Drilling Program (ICDP)

Call for Proposals

The International Continental Scientific Drilling Program, ICDP coordinates and supports multinational endeavours in continental scientific drilling. The program focuses on challenging themes of global geoscientific underpinning socio-economic challenges, including climate & ecosystem evolution, sustainable georesources, natural hazards and water quality and availability.

With this announcement, the ICDP invites Earth scientists to submit project proposals in which drilling is required to achieve critical research goals. This call is open to investigators from ICDP member countries (Austria, Belgium, China, Czech Republic, Finland, France, Germany, Iceland, India, Italy, Japan, New Zealand, Norway, South Korea, Spain, Sweden, Switzerland, The Netherlands, United Kingdom and United States of America) as well as from countries considering membership in the ICDP. Please note that ICDP provides operational support and allocates co-funding for drilling-related costs only; research grants for the project should be sought from other funding agencies. This concept of commingled funding and international cost sharing, in addition to an exchange of technological capabilities and expertise, has proven very successful.

ICDP aims to foster joint projects with the International Ocean Discovery Program and therefore cordially invites project proposals in which coordinated drilling on land and at sea is required or land-sea transect drilling series are planned (“amphibious projects”). Joint project proposal submissions will be accepted by both programs and will be jointly evaluated.

PROPOSAL PREPARATION

ICDP accepts three types of proposals: **Preliminary proposals** serve to briefly highlight a new research project idea and receive a brief assessment for further development. **Workshop proposals** request to hold an ICDP-funded workshop and comprise an outline of the main objectives, the scientific importance of the planned project, details of the proposed drill site, the expertise of the group of proponents, and envisaged international collaboration. The workshop serves to bring together a competitive international research team and to initiate the development of a **full proposal that can be submitted** following a successful workshop.

PROPOSAL EVALUATION

All proposals are evaluated by the Science Advisory Group (SAG) of the ICDP, which makes recommendations to the Executive Committee (EC) based on scientific quality and relevance. The EC then reviews technical and financial issues in order to ensure that projects are feasible within the constraints of ICDP’s annual and long-range plans as well as considering gender and career status. The EC informs the Principal Investigators of the outcome of the evaluation, and states whether further development of the proposal is to be encouraged or not.

The deadline for submission of all proposals to the ICDP is **January 15, 2018**. Please submit a digital version as a single file via e-mail to the ICDP Program Office using **proposal.submission@icdp-online.org**.

Detailed information on the scope of the ICDP, the submission of proposals, proposal format, and the process for development of a successful proposal is available at: **http://www.icdp-online.org/proposals**.

Sedimentary Geology and Paleobiology, and Tectonics. In addition, we seek program directors to support integrated research activities across the division. Further information about EAR and these programs can be found at http://www.nsf.gov/div/index.jsp?div=ear.

The individuals selected for these positions will be knowledgeable in the scientific areas covered by the respective programs and will help identify emerging opportunities in the Geosciences. In addition, the incumbent will undertake the design, development, analysis, documentation, management and implementation of programs and activities within the program and across disciplinary boundaries. Program Director responsibilities include long-range planning for the areas of science represented by the program; administration of the merit review process and proposal recommendations; preparation of press releases, feature articles and material describing advances in the research supported; and coordination with other NSF programs as well as those at other Federal agencies and organizations.

Candidates must have a Ph.D. in an appropriate field plus, after award of the Ph.D., six or more years of successful research, research administration, and/or managerial experience pertinent to the position.

Individuals interested in applying for these vacancies should submit their materials to the appropriate announcement:

Education and Human Resources Rotator, Permanent

Geoinformatics Rotator, Permanent

Geophysics Rotator

Geomorphology and Land-Use Dynamics Rotator, Permanent

Geobiology and Low-Temperature Geochemistry Rotator

Integrated Research Activities Rotator, Permanent

Sedimentary Geology and Paleobiology Rotator

Tectonics Rotator

Position requirements and application procedures are located on the NSF Home Page at www.nsf.gov/about/career_opps/. Hearing impaired individuals may call TDD 703-292-5090. Applications must be received by November 9, 2017.

NSF is an Equal Opportunity Employer.

Solid Earth Geophysics

Tenure-Track Faculty Position in Potential Fields Geophysics, University of Alabama

The Department of Geological Sciences at The University of Alabama (UA) invites applications for a tenure-track faculty position in

UMASS AMHERST

Tenure-Track Assistant/Associate Professor

Environmental Fluid Mechanics and Water Resources Engineering

The Department of Civil and Environmental Engineering at the University of Massachusetts Amherst invites applications for a tenure-track faculty position at the assistant or associate professor level in the area of Environmental Fluid Mechanics and Water Resources Engineering. The appointment is expected to begin September 1, 2018. We seek an individual who can provide innovative solutions to national and international water challenges, broadly defined. Specific areas of interest include, but are not limited to, hydroclimatology, land surface modeling, resilient water infrastructure design and management, and environmental data science with an emphasis on engineering applications and high powered computing.

The successful candidate will be responsible for establishing and maintaining a program of externally funded research. We anticipate the successful candidate will build research collaborations within the department as well as throughout the campus, including with the Department of Interior Northeast Climate Science Center and the Center for Data Science. The candidate should have graduate and undergraduate teaching interests that draw from one or more of the following areas: mathematical modeling, statistics, systems analysis, environmental fluid mechanics, hydrology and hydraulics. Applicants must have a Ph.D. in a civil engineering or a closely related field or anticipate such a degree by August 2018. Salary will be commensurate with qualifications and experience.

To apply or to learn more, please visit:
http://umass.interviewexchange.com/jobofferdetails.jsp?JOBID=90289
Review of applications will begin on December 15, 2017, and continue until a suitable candidate is identified.

The University is committed to active recruitment of a diverse faculty and student body. The University of Massachusetts Amherst is an Affirmative Action/Equal Opportunity Employer of women, minorities, protected veterans, and individuals with disabilities and encourages applications from these and other protected group members.

potential fields geophysics. This position will begin August 2018 and will be filled at the Assistant Professor level. Candidates who specialize in potential fields (gravity, magnetics, electricity, and/or electromagnetism), including data acquisition, processing, and interpretation, with research interests in near-surface, environmental, hydrologic, exploration, and solid-earth geophysics are invited to apply. It is expected that this position will enhance UA research focused on water, energy, and the environment with an emphasis on hydrogeology, petroleum systems, and/or tectonics. Candidates must have a strong record of research and teaching, and they must have received a Ph.D. in geology, geophysics, or a related field by the time of their appointment. The successful candidate will be expected to establish a vigorous, externally funded research program and to attract and advise high-quality graduate students. Teaching responsibilities will include undergraduate and graduate courses in his/her specialty and introductory geology. The department has a broad range of geophysical and computational facilities, in addition to University-shared facilities. Details regarding existing research programs, equipment and facilities, and departmental activities can be found at http://www.geo.ua.edu.

Questions should be directed to Dr. Fred Andrus (fandrus@ua.edu). Applicants should go to https://facultyjobs.ua.edu/postings/41952 to electronically apply for this position. When submitting an application, candidates must provide a cover letter, CV, research and teaching statements, and a list with the contact information for at least three references. Applications will be reviewed starting December 1, 2017 and will continue until the position is filled. The University of Alabama is an Equal Opportunity Affirmative Action Employer and actively seeks diversity in its employees.

Tectonophysics

University of Washington Faculty Position–Assistant or Associate Professor in Geology–Subduction Zone Initiative

The University of Washington (UW) seeks a geologist with a compelling vision for subduction zone research and the collaborative leadership skills to contribute to a new subduction zone initiative at UW. This faculty position is in the Department of Earth & Space Sciences (ESS) of the College of the Environment, and is expected to be at the rank of Assistant Professor (tenure track) or Associate Professor (with tenure). This position is a full-time position

Faculty Position in Faults, Fluids, and Fluid-Rock Interactions

The Department of Earth & Atmospheric Sciences (EAS) at Cornell University invites applications for a tenure-track faculty position with core expertise in geological, geochemical, geophysical, or geohydrological fundamentals as applied to subsurface fluid flow, fluid-rock interaction, and/or faulting. This position is part of a multi-departmental cluster hire in subsurface energy systems. The ideal candidate will apply these fundamentals in innovative research relevant to fields including geothermal energy, carbon sequestration, hydrocarbon systems and induced seismicity, as well as to natural earth phenomena such as earthquakes, volcanoes, mineralization and hydrochemistry. Scientists with expertise that is either observational or computational in nature are equally encouraged to apply.

Applicants must hold a Doctorate in an appropriate field, have a demonstrated ability to conduct outstanding research, and show promise for attracting external research support. The successful candidate will also be a committed educator, enthusiastic about teaching and supervising students at all levels in research. We anticipate filling the position at the Assistant Professor level, but will consider hiring at the Associate level.

All materials must be submitted online at: **https://academicjobsonline.org/ajo/jobs/10223**. Applicants should submit a cover letter addressed to Dr. Larry Brown, a full cv, research statement, teaching statement, and complete contact information for three references. Statements including leadership efforts, and contributions to diversity are encouraged. To ensure full consideration, applications should be received by December 1, 2017 when review of applications will begin until position is filled.

Cornell University embraces diversity and seek candidates who will create a climate that attracts students of all races, nationalities, and genders. Cornell understands the needs of dual career couples and is a member of the Upstate New York Higher Education Recruitment Consortium which assists dual career searches: **http://www.hercjobs.org/**. Cornell and Ithaca are family-friendly communities: Cornell has a comprehensive set of policies, services and benefits to help you, your partner and your children to feel welcome here, to support your well-being, and to help with child care, elder care and those with disabilities through their HR new employee Onboarding Program.

Diversity and Inclusion are a part of Cornell University's heritage. We are a recognized employer and educator valuing AA/EEO, Protected Veterans and Individuals with Disabilities.

icdp

ICDP Workshop on Scientific Drilling of Lake Nam Co (Tibetan Plateau)

Beijing, China, 22-24 May 2018

Lake Nam Co represents one of the largest and deepest lakes (100 m) on the Tibetan Plateau that supplies water to one third of the world's population. Due to its location, paleoclimate proxies reflect the spatial and temporal development of large-scale atmospheric circulation systems. Multiproxy studies on a 10.4 m long reference core provided a high-resolution paleoenvironmental record covering the past 24 cal ka BP with proxies that have been validated by extensive modern process studies. A comprehensive set of pre-site survey seismic data show an infill of >800 m of well-layered undisturbed sediments in the central part of the lake, likely spanning several glacial/interglacial cycles. Sediment accumulation rates measured on the reference core and seismostratigraphic investigations suggest an age of the lake formation of >1 Mio years.

The Tibetan Plateau is also characterized by a high degree of endemism of organisms that are dependent on continuously existing water bodies. Nam Co likely served as a dispersal center for these organisms, as most other lakes desiccated during dry glacial periods of the Cenozoic. Nam Co appears to be a first class example for studying the link between geological and biological evolution in highly isolated Tibetan Plateau ecosystems including the deep biosphere over long time scales.

A continuous, high-resolution, record for these long time scales from Nam Co can be recovered by drilling to study sediment budget changes under varying climatic and tectonic settings, and contribute to a better understanding of the Quaternary geomagnetic field.

Members of the international scientific community interested in the planning of and participating in the research project, are invited to apply for participation in the workshop. It will be held in Beijing, China, from 22-24 May 2018 to further develop the project's scientific goals and to discuss technical and logistic issues for a full proposal to ICDP.

Interested parties are requested to submit their application by **15 January 2018** to T. Haberzettl **(torsten.haberzettl@uni-jena.de)** and Liping Zhu **(lpzhu@itpcas.ac.cn)** with contact details, a summary of research interests and expertise, and a brief description of the intended project contribution. Preference will be given to scientists from ICDP member countries whose expertise complements that of current consortium members. We particularly aim to expand the research consortium with additional expertise in geochronology and outreach. Successful applicants will be notified in early March.

with an indefinite term and 9-month service period.

The new faculty member will be a geologist who studies the evolution of subduction systems through the interpretation of the rock record. Candidates should use geological field observations to establish context for interpreting the rock record, and combine these approaches with other analytical, theoretical, or experimental techniques. We particularly encourage applicants who examine high-temperature processes, and who complement existing strengths in ESS. We seek a colleague whose research will connect with other scientists in ESS and across the College. Candidates hired at the Assistant Professor level should demonstrate strong potential for collaborative, cross-disciplinary leadership contributing to a subduction zone initiative; candidates hired at the Associate Professor level should have a record of leadership.

Applicants should demonstrate the potential for or a track record of externally funded internationally recognized research, commensurate with experience, and show potential for high quality teaching in our undergraduate and graduate programs. Specifically, the faculty member must contribute to the undergraduate curriculum in Earth Materials/Mineralogy and Field Geology, and should demonstrate the ability to attract and effectively advise excellent research students. Applicants must hold a Ph.D. or foreign equivalent.

Application Instructions

https://ap.washington.edu/ahr/academic-jobs/position/aa25938/

To apply, please send a letter of interest, curriculum vitae with publication list, and the contact information of 3 references. Applicants should also send three statements (1–2 pages each): 1) A statement addressing research accomplishments, as well as future research plans. 2) A statement discussing teaching and mentoring philosophy, teaching effectiveness, and potential contributions to teaching field geology and earth materials. 3) A statement on their past or potential contributions to diversity, equity, and inclusion (see http://www.washington.edu/diversity/diversity-blueprint/), including advocacy for identity groups other than their own.

Electronic materials (.pdf) should be sent to essasst@uw.edu with "Subduction Zone Faculty Search: [Your Name]" in the subject line. Consideration of applications will begin immediately and continue until the position is filled. Preference will be given to applications received prior to January 2, 2018. Questions pertaining to the application process or potential disability accommodations can be addressed to Scott Dakins (essasst@uw.edu). Questions about the position can be addressed to Associate Professor Katharine Huntington, search committee chair (kate1@uw.edu).

All University of Washington faculty engage in teaching, research and service. The University of Washington is an affirmative action and equal opportunity employer. All qualified applicants will receive consideration for employment without regard to race, religion, color, sex, sexual orientation, gender identity, gender expression, national origin, age, protected veterans or disabled status, or genetic information.

GLOBAL WATER FUTURES
SOLUTIONS TO WATER THREATS IN AN ERA OF GLOBAL CHANGE

TENURE-TRACK OR TENURED POSITION IN EXPOSURE AND/OR RISK ASSESSMENT MODELLING AS ASSISTANT PROFESSOR, ASSOCIATE PROFESSOR, OR PROFESSOR.

The Global Institute for Water Security (GIWS), University of Saskatchewan (U of S), invites applications from outstanding researchers for position in the area of Exposure and/or Risk Assessment Modelling as **Assistant Professor, Associate Professor or Professor.** Tenured appointments may be offered where candidates hold tenured or equivalent status at a comparable institution. The position will report to the Director, GIWS, be based in the Global Water Futures (GWF) research group, and have an associated academic appointment and academic reporting line in an appropriate U of S college or school.

Visit **globalwaterfutures.ca** for more information and to apply.

Review of applications will begin now, and will continue until a suitable candidate is found.

Woods Hole Oceanographic Institution

FULL-TIME EXEMPT TENURE TRACK POSITION
WOODS HOLE OCEANOGRAPHIC INSTITUTION (WHOI)

The Physical Oceanography Department at WHOI invites candidates to apply for a tenure track position on our scientific staff. The successful candidate will join a collaborative group of scientists who address a wide range of fundamental problems in ocean and climate dynamics, as well as interdisciplinary research questions, using observations, modeling, theory, and laboratory experiments. We specifically seek individuals with expertise in these areas: 1) coastal dynamics, 2) high-latitude processes, 3) climate variability, and 4) submesoscale phenomena and mixing. We seek a balance of observational, modeling, and theoretical approaches, as well as interdisciplinary scientists with interests in the interplay between ocean dynamics and biological or geochemical processes.

Candidates with expertise in theoretical/dynamical approaches are encouraged to apply. Visit **http://jobs.whoi.edu** and respond to **Job Reference 17-09-11.**

Volcanology, Geochemistry, and Petrology

Assistant Professor, Earth Materials, University of Maryland–College Park

The Department of Geology at the University of Maryland invites applications for a tenure-track assistant professor in Earth Materials. Research areas of interest include, but are not limited to: experimental and theoretical aspects of petrology, mineral physics, nanogeoscience, and economic geology. The appointee will be expected to develop and maintain an active, externally funded research program that will involve both graduate and undergraduate students, and to participate fully in teaching at all levels, including mineralogy. We particularly encourage applications from those who integrate across traditional disciplinary boundaries both within the Department of Geology (http://www.geol.umd.edu) and throughout the College of Computer, Mathematics, and Natural Sciences (http://www.cmns.umd.edu). Candidates from underrepresented groups are encouraged to apply.

A Ph.D. in Geology or a related discipline is required at the time of appointment. The appointment may begin as early as August 1, 2018. Applications should be submitted online at https://ejobs.umd.edu/postings/54884 and should include the following: a letter of application stating research and teaching goals; a complete CV; and contact information for three (3) professional references. Review of applications will begin in December 2017, and will be ongoing until the position is filled.

The University of Maryland, College Park, an equal opportunity/affirmative action employer, complies with all applicable federal and state laws and regulations regarding nondiscrimination and affirmative action; all qualified applicants will receive consideration for employment. The University is committed to a policy of equal opportunity for all persons and does not discriminate on the basis of race, color, religion, sex, national origin, physical or mental disability, protected veteran status, age, gender identity or expression, sexual orientation, creed, marital status, political affiliation, personal appearance, or on the basis of rights secured by the First Amendment, in all aspects of employment, educational programs and activities, and admissions.

Postcards from the Field

Hi, Everyone:

I'm in Louisiana with biologist and artist Brandon Ballengée researching a book on art, culture, and climate change. Brandon is collaborating with Prosanta Chakrabarty (associate professor/curator of ichthyology, Louisiana State University) on an interdisciplinary art and science project called Crude Life. In its current form, the project consists of old trunks and chests containing dyed specimens and posters listing the species that have been adversely affected by, or simply gone missing since, the 2010 Gulf of Mexico oil spill.

In this photo, we're at A Studio in the Woods (Tulane University) for "Loss & Found," an event that is part of the Annual Wetlands Art Tour sponsored by Antenna::Signals. The portable museum is aesthetically bewitching, and people gravitate to it. Brandon talks with visitors about the aftermath of the oil spill, the 14 species of endemic Gulf fishes that have not been seen since the spill, and opens up dialogue about the ecology of Louisiana, its fossil fuel economy, and the fate of biodiversity in the Gulf.

—Thomas S. Davis, Associate Professor of English, Ohio State University, Columbus

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

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giving day AGU

Thursday, 14 December

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