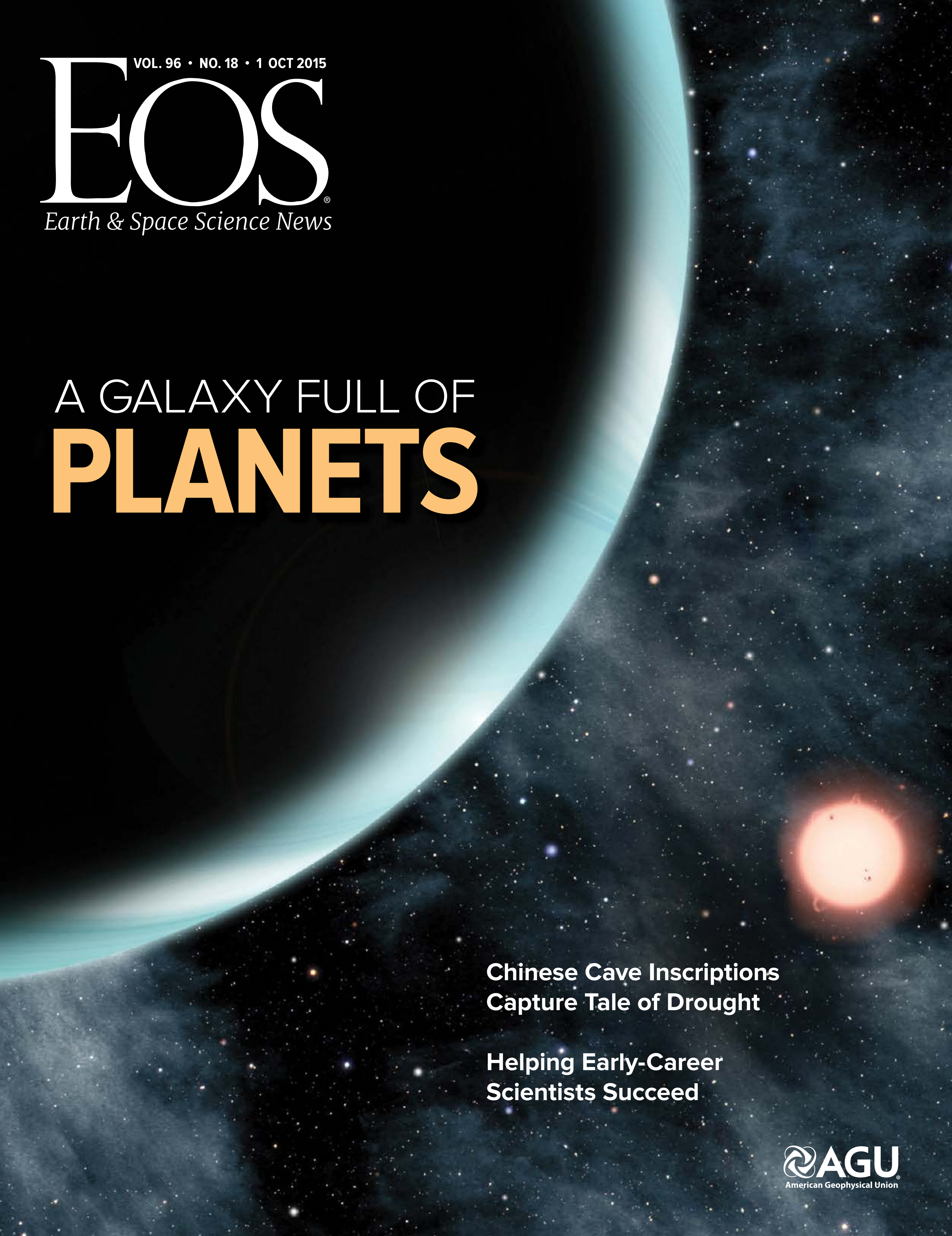

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Earth & Space Science News

A GALAXY FULL OF PLANETS

Chinese Cave Inscriptions Capture Tale of Drought

Helping Early-Career Scientists Succeed

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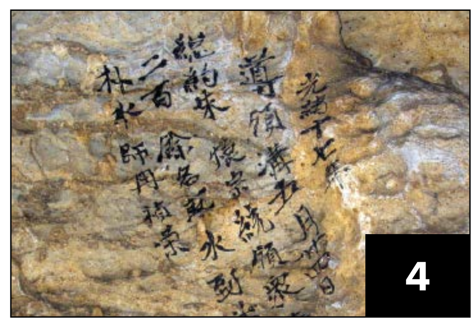
PROJECT UPDATE

NEWS



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On the Cover
Artist's conception of Kepler-421b, a Uranus-sized transiting exoplanet that circles its star once every 704 days. Kepler-421b orbits a star located about 1000 light-years from Earth in the constellation Lyra. Credit: Harvard-Smithsonian, Center for Astrophysics/D. A. Aguilar.

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Reduced Middle East Air Pollution Linked to Societal Disruption

Azad Lashkari/Reuters

A new study reveals that lower levels of air pollution in the Middle East can be tied to political and social unrest. Researchers suggest that unrest affects fuel costs and availability, as well as industrial activities. Here motorists queue up outside a gas station in Arbīl, Iraq, in June 2014. Fighting farther south disrupted fuel supplies.

Many areas in the Middle East have experienced rapidly declining air pollution emissions, and these decreases could be due to political conflict, according to a new study.

While investigating air pollution levels across Europe, Asia, and the Middle East between 2005 and 2014, a research team led by Jos Lelieveld, director of the Max Planck Institute for Chemistry in Mainz, Germany, observed a striking reversal: From 2005 to 2010, many cities in the Middle East ranked among the fastest growing air pollution emitters. Then, starting around 2010, sharp declines in certain emissions began in many of those same cities.

Although some of the decline reflects the effectiveness of recent environmental cleanup measures by governments such as that of Saudi Arabia, that's only a small part of the picture, the researchers say.

"A combination of air quality control and political factors, including economical crisis and armed conflict, has drastically altered the emission landscape," the researchers reported on 21 August in *Science Advances* (see http://bit.ly/Middle_East_NO2).

Nitrogen Dioxide and Sulfur Dioxide

Using measurements from the Ozone Monitoring Instrument aboard NASA's Aura satellite, which orbits Earth 14 times per day, Lelieveld and his colleagues studied the abundance of nitrogen dioxide, a highly reactive gas. Nitrogen dioxide, or NO_2, belongs to a class of gases known as NO_x that originate mainly from the combustion of fossil fuels but also from agriculture and natural sources.

The researchers also looked at emission trends of sulfur dioxide, a by-product also of fossil fuel combustion in power plants, industrial activities, and transportation, including burning of low-quality fuels in cargo ships.

Both NO_2 and sulfur dioxide are well-known pollutants that can cause adverse health effects and also contribute to climate change.

Emissions Swings Reflect Unrest

The research team observed dramatic changes in emissions levels in cities across the Middle East, where a variety of different circumstances could have contributed to the variations.

In Iraq, for example, researchers mainly saw increases in NO_2 until 2013, then a decrease in cities such as Tikrit and Samarra, which have recently been occupied by the Islamic State. Similarly, emissions in Baghdad began to decrease in 2010, around the time when activities of the Islamic State began, and began to increase in areas outside of Baghdad as people fled the city, Lelieveld said.

Mass migrations can also affect NO_x emissions, the authors wrote. As a violent civil war ravaged Syria, 1.2 million people sought refuge in neighboring Lebanon. Between 2005 and 2013, the authors report, NO_2 emissions increases over Lebanon ranged from 3% to 4%, soaring to 20%–30% in 2014.

In Egypt, political uprisings in early 2011 swept across the country, and during that period the satellite data reflect NO_2 emission reductions that occurred parallel to a decrease in the country's gross domestic product (GDP). Because no environmental or air quality policies were enacted during that time, the researchers suspect that a reduction in vehicle usage led to this drop in emissions.

Because declining NO_2 emissions often paralleled a falling GDP, these declines could be due to higher fuel costs, reduced vehicle use, or stagnating industrial activities, Lelieveld said.

Impact of Sanctions

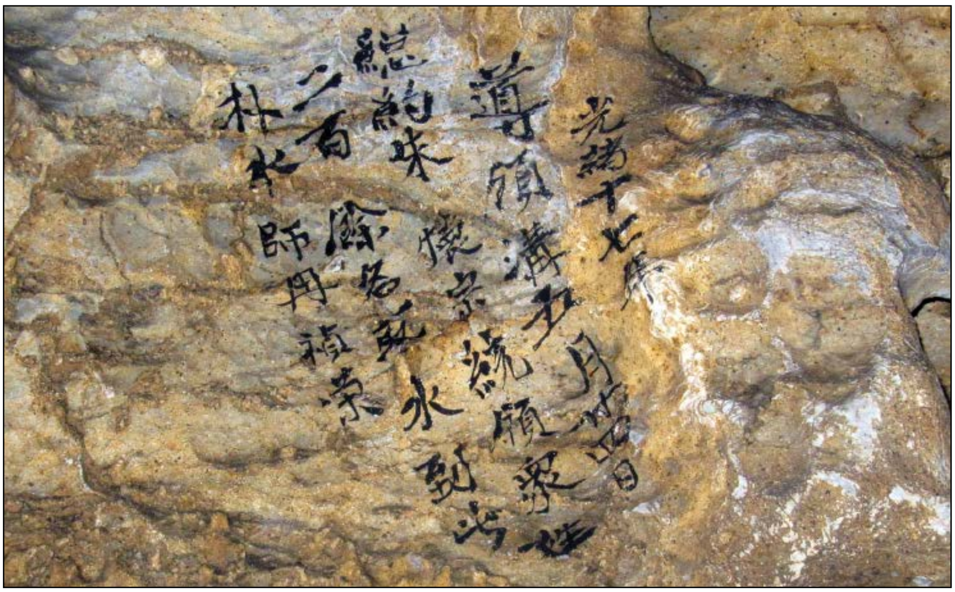
In Iran, the researchers found relatively high levels of NO_2 emissions in major cities such as Tehran and Esfahan in the years before the United Nations imposed economic sanctions in 2006. After these sanctions were tightened in 2010, NO_2 emissions decreased by 4% per year, parallel to a decreasing GDP that fell 6% per year starting in 2012.

In addition, the researchers found that sulfur dioxide emissions also fell 50% as economic sanctions slashed the volume of shipments, including oil exports, from and to Iranian ports, Lelieveld said.

"Since NO_2 pollution is a very effective indicator of economic activity, satellite measurements of NO_2 reduction help to reveal in a timely manner how political conflicts affect the socioeconomics," said Jintai Lin, an atmospheric scientist at Peking University in Beijing, China, who did not participate in the study. "The relation confirms that human activities—in this case, political conflicts—are effectively and rapidly perturbing the atmospheric environment," he added.

By **JoAnna Wendel,** Staff Writer

Chinese Cave Inscriptions Tell Woeful Tale of Drought



L. Tan

One of 70 inscriptions left by visitors to Dayu Cave (see http://bit.ly/CaveWords). It reads "On May 24th, 17th year of the Emperor Guangxu period, Qing Dynasty, the local mayor, Huaizong Zhu led more than 200 people into the cave to retrieve water. A fortune-teller named Zhenrong Ran prayed for rain during a ceremony."

"On June 8th, 46th year of the Emperor Kangxi period, Qing Dynasty, the governor of Ningqiang district came to the cave to pray for rain."

The above entry is just one out of 70 inscriptions found in Dayu Cave in central China, written on the wall during a severe drought in 1707. In a study published 13 August in *Scientific Reports* (http://bit.ly/SR_China_cave), scientists translated the cave inscriptions and found evidence in seven of them of major droughts—in 1528, 1596, 1707, 1756, 1839, 1891, and 1894—five of which were previously unknown to historians.

The researchers then used geochemical analysis of formations within the cave to confirm this record of droughts. With their findings, they were also able to model the likelihood of major future droughts in the region.

The Summer Monsoon

Agriculture in China depends on the summer monsoon, when roughly 70% of the year's rain falls in a few months. Chinese historical records recount political strife, widespread starvation, and even cannibalism during droughts, the study says. This suffering is reflected in the cave's graffiti, where record keepers wrote that the "mountains are crying due to drought" and that people came to pray for rain.

The inscriptions, which include dates from the Chinese calendar, add validity to the notion that drought may have undermined several Chinese dynasties, the researchers said.

The new findings show "the vulnerability of civilization to even relatively small changes in climate," said lead author Liangchen Tan of the Institute of Earth Environment at the Chinese Academy of Sciences in Beijing.

> Scientists translated the cave inscriptions and found evidence in seven of them of major droughts.

Building Records of Past Droughts

To find evidence of past droughts within the geochemical records of the cave, the scientists turned to stalagmites—limestone cones that grow upward from the cave floor over millenia. Stalagmites form when water percolating from above drips from the cave's ceiling to the floor below.

As the fallen water evaporates from the cave floor, it leaves behind a thin coating of solid minerals. Those deposits build, layer by layer, into a cone that holds a chemical record of the surrounding environment. These layers, much like tree rings, offer clues to temperature and rainfall abundance when each layer was added.

To conduct its analyses, the team looked at the ratios of heavy carbon and oxygen isotopes, specifically carbon-13 (^{13}C) and oxygen-18 (^{18}O), to lighter isotopes within each mineral layer.

When water drips into a cave, it immediately degasses, releasing absorbed carbon dioxide. The carbon dioxide molecules with the lighter carbon isotope ^{12}C will degas first, leaving relatively more ^{13}C behind.

If conditions are drier, there's more time between drips for lighter isotopes to leave, so the solid mineral left behind becomes especially enriched with ^{13}C and ^{18}O.

Importance of Cave Inscriptions

The researchers created a timeline of wet and dry periods using radiometric dating techniques along with the isotope measurements. They found that geochemical markers of drought aligned closely with the inscriptions that reflected a drought, Tan said.

"Our study also suggests the importance of cave inscriptions in climate and [historical] study, which were ignored before," Tan added.

"This study is unique as the authors capitalize on an opportunity to use in situ historical records of drought to test the ability of [stalagmite] isotopic and geochemical compositions to serve as a proxy of past drought," said Corinne Wong of the Department of Earth and Environmental Sciences at Boston College, who wasn't involved in the study.

Future Droughts

The researchers also used patterns of $^{18}O/^{16}O$ ratios within the stalagmite layers to develop a mathematical model to investigate future precipitation variability.

Although a model can't predict precisely when a drought might hit, if it recreates past events known to have occurred, scientists can better trust its projections, said Sebastian Breitenbach of the University of Cambridge in the United Kingdom, a coauthor of the paper.

In this case, the team's model, calibrated to the pre-1900 drought record obtained from Dayu Cave, did indeed reflect a major drought that occurred in China in the 1990s. By extrapolating to the year 2042, the researchers found that another drought could occur in the 2030s.

By **JoAnna Wendel,** Staff Writer

Does U.S. Hurricane Rating Scale Get the Danger Right?

Reuters/David J. Phillip

A helicopter rescues New Orleans residents from the floodwaters of Hurricane Katrina on 1 September 2005.

When Hurricane Katrina made landfall 10 years ago on 29 August, it claimed the lives of more than 1800 people and caused $108 billion in damages. Decades prior, in 1969, Hurricane Camille devastated the same region, although it resulted in only 262 deaths and about a billion dollars in damage ($6.2 billion in 2015 dollars).

So why was Katrina categorized as a 3 and Camille a 5?

The answer has to do with the physical differences between the storms, which is part of the reason some scientists think that the current way that the National Oceanic and Atmospheric Administration (NOAA) categorizes hurricanes—using the Saffir-Simpson hurricane scale (SSHS)—is inadequate.

"There's a strong feeling that the current scale doesn't accurately communicate hazard," said Chris Davis, a hurricane specialist at the National Center for Atmospheric Research in Boulder, Colo.

Size and Speed Matter

The SSHS was developed in the 1970s by Herb Saffir, a structural engineer, and Bob Simpson, a meteorologist, who attempted to quantify the physical damage incurred by hurricane-force winds and calibrated the numbers to a simple-to-read 1–5 scale, in which each category represents a range of wind speeds (see http://bit.ly/HurrScale).

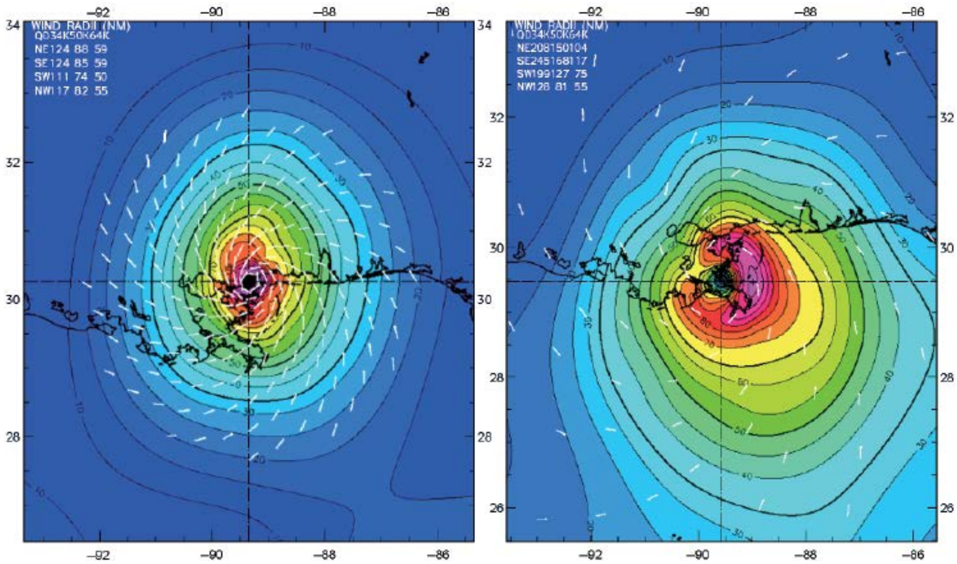
But winds alone don't make a hurricane dangerous. Hazards include the potential for flooding, from both rainfall and seawater inundation. A hurricane's powerful winds push waves toward the shore at speeds that are sometimes faster than the storm itself, piling up water near the shore before the storm even arrives.

Size was a major factor that differentiated relatively compact Camille from sprawling Katrina, said Mark Powell, a scientist formerly with NOAA's National Hurricane Research Division who now runs Hwind Scientific, a private company based in Tallahassee, Fla., that provides real-time hurricane analysis.

At its largest, Camille's hurricane-force winds stretched only 60 miles (97 kilometers) from the storm's center, whereas Katrina extended twice as far. Although Camille's maximum wind speed (more than 200 miles (322 kilometers) per hour) far exceeded Katrina's (130 miles (209 kilometers) per hour), Katrina's size allowed the storm to push 4 times as much water toward the shore.

When comparing storms like Camille and Katrina, "it's not important how strong the peak wind is; what's important is how big the storm is," according to Powell.

Davis noted that the speed at which a storm moves across the ocean can also affect its hazard potential. "It turns out that slower-moving storms can create more damage because the adverse conditions last longer," he said.



Mark Powell, NOAA Hurricane Research Division

Diagrams of Hurricane Camille (left; 1969, category 5) and Hurricane Katrina (right; 2005, category 3) show the vast difference in their sizes.

Weighing Scales

The Saffir-Simpson Scale

- Developed by Herb Saffir and Bob Simpson
- Quantifies wind damage on structures
- Range 1–5
- Katrina was a category 3

Alternative Hurricane Scales

Integrated Kinetic Energy

- Developed by Mark Powell and colleagues
- Represents wind force on the ocean; accounts for storm size and speed
- Range 0.00–5.99
- Katrina would have been a 4.9

Hurricane Intensity Index (HII) + Hurricane Hazard Index (HHI)

- Developed by Lakshmi Kantha
- Uses fluid dynamics to rate hurricane strength; for use with additional scales
- Range 0.3 to above 5.0 for HII, 0.3 to about 15.00 for HHI
- Katrina would have been a 3.0 on HII and a 14.5 on HHI

Cyclone Damage Potential

- Developed by George Holland, James Done, and colleagues
- Uses coupled atmosphere-ocean dynamics for interactions of wind, waves, currents
- Range 1–10
- Katrina would have been a 6.6

The SSHS scale takes into account neither a hurricane's size nor the speed it travels, Davis said.

Other Shortcomings

The SSHS also falls short, critics say, because any hurricane with wind speeds exceeding 156 miles (251 kilometers) per hour remains a category 5, no matter how much faster the wind blows. Given that scientists expect global warming to make hurricanes more intense, a new rating scale should not lump all the highest-wind speed storms into a single, open-ended category, said Lakshmi Kantha, a scientist at the University of Colorado in Boulder.

Another one of Kantha's main criticisms of the scale is that because each of the SSHS categories encompasses a wide range of wind speeds, a small difference in wind speed at the edge of a storm's range can dramatically alter a hurricane's rating.

For instance, a category 3 hurricane sustains wind speeds between 111 and 130 miles (179 and 209 kilometers) per hour, whereas a category 2 storm's winds blow at 96 to 110 miles (154 to 177 kilometers) per hour. So a wind speed a few miles per hour slower could bump a hurricane down a whole category but not necessarily affect its strength or potential to cause serious damage, Kantha said. That's why he calls for a hurricane scale with more precise numbers, like 2.4 or 3.8, for communicating hurricane strength.

Alternate Scales

Kantha urges use of multiple scales—an intensity scale like SSHS with others that rate the potential damage from, say, winds or storm surge. Because such factors are hard to combine into one simple-to-use scale, Kantha suggests providing them separately but simultaneously. Kantha's proposed intensity scale, which he calls a "hurricane intensity index," uses laws of fluid dynamics, which he says more accurately portray a hurricane's intensity.

Powell, meanwhile, analyzes hurricanes using a concept called "integrated kinetic energy"—a measurement of the hurricane's total energy based on wind speed as well as size. Applied to a numerical rating system akin to the SSHS, these measurements might be able to better reflect how much damage a hurricane could cause, Powell said.

Even if hurricane experts all agreed that an alternate scale is needed, the challenge lies in devising one as easy to understand as the SSHS, Davis noted. Even though agencies like NOAA make supplemental information about the size and the speed of storms available, he said, the data are useless to most people "unless you know where to look for it and how to interpret it."

Going Beyond the SSHS

Scientists at NOAA recognize that the SSHS alone inadequately communicates hurricane hazard, said Jamie Rhome, a scientist in the National Hurricane Center's Storm Surge Unit in Miami, Fla. Instead of starting from scratch and creating a new scale, the center has begun to develop other measures and warnings of storm surge and flooding to provide what the SSHS leaves out.

"We're about 7 years into a 10-year journey to bring storm surge into the forefront because that's what's killing the largest number of people in hurricanes," he said.

The team is "effectively de-emphasizing the Saffir-Simpson scale to communicate the hazards of a hurricane," Rhome said. "We're breaking out the hazards individually and then dealing with them with their own separate communication mechanism."

The research center has started testing the effectiveness of flood risk maps that communicate how high water could get during a storm and how far inland it could go. Additionally, to supplement the SSHS, center scientists rolled out prototype alerts to be issued if a life-threatening storm surge is imminent. This warning system should go into effect in 2017.

By **JoAnna Wendel,** Staff Writer

Honoring Earth and Space Scientists

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The Geological Society of America (GSA) recently announced its 2015 fellows (http://bit.ly/GSAFellows), many of whom are AGU members.

In addition, the following individuals will receive awards at the GSA annual meeting in November: **James W. Head,** of Brown University in Providence, R.I., will receive the Penrose Medal. **John W. "Jack" Hess,** former GSA executive director (2002–2015) and current GSA foundation president, will receive the GSA Distinguished Service Award. **Priya Ganguli,** of Woods Hole Oceanographic Institution in Woods Hole, Mass., will receive the Doris M. Curtis Outstanding Woman in Science Award. **Jerry X. Mitrovica,** of Harvard University in Cambridge, Mass., will be awarded the Arthur L. Day Medal. **Naomi Oreskes,** of Harvard University, will receive the GSA Public Service Award. **John M. Proffett,** an independent consulting geologist in Eagle River, Alaska, will receive the Geologic Mapping Award in honor of Florence Bascom. **Brandon Schmandt,** of the University of New Mexico in Albuquerque, will receive the Young Scientist Award (Donath Medal). **Steven W. Squyres,** of Cornell University in Ithaca, N.Y., will receive the 2015 President's Medal. **Dawn J. Wright,** chief scientist at the Environmental Systems Research Institute in Redlands, Calif., and professor at Oregon State University in Corvallis, will receive the Randolph W. "Bill" and Cecile T. Bromery Award for the Minorities.

Jessica Hellmann is the new director of the Institute on the Environment at the University of Minnesota Twin Cities in St. Paul. Before joining the institute, she was an associate professor in the University of Notre Dame's Department of Biological Sciences.

Jacqueline Huntoon professor of geological and mining engineering and dean of the graduate school at Michigan Technological University in Houghton, is the new provost and vice president for academic affairs.

Michael Thompson is the new interim president for the University Corporation for Atmospheric Research, Boulder, Colo.

Focusing Attention on Climate Change and Pacific Island Nations

The 2014 Pan Pacific Partnership on Climate Change Adaptation
Taipei, Taiwan, 29 September to 2 October 2014

Palau, seen here from above, risks being overrun as sea levels rise.

Many island nations across the Pacific Ocean face greater threats from climate changes and associated changes in sea level and ocean acidification than most mainland countries. These island nations have low elevation, long coastlines, and a critical dependence on the seas around them for their livelihoods. The United Nations Environment Programme (UNEP) named 2014 the "Small Island Developing States (SIDS) International Year," raising international attention on these small island countries.

"Raise Your Voice, Not the Sea Level" served as the theme for last year's World Environment Day, during which UNEP called on the international community to take action with island nations to prepare themselves for disasters that may come as climate changes. To this end, the Environmental Protection Administration of Taiwan developed and led an international conference and workshop (see http://bit.ly/PanPacificCC).

Participants included scientists and policy makers from Taiwan, the United States, a number of the Pacific island nations, and Southeast Asia. The conference, held at National Taiwan University, drew more than 300 attendees. In addition, the presentations and panels were broadcast live to various universities and colleges in the region.

Conference goals included the following:

- promoting public awareness and enhancing communication among decision makers, subject matter experts, and academia about policy making, adaptation strategies, tool development, and implementation pathways
- identifying and prioritizing issues that span the Pacific, establishing public and private partnerships, and facilitating adaptation policies and the exchange of information on mitigation strategies
- exploring the possibility of establishing a "Climate Change Adaptation Center" as a hub for research and education to promote usage of open and big climate data, as well as organizational networking

Many presentations focused on the need for adaptation policies. For instance, because of sea level rise and increases in extreme events, island countries and Southeast Asian nations confront the dilemma of adapting to changing conditions for survival, stimulating economic development, and/or meeting human needs. In some cases, such as those of the Republic of Palau and the Republic of Kiribati, the entire nation's existence is threatened. To better adapt to climate change, international cooperation is required to improve climate-related legislation, policy-making processes, human capabilities, education, technology, and financial support.

Speakers also called on scientists to push harder for policy makers to include climate adaptation planning in decisions. As part of this effort, the meeting participants concluded that a formal international environmental partnership should be established that would include representatives from the United States, the Southeast Asia nations, and Pacific island nations. Such a partnership could strengthen efforts, remove barriers, pursue sustainable development, and promote creativity. A strong international partnership is essential to support ambitious domestic action.

Speakers called on scientists to push harder for policy makers to include climate adaptation planning in decisions.

After the conference, 35 participants from 7 nations spent 2 days at a workshop, discussing the stresses of climate change. Workshop attendees discussed adaptation policies specifically for Pacific island nations. Participants reiterated the need for establishing an international platform for cooperative efforts to adapt to climate change together. To continue the efforts, a follow-up meeting to be held in Vietnam is planned for autumn 2015.

Acknowledgment
We give special thanks to Chi Ming Peng of WeatherRisk Inc. (Taipei, Taiwan) and S. K. Yang of the National Oceanic and Atmospheric Administration's Climate Prediction Center (College Park, Md.) for the outstanding contributions they made to organizing this meeting, as well as their contributions to this report.

By **Donald Wuebbles,** Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana; email: wuebbles@illinois.edu; **Wayne Higgins,** Climate Program Office, National Oceanic and Atmospheric Administration, Silver Spring, Md.; and **Hui-Chen Chien,** Environmental Protection Administration, Taipei, Taiwan

Ten Years After Katrina: What Have We Learned?

Fortune is an arbiter of half of our actions. ... I liken her to one of these violent rivers which, when they become enraged, flood the plains, ruin the trees and the buildings. ... It is not as if men, when times are quiet, could not provide for them with dikes and dams so that when they rise later ... their impetus is neither so wanton nor so damaging.
The Prince [Machiavelli, *1532; translation, 1985*]

On 29 August 2005, Hurricane Katrina struck coastal Mississippi, Alabama, and Louisiana. Damage was widespread, but the city of New Orleans was hit especially hard.

On this tenth anniversary of the disaster, it's worth looking back on how scientists and the nation responded to Katrina. Looking forward—given continuing coastal development, accelerating sea level rise, and warming oceans that can intensify storm surge—how can we prepare for future threats and disasters?

One mitigation strategy—relocating people and sensitive infrastructure to higher ground—has not been explored fully and eventually will need to be considered here and in other coastal areas as sea level rise accelerates.

A Brief History of the Storm and Its Aftermath

2005 had an active hurricane season, with 28 named storms and four category 5 hurricanes. After crossing Florida, Katrina intensified to category 5 as it passed over the warm waters of the Gulf of Mexico [*Trenberth et al.*,2007] but probably declined to category 3 by the time it struck the city.

Although warned in advance, some residents were unable or unwilling to evacuate. Of the approximately 1800 fatalities associated with Katrina, about a thousand were New Orleans residents who remained behind. Responders attributed many deaths to drowning; rising water trapped many people in the attics of single-story homes.

During the storm, Katrina breached many of the city's levees, which previously had protected the city from flooding by the Mississippi River and Lake Pontchartrain. For many days after the disaster, television news showed heartbreaking pictures of people in squalid conditions, awaiting relief and evacuation that seemed painfully slow. Analysts and community leaders widely criticized federal, state, and local governments for inadequate preparation and inept relief efforts.

Katrina stands as the costliest disaster in U.S. history, with losses exceeding $100 billion, and the third deadliest hurricane, after the 1900 Galveston hurricane that killed more than 6000 people and the 1928 Okeechobee hurricane that killed between 1800 and 2500 people. Many observers were surprised that a disaster like Katrina could befall a wealthy, technologically advanced nation like the United States. Ten years later, the population of New Orleans remains below prestorm levels, and some areas remain damaged.

Flood Mitigation and Geology

Experts pointed out the dangers of flooding from hurricane storm surge in New Orleans many years before Katrina struck. Similar events in 1965 and 1969 from Hurricanes Betsy and Camille flooded parts of the city.

New Orleans's unique geography makes it especially susceptible to flooding. Although all coastal cities are experiencing rising sea levels, New Orleans faces the additional problem of subsidence.

The city is constructed on the Mississippi Delta, and deltas subside from processes that include sediment compaction and crustal loading. In a natural deltaic system, sediment deposition occurs during spring floods and, over time, maintains the delta surface at or near sea level, compensating for subsidence. Along the lower Mississippi, levees prevent this natural renewal, and the channelized bed forces sediment deposition farther out in the Gulf of Mexico. Dams on the upper Mississippi also reduce sediment supply.

Settlers built the original town of New Orleans (the popular French Quarter familiar to tourists) on relatively high elevation natural levees adjacent to the river. However, the city grew far beyond this favorable site in the pre-Katrina years, occupying lower-elevation areas.

The highest rates of subsidence can be found in recently reclaimed land along the shore of Lake Pontchartrain, where sediments tend to compact at high rates for several decades after reclamation [e.g., *Kim et al.*, 2010], or in former marshes drained for urbanization, exposing organic matter to oxidation. At the time of Katrina, New Orleans was subsiding by about 5–6 millimeters per year, with some areas sinking faster than 20 millimeters per year [*Dixon et al.*, 2006].

Experts pointed out the dangers of flooding from hurricane storm surge in New Orleans many years before Katrina struck.

NOAA

A GOES-12 visible image of Hurricane Katrina shortly after landfall on 29 August 2005.

Marty Bahamonde/FEMA

Flooding from breached levees in New Orleans, La., following Hurricane Katrina. Photo taken 29 August 2005.

This latter process likely explains some of the lowest-lying areas of New Orleans, which were drained for urbanization in the mid- to late 1800s. Some of these areas currently lie 3 meters or more below sea level.

Costs

Disasters in the United States have been mainly associated with weather- and climate-related events such as floods, droughts, and wildfires. What's more, the costs of such disasters are increasing (Figure 1).

Some of the cost increase simply reflects increased population. However, since 1980, costs have increased fivefold during a period when population increased by only about 35%.

Some of the cost increase therefore likely reflects increasing frequency and intensity of weather-related events, although a detailed analysis would have to account for the increased value of coastal real estate.

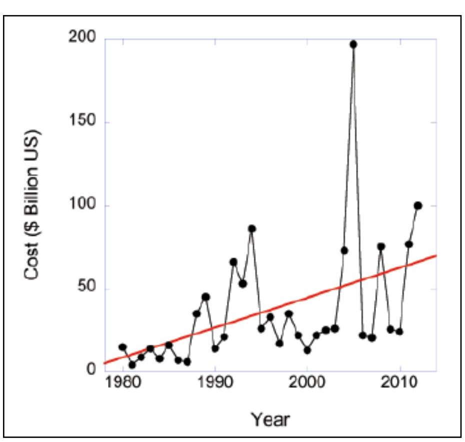

Fig. 1. Cost of natural disasters (insured plus uninsured losses) in the United States from 1980 to 2012 (in 2012 dollars). The best-fit line through the data has a slope of about $1.7 billion per year. The large spike in 2005 mainly represents Katrina. Data from Munich Re.

What Have We Learned?

Katrina represented a major disaster for the United States but also provides an opportunity for the nation and the world to learn from past mistakes. Scientists and engineers have conducted forensic analysis [*American Society of Civil Engineers* (*ASCE*), 2007; *Interagency Performance Evaluation Task Force* (*IPET*), 2007–2009] of some infrastructure failures, but to my knowledge, a far-reaching analysis of the various political, engineering, and scientific missteps that led to the disaster and its aftermath has never been done.

Katrina won't be our last major disaster. But using Katrina as a lens, we can take a hard look at all aspects of our preparations for and responses to disasters to ensure better future outcomes. Although some aspects of the Katrina disaster are unique (e.g., the low elevation of parts of New Orleans), the event shares common factors with a wide range of natural and human-made disasters.

Levee Failures, Pumping Stations, and Backup Power

The Army Corps of Engineers and the American Society of Civil Engineers [*ASCE*, 2007; *IPET*, 2007–2009] reviewed the levee failures. One conclusion: Low elevation contributed to several levee failures when storm surge overtopped and then eroded earthen structures.

The levee adjacent to the Mississippi River–Gulf Outlet Canal failed in this way, contributing to flooding of St. Bernard Parish, where 80% of housing was destroyed or damaged. Measurements by satellite geodesy between 2002 and 2005 showed this levee subsiding at rates sufficient to lower its elevation by about 1 meter since its construction in the 1960s [*Dixon et al.*, 2006].

An important note: Engineers conducted previous geodetic measurements on the levees with terrestrial leveling, requiring the use of a local reference point, which may also have been subsiding [*ASCE*, 2007].

Low-elevation pumping stations, control facilities, and backup power at critical facilities in New Orleans failed during flooding [e.g., *ASCE*, 2007; *Fink*, 2013]. A similar design flaw doomed the Fukushima nuclear facility in Japan 6 years later when backup power was disrupted by tsunami-induced flooding, leading to overheating and large-scale radiation release [*Nöggerath et al.*, 2011].

How to Rebuild After Disasters?

One opportunity missed during the rebuilding phase was the chance to move sensitive infrastructure and housing to higher ground (a significant fraction of the city is located at or above sea level). Sea level rise is accelerating in the Gulf region [e.g., *Karegar et al.*, 2015], and subsidence continues, so Katrina is unlikely to be the last flood experienced by the city.

Many people believe that widespread relocation is unrealistic. People would refuse to move, and in any case, it would be too expensive to subsidize the transition, they argue.

I can't speak to refusals to move, but a generous government subsidy, combined with a clear scientific statement about long-term flood risk, could be useful to help persuade people to shift to higher ground. To my knowledge, no such statement was ever made following Katrina.

Regarding the actual cost of relocation, less than 20% of the population lives at dangerously low elevation. My back-of-the-envelope calculations suggest that people could be moved to nearby higher ground for far less than the United States spent on bailing out bankrupt firms in the 2008 financial crisis.

Seven years after Katrina, 2012's Hurricane Sandy, with many features in common with Katrina—including prior expert warnings and the role of low elevation and warm ocean water—showed us how little progress we've made regarding storm mitigation.

Recommendations

Warming seas and rising seas increase the likelihood of future storm surge–induced flooding (see Figure 2). As scientists, we struggle to communicate to the public and policy makers how apparently small long-term average changes in temperature and sea level, convolved with natural short-term variability and increased coastal population density, lead to big increases in the risk of coastal flooding.

The local subsidence that played a role in Katrina's flooding makes it a useful indicator—a teachable moment—and a harbinger of disasters that will come eventually over a much broader area of the coastal

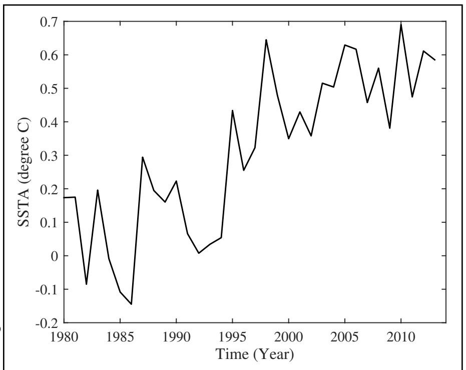

*Fig. 2. Average sea surface temperature (SST) in the North Atlantic since 1980, relative to 1901–1970, for the ocean area bounded by 0°–50°N and 10°W–80°W. Computed from the Hadley Centre Global Sea Ice and Sea Surface Temperature data set [*Rayner et al., *2003].*

United States. Houston, Tampa Bay, Miami, and cities around the Chesapeake Bay, such as Norfolk and Baltimore, are especially at risk.

Somehow, scientists need to make it clear that one degree of average temperature increase and a few millimeters per year of annual sea level rise mean many more Katrinas, each with the potential to cause thousands of fatalities, tens of billions of dollars in damages, and the destruction of major cities.

Everyone has his or her own list of lessons learned from Katrina. Here is a subset of my list, focusing on issues that apply beyond New Orleans:

- Scientists need to do a better job of communicating the long-term risks associated with rising sea level, increasing atmospheric and ocean temperatures, and intensifying storm surge. Devastation following Sandy highlighted that Katrina was not an anomaly—the prior storm just happened to be the first to get our attention.
- Geodesy has a role to play in highlighting coastal areas undergoing rapid subsidence. These areas serve as important canaries in the coal mine for the public and policy makers, illustrating in the short term (over the next few decades) what long-term (over the next few centuries) sea level rise will actually look like.
- Safety features such as backup power and communication and control facilities need to be designed and sited to be safe from flooding, high winds, and other damaging conditions.
- We need to develop recovery mechanisms for natural disasters that do not necessarily involve rebuilding in exactly the same spot. In the case of sea level rise and low-lying coastal areas, this means zoning and other policies that limit new construction in sensitive areas and promote a managed retreat from the coast, allowing some places to revert to green space and wetland.

Because the economic lifetime of many buildings is on the order of 50 years, relocation to higher ground should be possible without huge economic disruption and could be encouraged with tax incentives and relocation subsidies after a disaster. The 50-year time scale is longer than normally used in government and business planning but may be required if we are to avoid the worst effects of sea level rise.

Future Disasters and Our New Reality

It's true that the next disaster will occur at some unpredictable time in the future, but the devastation from Katrina and Sandy is a reminder that this future is not necessarily far away.

On this tenth anniversary of Hurricane Katrina and its devastation of New Orleans, let's resolve to do better, as scientists and as communities, in the ways that we communicate and listen about future threats and in the ways that we prepare for and respond to these inevitable disasters.

Acknowledgments

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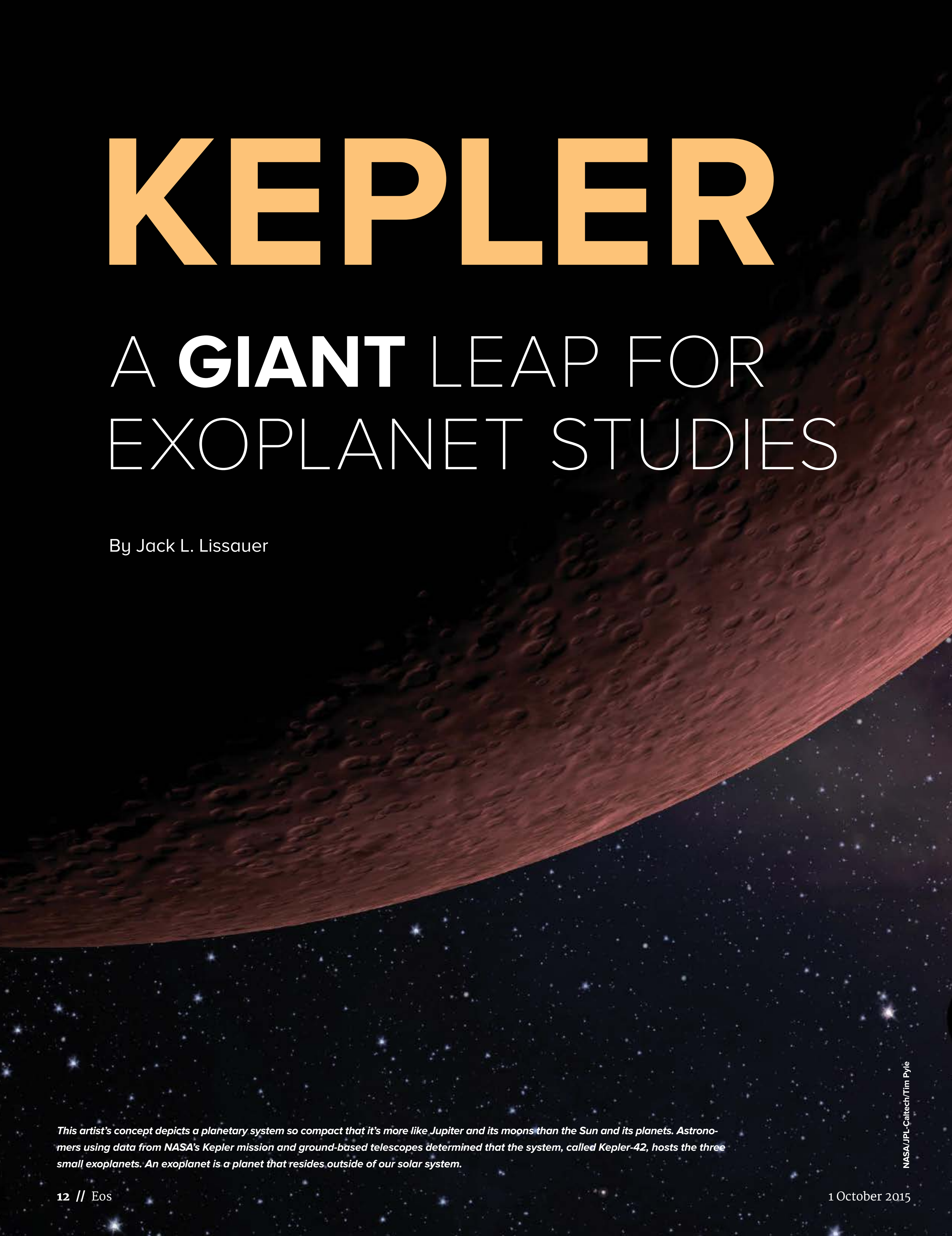
Mario Tama/Getty Images

Two men paddle in high water in New Orleans' Ninth Ward on 31 August 2005 after Hurricane Katrina devastated the Gulf coast.

KEPLER

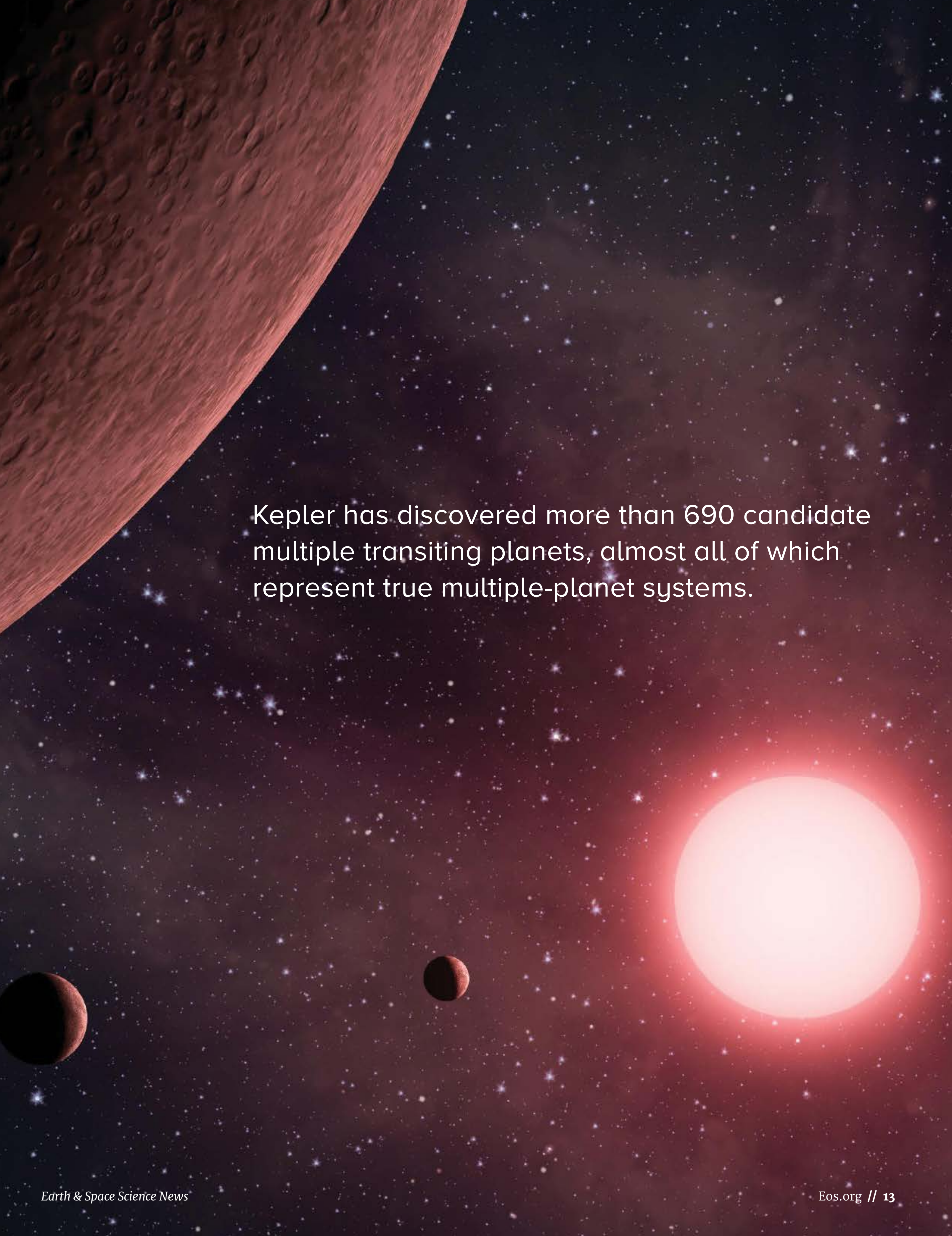
A GIANT LEAP FOR EXOPLANET STUDIES

By Jack L. Lissauer



This artist's concept depicts a planetary system so compact that it's more like Jupiter and its moons than the Sun and its planets. Astronomers using data from NASA's Kepler mission and ground-based telescopes determined that the system, called Kepler-42, hosts the three small exoplanets. An exoplanet is a planet that resides outside of our solar system.

NASA/JPL-Caltech/Tim Pyle



Kepler has discovered more than 690 candidate multiple transiting planets, almost all of which represent true multiple-planet systems.

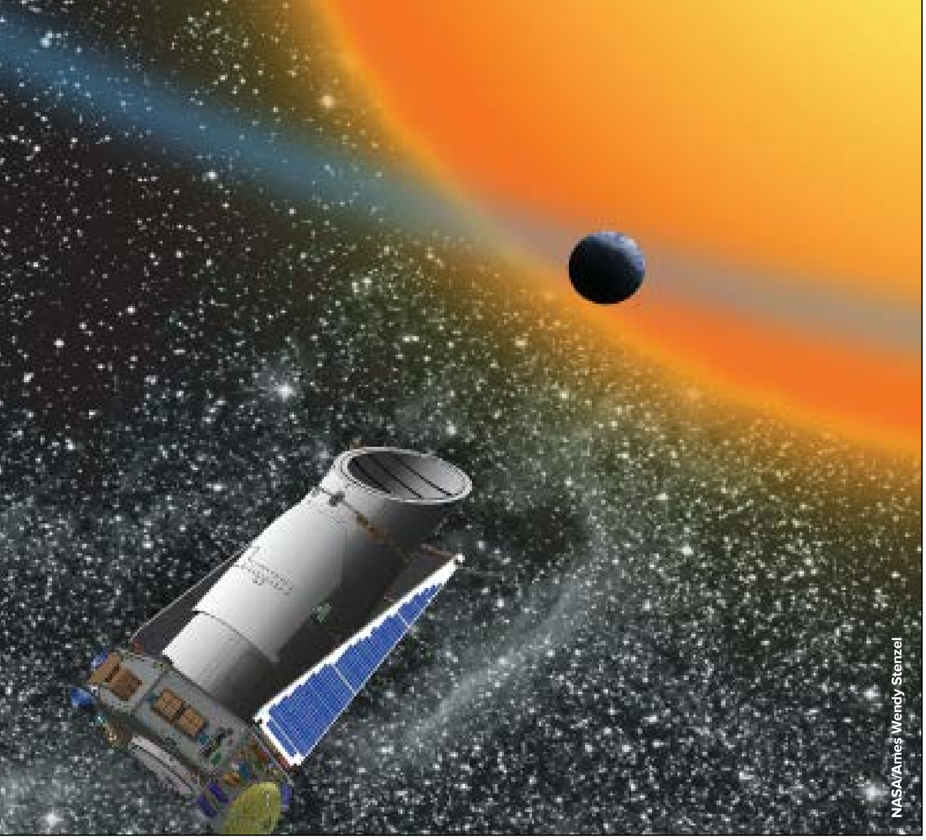


Fig. 1. An artist's rendition of NASA's Kepler space telescope.

Kepler data tell us that systems containing multiple planets on closely spaced orbits are quite common.

A mere quarter century ago, the only planets that we knew about orbited our Sun. Astronomers didn't know whether our solar system—eight planets, plus assorted moons, asteroids, and comets—was an analogue for other planetary systems and had no direct evidence that other planetary systems even existed at all.

Now, thanks to the recent findings of NASA's Kepler space telescope (Figure 1), our understanding of our galactic neighborhood has drastically changed. We know that we live in a galaxy full of planets that lie outside of our solar system.

These bodies, referred to as extrasolar planets, or exoplanets, include many kinds of objects and showcase a level of diversity that took astronomers by surprise. Extrasolar planets include gas giants and rocky worlds so close to their stars that they whip around them in less than one Earth week and planets only a few times as massive as Earth that have voluminous low-density atmospheres, like shrunken versions of Uranus or Neptune.

This diversity shook up scientists' ideas about how planets form and what a "normal" planetary system looks like. Now, 20 years to the month after scientists' first discovery of a planet around a star other than our Sun, we can take stock of how Kepler has revolutionized our understanding of worlds beyond our solar system.

The Hunt for Earth-Like Worlds

The search for planets outside of our solar system dates back more than 150 years, but early claims of discovery turned out to be erroneous. The first exoplanets discovered that have withstood the test of time are two small planets orbiting a pulsar [*Wolszczan and Frail*, 1992], but pulsars are stellar remnants rather than true stars, and few other planets have been discovered in orbit about them.

The floodgates opened 20 years ago this month with the discovery of 51 Pegasi b [*Mayor and Queloz*, 1995], a planet about half as massive as Jupiter whipping around a star not unlike our Sun, with an orbital period of only 4.23 days. Hundreds of planets have since been found from the ground, but all are much larger than Earth and/or orbit very close to their stars and are consequently very hot.

To find smaller worlds, NASA launched the 0.95-meter-aperture Kepler space telescope into an orbit around the Sun in 2009 [*Borucki et al.*, 2010; *Koch et al.*, 2010]. Above Earth's atmosphere and away from the glare and temperature variations of low Earth orbit, Kepler simultaneously monitored more than 150,000 stars, measuring their brightness every 30 minutes.

Kepler's mission centered on searching for periodic dips caused by planets crossing in front of their host stars as they orbited—events called transits. The spacecraft stared at the same patch of sky for 4 years, until the failure of two reaction wheels—the gyroscope-like flywheels that point and stabilize the craft—which ended the main mission in May 2013.

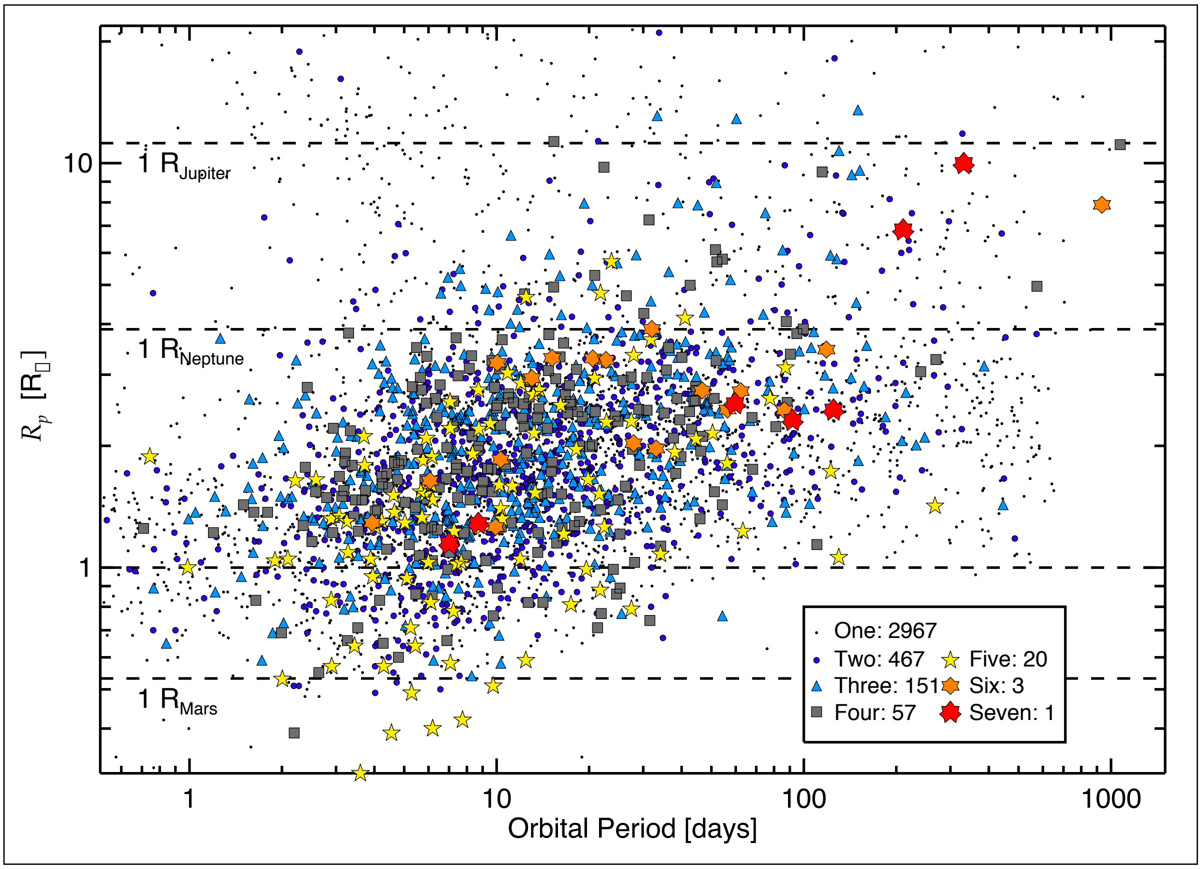
Scanning for transits requires high-precision photometry. Although the transit of a Jupiter-size planet across the disk of a Sun-like star blocks 1% of the stellar flux and can readily be identified using a ground-based telescope, an Earth-size transiting planet dims the same star by less than one hundredth of a percent.

Kepler's stability and custom-designed electronics allowed it to detect patterns of dips in brightness suggestive of more than 4600 planet candidates (Figure 2). Statistical analysis indicates that the vast majority of these signals represent true exoplanets.

In some respects, many of these systems look like miniature versions of our own solar system. Most of the planet candidates found by Kepler have years that are shorter than a few Earth months and sizes in between those of Earth and Neptune, a size that our solar system lacks. In addition, their orbits can be much more tightly spaced. More than one third orbit in systems where multiple transiting planets have been found, and Kepler data tell us that systems containing multiple planets on closely spaced orbits are quite common.

A Bounty of Planets

Individual planets and planetary systems can be exciting and illuminating discoveries [*Lissauer et al.*, 2014]. However, Kepler is primarily a statistical mission, designed to determine the abundance of planets as small as Earth that orbit within their star's habitable zones—the distance where planets with an atmosphere similar to Earth's



Rebekah Dawson, University of California, Berkeley

Fig. 2. Orbital period versus planetary radius for Kepler planetary candidates. The colored symbols represent how many planets orbit a given star, and the legend lists how many of this type of system are in the catalog. (For example, the catalog lists 2967 stars with only one planet orbiting them.) Planets with shorter orbital periods are overrepresented because geometric factors and frequent transits make them easier for Kepler to detect. The upward slope in the lower envelope of these points is caused by the difficulty in detecting small planets with long orbital periods, for which transits are shallow and few are observed.

receive the right amount of stellar radiation to maintain reservoirs of liquid water on their surfaces.

Kepler measures the sizes of planets when they flit in front of their host star: The bigger the dip in brightness is, the larger the size of the planet is relative to its star. Astronomers determine the size and density of the host star itself by combining ground-based observations with stellar models. In some cases, Kepler data can further refine these estimates on the basis of tiny variations in brightness caused by the stars' internal vibrations or by the shapes and lengths of the transits themselves.

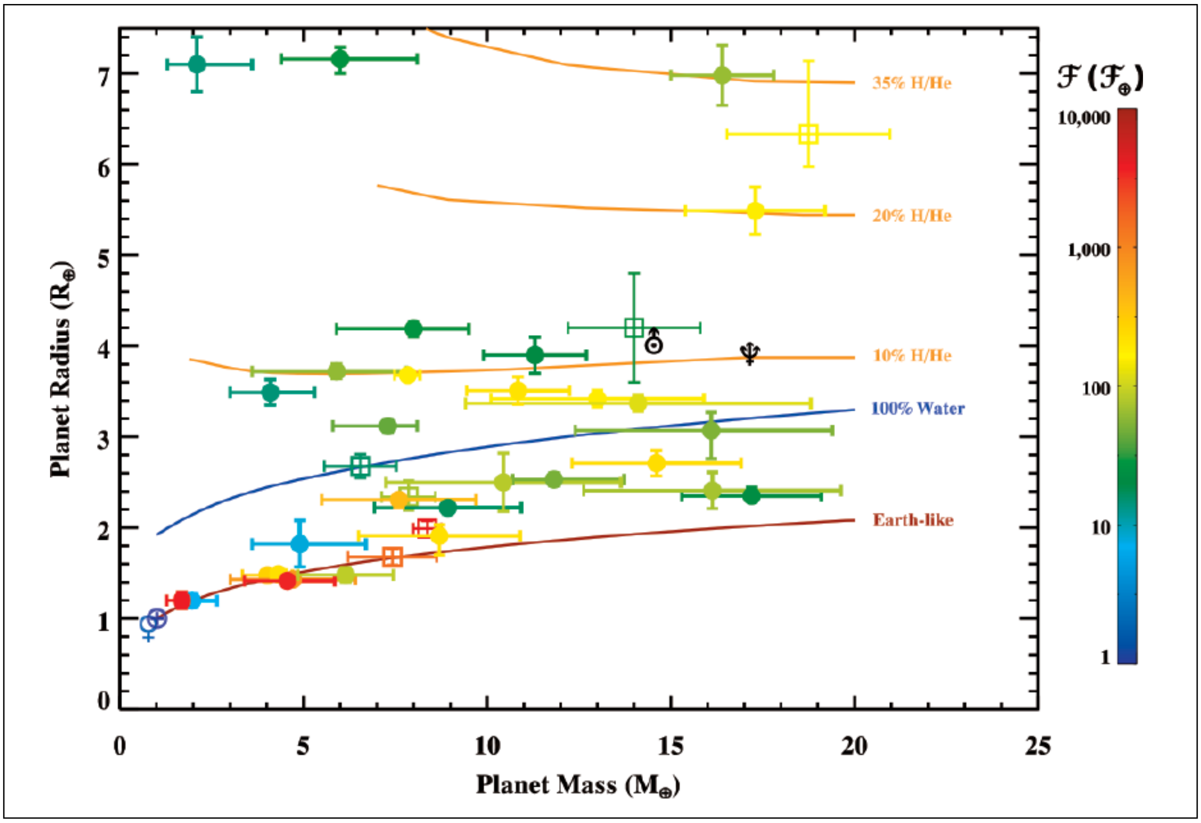
This ability to size up planets has led to the realization that planets smaller than Neptune (which is 4 times as large as Earth) are far more common than giant planets. Although the number changes from catalog to catalog, more than half of the planet candidates found by Kepler are 1–3 times the size of Earth and take less then 100 days to orbit their stars [*Batalha*, 2014]. The number of planets drops off gradually for periods below 10 days, but planets with periods as short as about 8 hours have been found.

What Are Exoplanets Made Of?

To find out what a planet is made of—and whether it is rocky, Earth-like, and potentially capable of supporting life—astronomers need to determine not just the size of a planet but also its mass. Traditionally, many of these mass measurements have come from the Doppler technique, which typically uses large ground-based telescopes to measure how the light of a host star shifts to redder and bluer wavelengths as it rocks back and forth in response to the gravitational tugs of the planet. This works best on planets with very short period orbits around relatively bright stars [*Marcy et al.*, 2014].

Kepler isn't able to directly measure masses (except for a few massive planets on very short period orbits that tidally distort their star to a measurable degree). However, astronomers can sometimes use Kepler data to indirectly determine the masses of planets in multiplanet systems by studying how their gravitational tugs pull on each other, which very slightly disturbs their orbits.

Such perturbations cause orbital paths to deviate from purely mathematical ellipses, speeding them up or slowing them down and interrupting the otherwise clockwork timing of their transits. The masses of dozens of Kepler planets, including some not much larger than Earth and others with orbital periods of up to a few months, have been measured by studying the transit timing variations (TTVs) produced by these perturbations.



Eric Lopez, University of Edinburgh

Fig. 3. Mass-radius diagram for planets with masses less than 20 times the mass of Earth, along with theoretical curves for different compositions. Planets are color-coded by incident flux of starlight as a multiple of the sunlight intercepted by Earth. Kepler planets are shown by solid circles; other exoplanets are shown by open squares. For comparison, Venus and Earth (lower left), Uranus (center), and Neptune (center right) are indicated by their planetary symbols. The maroon curve is for Earth-like composition, the blue curve is for pure water, and the orange curve is for an envelope of a 1% hydrogen-to-helium ratio atop a core of (bulk) Earth composition.

These measurements have revealed a class of planets astronomers didn't know existed: low-mass, gas-rich worlds. In fact, most planets with radii between 2 and 8 times that of Earth and orbital periods less than 100 days have quite low density, indicating that most of the planets' volume is filled with hydrogen and helium gas. However, using mass measurements, scientists know that heavier elements must comprise the vast majority of the masses of most of these large and light worlds.

There appears to be a fuzzy boundary between Earth-like rocky worlds with a thin atmosphere and these mini-Saturns with large, fluffy layers of gas. The data currently suggest that the upper end of the boundary region between rocky and other planets is at about 1.6 times the size of Earth (Figure 3). However, mass data remain sparse, are measurable only for planets around very bright stars, and suffer from detectability biases, so it remains unclear where the lower end of this boundary region lies.

Multiplanetary Systems

Kepler was designed to search for small planets in the habitable zone, but its ultraprecise, long-duration photometry is also ideal for finding systems with multiple transiting planets (multis). Kepler has discovered more than 690 candidate multis, almost all of which represent true multiple-planet systems.

The multitransiting systems observed by Kepler provide a large and very rich data set of short-period planets (with orbits cycling every few days to several months, in Earth terms) that can be used to powerfully test theoretical predictions of the formation and evolution of planetary systems. For one, the sheer number of Kepler multis implies that such systems with multiple close-in planets are common, with about 5% of stars having two or more planets that are at least 1.5 times as large as Earth and that complete full orbits in less than 100 Earth days.

Candidate systems with two or more transiting planets seem to orbit close to the same plane [*Fabrycky et al.*, 2014], suggesting mutual inclinations similar to our solar system. Orbits are nearly circular, with typical eccentricities of only a few percent. This ellipticity is similar to our solar system but small compared to those of most giant exoplanets with orbital periods of more than 10 days.

How Common Are Planets Like Earth?

Although Kepler has discovered planets smaller than Earth, these are hot worlds orbiting close to their stars or orbit stars much smaller than our Sun. Probably the best Earth analogue to date is Kepler-62f, which is 40% larger than Earth and therefore has a fairly good chance of being rocky. The exoplanet orbits a star about 30% smaller than the Sun at the right distance to have liquid water on its

These findings will continue to improve our understanding of how rare or ubiquitous planets like Earth are in our galaxy.

surface if it has an Earth-like atmosphere. Another possible Earth analogue is Kepler-186f, intermediate in size between Earth and Kepler-62f. This orb is likely to be rocky, but it orbits a much smaller star and thus is likely to be in a tougher environment for life as we know it to flourish.

As scientists continue to analyze the Kepler data, they expect to find hundreds if not thousands of additional Kepler planet candidates. In addition, better estimates of stellar parameters will lead to more accurate values for planetary sizes. Many more candidates will be verified as planets, and some of the false positives will be removed from the candidate pool. Many of the planets will be characterized better through future observations and analysis of TTVs.

As the numbers improve, scientists will seek to better quantify the fraction of stars hosting Earth analogues. This is of great interest to astrobiologists—it's an important step in determining how common the conditions for life are in the galaxy.

Prior to Kepler, the best estimates on the number of Earth analogues were based not on data but on theoretical models of planet formation. So far, Kepler has provided very good estimates of the abundance of Earth-sized planets only for those near their stars, which are easier to detect. Extrapolating these numbers suggests that Earth analogues are fairly common, albeit far from ubiquitous.

As data analysis proceeds, however, scientists will find more longer-period planet candidates, and good figures for the abundance of Earth-sized planets will probably be available for those with orbiting periods out to 100 days. At periods of 1 year, good abundances will probably be available for planets twice the size of Earth.

These data will allow much better estimates of the number of Earth analogues, requiring less extrapolation. Some extrapolation will still be necessary and will extend in two directions: upward in period for Earth-size planets and downward in size for planets with orbital periods similar to that of Earth. This will provide a consistency check on results.

What's Next for Exoplanet Studies?

Although the hobbled Kepler spacecraft cannot observe its original star field any longer, its engineers were able to reconfigure the craft for a new mission, dubbed K2, to continue its search for other worlds. With only two good reaction wheels, the craft can maintain the necessary stability along only two axes. To remain stable enough to take good data, Kepler must point nearly parallel to its orbital path around the Sun so that sunlight falls on it evenly and the resulting pressure doesn't send the spacecraft into a spin.

K2 can study a specific patch of sky for up to 83 days—at which point the spacecraft must rotate to prevent sunlight from entering the telescope. Since Kepler typically needs to see two or three transits before declaring a signal to be a potential planet, it is primarily discovering planets with orbital periods of less than 30 days.

The European Space Agency's Gaia spacecraft, launched in 2013, is also aiding exoplanet scientists by helping to determine the distances to Kepler planet-hosting stars very accurately, enabling better estimates of their sizes and therefore of the sizes of their planets. Gaia will also discover new planets, primarily massive ones with orbital periods of 1 to a few years around nearby stars, from observing the wobble that these planets induce in the positions of their stars on the sky.

Kepler will soon have a true spiritual successor: The Transiting Exoplanet Survey Satellite, or TESS, a NASA mission scheduled to launch in 2017, will scan the entire sky for transiting planets around the nearest and brightest stars. Their brightness means that the planets TESS discovers will be easier targets for follow-up observations from the ground and NASA's James Webb Space Telescope (to launch in 2018).

TESS will observe Kepler planets during a portion of its mission, which will allow it to collect more observations of TTVs for those targets. This will be very useful; having TTVs that span a large range of time greatly improves the accuracy of the measurements of the masses and orbital characteristics of the planets. Planetary Transits and Oscillations of Stars (PLATO), a European mission scheduled for launch by 2024, will also take additional TTV measurements for Kepler targets, as will ground-based telescopes.

These findings will continue to improve our understanding of the masses and radii of rocky exoplanets—and ultimately how rare or ubiquitous planets like Earth are in our galaxy.

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Early-career scientists sample the hydrothermal field in Furnas Volcano in the Azores.

Helping Early-Career Researchers SUCCEED

By Harmony V. Colella, Derek L. Schutt, Danielle F. Sumy, and Andrew M. Frassetto

The early years of a scientist's career are no doubt some of the most demanding. As scientists transition from senior graduate students through postdoctoral fellowships and into pretenure faculty positions or to employment opportunities outside of academia, they are faced with a multitude of challenges.

These junior scientists must develop as independent researchers while also establishing new collaborations. Many must also adapt to the

Early-career investigators expressed appreciation for exposure to a variety of workforce options, as discussions at their home institutions tend to focus primarily on academic careers.

classroom, despite the limited teacher training available in graduate school. However, many receive little mentoring and guidance during this difficult transition period.

In an effort to help newly minted scientists, researchers, and educators succeed, the Incorporated Research Institutions for Seismology (IRIS) Consortium created an early-career investigator (ECI) working group in late 2011. Its mission is to organize practical resources and professional development opportunities for ECIs (see http://www.iris.edu/hq/eci).

Over the past 4 years, the working group has strived to build a network among ECIs to generate new collaborations, bring awareness of nonacademic career paths, and create a centralized set of research and educational resources that ECIs can share. Through a series of lectureships and joint partnerships, the working group has also sought to increase the visibility of ECIs and their research and has promoted mentorship and collaboration between junior and senior scientists.

Charting a Career Path

To grow the ECI community, provide a forum for in-depth discussion, and disseminate information to a broader audience, the working group organized mini-workshops and discussions at several national meetings, including those hosted by AGU, IRIS, and the National Science Foundation's (NSF) EarthScope program. Up to 70 ECIs attended each event, which exposed participants to the working group's initiatives and resources, provided insight into various career paths, and better informed working group organizers about the needs of the community.

Career-oriented fora have included discussions with more senior researchers in diverse academic and government careers, such as those at research universities, undergraduate institutions, and the U.S. Geological Survey. The panelists discussed the expectations at their type of institution and shared their personal obstacles to achieve tenure.

Events also focused on nonacademic career paths. About 45 ECIs attended a workshop held before the 2013 EarthScope National Meeting in Raleigh, N.C., where a geophysicist from British Petroleum provided an insider's view of the challenges and rewards of a career at a major oil company. Roughly 30 ECIs attended a workshop before the 2014 IRIS meeting, where representatives from the American Geosciences Institute and Department of Energy highlighted the plethora of job opportunities available outside of academia, including in science writing, public policy, and consulting. Throughout each event, speakers fielded candid questions about the challenges and successes one might experience in such careers.

The career-focused workshops have been very popular. Notably, ECIs have repeatedly expressed their appreciation to workshop conveners for the exposure to a variety of workforce options, as discussions at their home institutions tend to focus primarily on academic careers.

Tackling Career Obstacles

The working group also organized fora that tackled other issues of importance, such as funding opportunities, featuring presentations from a NSF program officer, as well as the ever-present concern of "work-life balance," featuring panelists spanning different stages in an academic career (postdoctoral researchers to full professors).

In 2014, IRIS co-organized a webinar and a luncheon with the geodesy consortium UNAVCO. The webinar, which aired 2 weeks before AGU's Fall Meeting, focused on best practices in scientific communications to prepare ECIs for the luncheon. During the luncheon at AGU's Fall Meeting, roughly 30 ECIs presented 2-minute "elevator talks" on their research, which were immediately followed by discussion among the attendees about research challenges and potential collaborations.

AGU meetings have also provided a great opportunity for the working group to reach across the geophysics and geology subfields to showcase its work and initiatives. At AGU's 2012 Fall Meeting, we held an ECI luncheon cosponsored by the national offices of EarthScope and the NSF-supported Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS) initiative.

The luncheon was advertised via a variety of listservs, Facebook, *Eos*, and word of mouth. The primary purpose involved encouraging interdisciplinary networking among the roughly 60 attendees, whose fields spanned a broad range of geoscience disciplines. This enabled ocean- and land-based geologists and geophysicists, from geochemists to geophysicists, to explore collaborative amphibious projects based on field location or research site.

A Portal to Resources

The ECI working group also strives to share its online resources. It created a website (see http://www.iris.edu/hq/eci) and mailing list and established a social media presence via Facebook and Twitter to collect and distribute various ECI-related resources.

The website collects and organizes relevant community resources. These include profiles of posttenure seismologists and geodesists who volunteered to serve as mentors, abstracts from ECIs who are available to present departmental colloquia, a list of notable funding opportunities, and links to other resources such as the seismology code repository developed by IRIS Data Services.

Graduate students and faculty participate in a field trip to the Newark rift basin, held the day before the GeoPRISMS Planning Workshop for the East African Rift System in Morristown, N.J., in October 2012. Here participants examine a normal fault developed in Late Triassic mudstone in Kintnersville, Pa.

As a result of popular demand from the community, we continue to offer regular ECI-centric webinars, which focus on topics that span technical software tutorials, proper presentation of scientific lectures, how to navigate federal funding agencies, and best research-based teaching practices. The webinars are streamed live with interactive question-and-answer sessions and can be viewed on the IRIS Education and Public Outreach YouTube channel (http://bit.ly/IRIS_YT), where they are permanently archived. ECI-centric webinars have quickly become the most popular of all IRIS webinars.

A Course Repository for ECIs

Instructors invest a significant amount of time in proper course and curriculum preparation. This process is especially burdensome for ECIs who must develop courses for the first time. To ease the workload, the working group is building a curated community course repository with materials that will range from complete courses to individual exercises.

Through this repository, ECIs will be able to download a whole course on seismology, for instance, which would include lecture notes, homework, and test keys. Alternatively, they could augment an existing course by downloading an independent laboratory exercise about focal mechanisms or moment tensors, for instance. The repository, which will be housed on the IRIS website, will start with the course "Introduction to Seismology." More advanced course materials will be added gradually once this example course is complete.

We plan to solicit course materials for other common classes that tenure-track ECIs teach during their first year, such as geodynamics or geophysics. An important component of this effort is that the repository database will initially be password protected, with the hope that full courses will be submitted for curation. As courses are improved by users and modifications are uploaded, we plan to turn highly downloaded courses into community-based courses that will be publicly available (minus any homework or test keys).

To our knowledge, such a teaching resource is unprecedented in academia, and its implementation will be closely monitored by IRIS and the ECI working group to evaluate its success.

Helping ECIs Form Collaborations

One of the most important tasks for ECIs' career advancement involves reaching out to the greater geoscience community by dissemination of their research results and establishing collaborations at other institutions. Some of the best opportunities to do both arise from invitations from other departments to give colloquia talks, which allow researchers to present their work and have face-to-face time with potential collaborators.

However, ECIs are being shut out from these opportunities under the current economic climate, in which many universities are under strict budget constraints that rarely cover the travel costs of distant colloquium speakers. Furthermore, those who typically organize a department's colloquia often fail to recognize ECIs as potential speakers

Today’s ECI must understand the challenges that lie ahead, particularly given the weak domestic economic, government funding, and employment climate.

because they lack name recognition. The lack of speaking opportunities not only hurts ECIs but also deprives departments of exposure to new blood and fresh ideas.

To address this challenge, the working group piloted two programs in 2014 to help ECIs develop new collaborations across the member institutions of the IRIS Consortium. In the inaugural year, five ECIs were awarded fund-matching lectureships to travel to another institution as a colloquium speaker, with extra time allotted (up to 1 week) to develop new collaborations. Under the second program, two ECIs were awarded extended stays of up to a month to collaborate with and learn from a senior scientist with complementary skills and give a colloquium talk.

The ECIs funded by the program reported that new collaborations were indeed established, which resulted in meaningful science and proposal opportunities. Of the five ECI colloquium speakers, three submitted proposals to the NSF, and one presented preliminary results at the 2014 Seismological Society of America meeting in Anchorage, Alaska. Two additional proposals were submitted to NSF by ECIs who had extended junior-senior scientist visits.

Moving Forward

Today’s ECI must understand the challenges that lie ahead, particularly given the weak domestic economic, government funding, and employment climate. Feedback from ECIs to working group organizers indicates that ECIs know too little about employment opportunities outside of academia and the energy industry. Additionally, ECIs request guidance and resources on how the skills and expertise acquired in graduate school are applicable to the widest range of careers. The IRIS ECI working group continues to address these topics through workshops at annual meetings and webinars.

ECIs have requested that IRIS develop a formal mentoring program that pairs young geoscientists with mentors within their discipline. Ideally, the program would be a tiered mentor network that consists of an undergraduate student, graduate student, postdoctoral researcher, pretenure faculty, and senior scientist. Such a program is also ideal for a mentor training program, which could be done within, or across, several NSF-funded programs (e.g., EarthScope, GeoPRISMS, or IRIS).

Expanding to Other Geoscience Disciplines

Many of the concerns and potential resources described here are not specific to the solid Earth sciences, and the activities we have described are transferable to other disciplines. Other geoscience organizations and consortiums should consider a focused effort to develop resources for ECIs.

Furthermore, it would be beneficial to develop interdisciplinary resources that many different scientific communities and networks can share. This “across the aisle” collaboration is particularly important in today’s increasingly limited funding environment, where collaborative research proposals that focus on interdisciplinary research are often more competitive.

The ECI working group is open to collaborations and partnerships with other consortiums, organizations, or groups to expand the reach of and increase the resources available to ECIs. We hope to work together to build a large-scale, geoscience-centric ECI organization to aid the success of ECIs, no matter what path they pursue.

Author Information

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AGU, ESA Foster Network Collaborations


JoAnna Wendel

Eric Davidson and Jill Baron hold the official citation celebrating the partnership between AGU and the Ecological Society of America.

Scientists, educators, program directors, and students gathered 10 August to celebrate the new partnership between the Ecological Society of America (ESA) and AGU. The partnership aims to foster collaboration opportunities among research networks on global, continental, and regional scales.

The evening event, the first official joint gathering between ESA and AGU, was held at ESA's 100th annual meeting in Baltimore, Md. It brought together representatives from several research networks—including the Critical Zone Observatories, the Long Term Ecological Research Network, and the National Ecological Observatory Network (NEON)—to "demonstrate the synergies among those networks and the synergies between the science of AGU and ESA," Eric Davidson, AGU president-elect and director of the University of Maryland's Center for Environmental Science, told *Eos*.

Representatives from the various research networks explained how the networks can be used for collaboration across regional and global scales.

With opportunities for scientists to work together "across the different science activities and data structures, we start becoming more and more interoperable," said Russ Lea, the chief executive officer of NEON.

With this partnership, "we can start taking the data from one side against another side against another location and start building hypotheses," he said.

When Jill Baron, a past president of ESA and current researcher at the U.S. Geological Survey, asked how many audience members were also AGU members, the majority of attendees raised their hands.

"These are truly societies that are joined beautifully between understanding the aboveground ecosystems and the belowground ecosystems, and that [partnership] will only grow," Baron said in response to the raised hands.

Davidson also presented Baron with an official citation from AGU celebrating the newly formed partnership.

By **JoAnna Wendel,** Staff Writer

Global Warming Intensifies Drought Conditions in California

Elena Aravina, CC BY-SA 2.0 (http://bit.ly/ccbysa2-0)

"Bathtub rings" around California's Lake Oroville show just how far the waters have receded.

The Golden State earned its name for the precious metal, but for the agricultural giant, the most precious commodity of all might be water. The recent drought dealt a heavy blow to western states, which manifested in groundwater depletion, fields left fallow, tree die-offs, and the latest rise in wildfires. The 2012–2014 drought broke records in California's key agricultural regions, and conditions in 2014 were record-breaking statewide.

A recent study evaluates the role of anthropogenic climate change on these severe drought conditions. The new insight is fundamental to better protecting communities and ecosystems that depend on California's most precious resource. Decreasing soil moisture, lowering river levels, and diminishing groundwater reserves could be disastrous for the state, especially in the Central Valley, the primary agricultural region that relies on steady irrigation.

Williams et al. drew data from the Palmer drought severity index, a proxy for drought conditions that calculates near-surface soil moisture from precipitation and temperature records. They looked at records between 1901 and 2014 to identify the impact of rising global temperatures on drought severity. The team also worked to distinguish natural temperature variability from anthropogenic warming. The authors conclude that "anthropogenic warming is estimated to have accounted for 8–27% of the observed drought anomaly in 2012–2014 and 5–18% in 2014."

The researchers found that the current droughts naturally occur but got intensified by the rise in global temperatures since 1901. Although lack of precipitation is still the primary driver of drought, anthropogenic warming has resulted in a significant trend toward drought and has increased the probability of severe drought overall.

The trend toward drought emerged because warming disrupts the natural climate variability that would normally offset drying. Warming since the early 1900s causes an additional 9 centimeters of annual evaporation during a given year, effectively making each raindrop or snowflake less valuable to humans and ecosystems because it is more readily evaporated.

With warming projected to continue throughout the 21st century, this study highlights the need for long-term planning to improve drought resilience. A steadily warming planet will have profound local impacts that require conscientious resource management to safeguard lives and livelihoods. (*Geophysical Research Letters*, doi:10.1002/2015GL064924, 2015) **—Lily Strelich, Freelance Writer**

Surface Climate Processes Keep Earth's Energy Balance in Check

Bumping up atmospheric carbon dioxide (CO_2) levels causes temperatures to rise across Earth's surface. This direct climate correlation is well established, but measuring CO_2 levels is not enough to build accurate climate models. Making precise predictions of temperature and weather patterns around the globe requires models that incorporate what scientists call feedbacks, an array of secondary changes that can amplify or diminish climate change.

As Earth warms, it radiates heat back into space, creating a negative feedback. But extra moisture in the air acts to trap outgoing radiation, further increasing the temperature. When the Earth's atmosphere absorbs more energy than it reflects or releases, the planet warms and vice versa. Taken together, these processes direct radiative forcing, or the overall balance of energy, to keep energy gains and losses in equilibrium.

Traditionally, scientists have studied the processes behind these gains and losses in energy where the action happens—at the top of Earth's atmosphere. There the feedback processes at work to keep the amount of energy lost and gained in equilibrium determine global temperatures.

Previous research has shown that these same processes operate at the planet's surface and can drive fluctuations in surface temperatures, the water cycle, and weather patterns that have direct impacts on humans and the environment. But uncertainties in the strength and structure of surface energy responses remained. Recently, *Colman* aimed to create a more comprehensive picture of the radiative feedbacks operating at Earth's surface when CO_2 levels steeply climb.

Colman used a global circulation model to examine surface radiation changes under scenarios in which CO_2 was doubled or quadrupled. He found that changes in cloud formation, relative humidity, and latent heat flux all contributed to a rapid response in surface energy. Ultimately, the study showed that as Earth's surface warms, extra radiation trapping from increased water vapor will exceed direct surface radiative cooling, driving a net increase in evaporation.

Overall, his findings indicate that feedback processes at Earth's surface differ widely from those at the top of Earth's atmosphere, where they're commonly measured. (*Journal of Geophysical Research: Atmospheres,* doi:10.1002/2014jd022896, 2015) **—Eric Betz, Freelance Writer**

Refining Solar Wind Models to Better Predict Space Weather

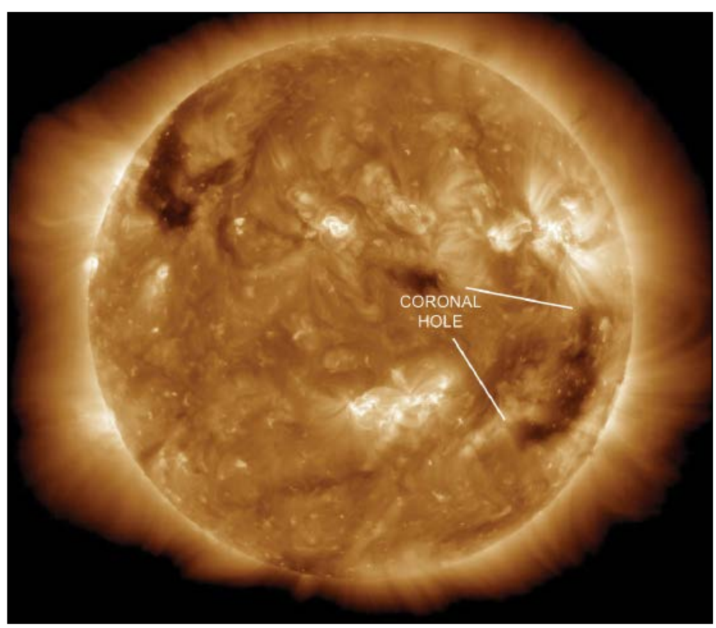
In the early 1970s, Apollo astronauts employed X-ray telescopes on board Skylab to continuously track coronal holes on our Sun for the first time. Their images showed dark areas with unusually low temperatures and densities where our star's magnetic field reached out into space instead of looping back, allowing particles to stream out from the Sun. During most of the 11-year solar cycle, these holes only cover the Sun's polar caps, but in active periods, the holes can exist anywhere.

Two decades of observations built on the Skylab results, and in 1990, that research allowed astronomers from the Naval Research Laboratory to tie solar wind speed to the expansion factor of the Sun's magnetic field lines. This model, first suggested by Wang and Sheeley, still underpins space weather forecasts today, helping the National Oceanic and Atmospheric Administration predict background solar wind speeds and Earth's magnetic field.

Now *Riley et al.* suggest that models have evolved so much that the expansion factor underlying the 25-year-old observed relationship might no longer be needed. Instead, the authors suggest that solar wind speed might be dependent on the distance from the coronal hole boundary.

The team compared predictions they made using the original relationship to a new version of the model that calculates solar wind speed by measuring the perpendicular distance to the coronal hole boundary. The model also maps solar wind trajectories out from the Sun's visible surface to the edge of its corona—the Sun's outer atmosphere—and even out to Earth.

Their technique showed better agreement between observations and models than with the original relationship alone. The team also suggests that by studying various predictions made by each model, scientists might be able to better understand the origin of the solar wind itself. (*Space Weather,* doi:10.1002/2014SW001144, 2015) **—Eric Betz, Freelance Writer**



This coronal hole–roughly 30 times wider than Earth–dominated the Sun's surface in June 2011. The solar magnetic field is open-ended in these dark regions, allowing high-speed solar winds to stream into space.

Atmospheric Sciences

Associate Professional Specialist/Professional Specialist Position in Intraseasonal-to-Decadal Real-time Predictions and Predictability Research

In collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), the Atmospheric and Oceanic Sciences Program at Princeton University is seeking candidates with a strong computational and technical background to fill an associate professional specialist/professional specialist position.

Candidates will join a vibrant research team and play a leading role in supporting real-time seasonal forecasting of climate using complex models simulating the Earth system. The position will require performing predictions every month, as well as research into predictability. This will involve configuration, running and analysis of state-of-the-art coupled climate models running on supercomputers.

Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding. Some amount of travel (to conferences or workshops) may be required. Salary commensurate with experience.

Complete applications, including a CV, copies of recent publications, names and contact information for at least 3 references are required in order to solicit letters of recommendation; applications should be submitted by October 15, 2015 for full consideration. Applicants should apply online to http://jobs.princeton.edu, Requisition #1500566. For additional information, contact Gabriel Vecchi (gabriel.a.vecchi@noaa.gov).

This position is subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

COLORADO STATE UNIVERSITY ATMOSPHERIC SCIENCE TENURE TRACK FACULTY POSITIONS COLLEGE OF ENGINEERING

The Department of Atmospheric Science at Colorado State University invites applications for two tenure-track faculty positions at the assistant or associate professor level. We solicit candidates in the research areas of (1) clouds and mesoscale processes, and (2) surface-atmosphere interactions - with expertise in land-atmosphere coupling preferred.

Further information about the open positions and details on how to apply can be found at http://jobs.colostate.edu/postings/17728.

Applications and nominations will be considered until the positions are filled; however, applications should be received by October 31, 2015 to ensure full consideration. Applicants should submit a cover letter, one to two page statements on research and teaching interests, curriculum vitae, and the names of four references.

CSU is an EO/EA/AA employer.

Colorado State University conducts background checks on all final candidates.

Postdoctoral Scientist in "Multi-Decadal Internal Climate Variability and Its Role in Climate Change"

The Atmospheric and Oceanic Sciences Program at Princeton University, in cooperation with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral scientist for research related to multi-decadal internal (natural) climate variability and its potential role in explaining observed climate changes. A key focus is to improve understanding of the role of low frequency internal climate variability in the current "hiatus" in global warming, as well as previous hiatus and accelerated-warming periods during the 20th century. Such understanding plays an important role in the detection and attribution of observed climate changes. The research will use various approaches to understand the physical mechanisms causing the observed decadal changes including quantification of contributions from both internal climate variability and responses of the climate system to various natural and anthropogenic forcing agents (e.g., greenhouse gases, aerosols, and volcanic eruptions). The research will make extensive use of both observations and a variety of modeling tools. The selected candidate will have a Ph.D. and one or more of the following attributes: (a) a strong background in climate/ocean dynamics or coupled air-sea interactions, (b) experience conducting and analyzing coupled climate model experiments, and (c) strong diagnostic skills in analyzing simulated and observed data sets.

This is a two-year position (subject to renewal after the first year contingent upon satisfactory performance and funding availability) based at GFDL/NOAA in Princeton, New Jersey. Complete applications, including a CV, publication list, names of 3 references for letters of recommendation, and a one-to-two page statement of research interests should be submitted. Review of applications will begin as soon as they are received and continue until the position is filled. Applicants should apply online to http://jobs.princeton.edu, Requisition #1500509. For additional information on the position, please contact Rong Zhang (Rong.Zhang@noaa.gov) or Tom Knutson (Tom.Knutson@noaa.gov). This position is subject to the University's background check policy.

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

Geochemistry

Lecturer, Department of Geosciences College of Sciences and Mathematics, Auburn University

The Department of Geosciences at Auburn University invites applications for a 9-month non-tenure track faculty position in Geology beginning January 1st, 2016. The position is a one-year appointment subject to annual review based on performance and funding. The candidate should be pedagogically trained to teach courses in economic geology and geochemistry.

Applicants must have either a Ph.D. or M.S. in Geology/Geoscience with demonstrable teaching experience. The successful candidate will teach two or more lecture sections and possibly one or more lab sections per term, and serve as laboratory coordinator for his/her labs. Required qualifications include excellent written and interpersonal communication skills. The candidate selected for the position must meet eligibility requirements to work in the United States at the time the appointment begins.

Review of applications will begin October 15th, 2015, and will continue until a suitable applicant is found. Applicants should submit curriculum vitae, a letter of application (1-2 pages) describing teaching philosophy and experience, and the names and contact information of at least three references.

In order to apply for this position and view full details, please visit our online website at http://aufacultypositions.peopleadmin.com/postings/1195.

Applicants are encouraged to visit the AU website to learn more about Auburn University and the Department of Geosciences (http://www.auburn.edu/academic/cosam/departments/geosciences/).

Auburn University is an EEO/VET/Disability Employer

Postdoctoral researcher in stable isotope geochemistry

A postdoctoral position in stable isotope geochemistry is available in the Department of Earth, Planetary, and Space Sciences at UCLA. The successful candidate will join a burgeoning team dedicated to developing novel isotopic molecular tracers using the unique high-mass-resolution gas-source mass spectrometer housed in the Department (Panorama). Emphasis will be placed on studies related to the provenance of methane gas in a broad spectrum of settings, but the new laboratory offers opportunities for studies of rare isotopologues for a range of molecular species and isotope systems. We seek an individual with experience in isotope ratio mass spectrometry and the creativity and motivation to develop new analytical techniques and novel avenues of inquiry.

To apply, please forward you resume to: To Professor Ed Young at EYoung@epss.ucla.edu

Ocean Sciences

Department of Marine, Earth, and Atmospheric Sciences Assistant Professor - Marine Microbiology

The Department of Marine, Earth, and Atmospheric Sciences (MEAS) at North Carolina State University (NC State) is seeking to fill a tenure-track faculty position at the Assistant Professor level in the area of marine microbiology. Expertise is desired in prokaryote ecology and molecular diversity with interests in genetic and biogeochemical methods for examining community composition and function in marine systems. Possible associated research areas include: biogeochemical-based ecosystem modeling; climate change; elemental cycling; extreme environments; food safety/security/public health; or water quality. A research focus on experimental and field studies using state-of-the art molecular techniques is preferred, as are experience and a strong interest in interdisciplinary collaborations across and beyond the geosciences.

The position is available 1 August 2016. Applicants must hold a Ph.D. degree in the oceanographic or related sciences. The successful candidate must demonstrate strong potential for outstanding accomplishments in research, research supervision, and teaching. Specific course offerings may include undergraduate or graduate biological oceanography or marine microbiology, or other classes commensurate with the candidate's interest and expertise. An interest in participating in the Department's capstone undergraduate coastal processes field course also is desirable. MEAS places a high value on excellent instruction and the use of innovative teaching methods.

Located within the College of Sciences at NC State, MEAS is one of the largest interdisciplinary geoscience departments in the nation. Opportunities exist for disciplinary and interdisciplinary interactions with more than 30 marine, earth and atmospheric scientists. MEAS is one of six departments across three colleges with a presence at the NC State Center for Marine Sciences and Technology (CMAST), a coastal and marine science research facility located on Bogue Sound in Morehead City, NC. Additional information about the department and its facilities can be found on the web page: http://www.meas.ncsu.edu and http://www.cmast.ncsu.edu NC State also hosts large programs in microbiology and biotechnology: http://www.microbiology.ncsu.edu/ & http://biotech.ncsu.edu/ and has recently established the Center for Geospatial Analytics: http://geospatial.ncsu.edu.

Review of applications will begin on 10 October 2015; the position will remain open until filled. Applications, including cover letters, curriculum vitae, teaching and research statements, and contact information for three references must be submitted online at https://jobs.ncsu.edu/postings/56255.

Founded in 1887, NC State is a land-grant institution distinguished by its exceptional quality of research, teaching, extension, and public service. Located in Raleigh, North Carolina, NC State is the largest university in North Carolina, with more than 34,000 students and 8,000 faculty and staff. National rankings consistently rate Raleigh and its surrounding region among the five best places in the country to live and work, with a highly educated workforce, moderate weather, reasonable cost of living, and a welcoming environment. A collaborative, supportive environment for business and innovation and research collaborations with area universities and the Research Triangle Park are compelling reasons for relocation to the area. NC State is an equal opportunity and affirmative action employer. All qualified applicants will receive consideration for employment without regard to race, color, national origin, religion, sex, sexual orientation, age, veteran status, or disability. Applications from women, minorities, and persons with disabilities are encouraged.

Postdoctoral Research Associate in Oceanic Variability, Predictability and Change

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral research associate or a more senior for research related to intraseasonal-to-decadal oceanic variability, predictability and change. A key focus will be systematic comparison of observations and dynamical models to understand the character of and causes behind past changes to the ocean, with focus on the impact of the ocean on intraseasonal-to-decadal predictability. This would likely include assessment of and modifications to coupled and ocean data-assimilation systems. This will include assessments of predictability arising both from natural variability and radiative forcing changes. The research will also examine interactions between natural decadal variability and the climate system response to radiative forcing changes, including attribution of observed ocean changes. The research will make extensive use of both observations and a variety of modeling tools, including newly developed high-resolution global climate models. The selected candidate will have one or more of the following attributes: (a) a strong background in physical oceanography, climate dynamics, or a closely related field; (b) experience using and analyzing advanced climate models and ocean observational datasets, and (c) strong diagnostic skills in analyzing large data sets.

Candidate must have a PhD. Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding.

Complete applications, including a CV, publication list, at least 3 letters of recommendation, and a statement of research interests should be submitted by October 15, 2015 for full consideration. Applicants should apply online to http://jobs.princeton.edu, Requisition #1500567. For additional information, contact Gabriel Vecchi (gabriel.a.vecchi@noaa.gov).

This position is subject to the University's background check policy. Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Postdoctoral Scientist in Ocean Modelling

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) and the Department of Geophysical Sciences at The University of Chicago, seeks a postdoctoral or more senior research associate for research related to the parameterization of mesoscale eddies in non-eddying and eddy-permitting numerical ocean models. The work will involve theoretical develop-

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Assistant Professor in GIS & Remote Sensing – Department of Atmospheric Science
The University of Alabama in Huntsville

The Department of Atmospheric Science at the University of Alabama in Huntsville (UAH) seeks applicants for an assistant professor faculty position. The successful candidate will be asked to enthusiastically contribute to the Department of Atmospheric Science programs of B.S. and M.S. in Earth System Science (ESS) and M.S. and Ph.D. in Atmospheric Science. Responsibilities of the position will include teaching graduate and undergraduate courses and providing effective service to the growing department, University and the larger community while also enhancing their own research program through student mentorship, submission of peer-reviewed proposals and papers. Applicants must have a Ph.D. in Atmospheric or Earth Science or related field. Candidates should have a developing record of scholarship, teaching experience and demonstrate significant future promise in securing research funding.

Research experience in Earth Science remote sensing theory and applied use of remote sensing and Geographic Information Systems (GIS) is required. Experience in information science infrastructure development is desirable but not required. Candidates should have an emerging research program that can respond to evolving funding opportunities and also complement ongoing research at UAH (http://www.uah.edu/science/departments/atmospheric-science/research). Candidates should be capable of developing collaborations with industry partners in the adjacent Cummings Research Park, the second largest research park in the country. Expected teaching capabilities include graduate and undergraduate courses in principles of remote sensing and applications of remote sensing and GIS.

The chosen candidate will be offered a highly competitive salary and start-up package, and have full access to high-quality research space, state-of-the-art instrumentation and observational datasets, as well as to computing and facilities in academic and research center units. The successful candidate will benefit from potential collaborations within a wide array of nationally and internationally recognized research and operational organizations hosted at the National Space Science and Technology Center (NSSTC), including NASA Marshall Space Flight Center's Earth Science Office, the co-located Huntsville National Weather Service Forecast Office, the Earth System Science Center (ESSC), and the Severe Weather Institute and Radar & Lightning Laboratories (SWIRLL).

Required application materials include curriculum vitae, names of four references and statements of teaching and research philosophies. The candidate must also outline how their scientific skills will enhance the department's ongoing research, teaching and outreach activities. Email the application material to chair@nsstc.uah.edu. Please contact Dr. Larry D. Carey, Chair of the Atmospheric Science Department at the University of Alabama in Huntsville for further information (chair@nsstc.uah.edu). Information about the department can be found at: http://www.nsstc.uah.edu/atmos/.

Review of applications will begin on 2 November 2015 and continue until the position is filled.

The University of Alabama in Huntsville is an affirmative action / equal opportunity employer of minorities / females / veterans / disabled
Please refer to log number 16/17-500

Junior Tenure-Track Faculty Position
Earth Surface Processes
Dartmouth College

The Department of Earth Sciences at Dartmouth College invites applications for a junior rank tenure-track position in the general area of Earth Surface Processes. We especially welcome applications from candidates with research interests in the generation, transport and deposition of sediments and related contaminants in hill slope and stream channel environments, potentially with additional research interests in the biological mediation of physical processes and forms. Particular attention will be given to candidates who combine a focus on understanding fundamental processes with state-of-the-art laboratory and/or field research programs that complement and contribute to ongoing research activities in the Department as well as in Dartmouth's Department of Biological Sciences, Department of Geography, and the Thayer School of Engineering. The successful candidate will continue Dartmouth's strong traditions in graduate and undergraduate research and teaching. Teaching responsibilities consist of three courses spread over three of four ten-week terms.

The Department of Earth Sciences is home to 11 tenured and tenure-track faculty members in the School of Arts and Sciences, and enjoys strong Ph.D. and M.S. programs and outstanding undergraduate majors. To create an atmosphere supportive of research, Dartmouth College offers new faculty members grants for research-related expenses, a quarter of sabbatical leave for each three academic years in residence, and flexible scheduling of teaching responsibilities.

Dartmouth College, a member of the Ivy League, is located in Hanover, New Hampshire (on the Vermont border). Dartmouth has a beautiful, historic campus located in a scenic area on the Connecticut River. Recreational opportunities abound all year round. To learn more about Dartmouth College and the Department of Earth Sciences, visit http://www.dartmouth.edu/~earthsci.

To submit an application, send curriculum vitae, statements of teaching and research interests and objectives, reprints or preprints of up to three of your most significant publications, and the name, address (including street address), e-mail address and fax/phone numbers of at least three references to: **http://apply.interfolio.com/30984** Applications received by November 11, 2015 will receive first consideration. The appointment will be effective July 1, 2016.

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

ments underpinning a sub-grid scale energy-based, resolution-aware eddy parameterization; implementation of the sub-grid scale parameterization in a numerical ocean general circulation model; and configuring, running and analyzing ocean climate models to assess the parameterization.

The ideal candidate has a strong background in geophysical fluid dynamics and physical oceanography, as well as experience using and analyzing numerical models and/or large observational datasets.

Candidates must have a PhD in physical oceanography or a related field. Initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding. The candidate is expected to spend the first six months at Princeton University, where they will be introduced to working with the ocean climate model, MOM6. Thereafter, the candidate will be located at The University of Chicago, working both remotely with the ocean climate model and locally on theoretical developments and analysis.

Complete applications, including a CV, a statement of research interests, and contact information of 3 references should be submitted by November 15, 2015 for full consideration. Applicants should apply online to http://jobs.princeton.edu, Requisition #1500697. For more information about the research project and application process, please contact Alistair Adcroft (aadcroft@princeton.edu) and Malte Jansen (mfj@uchicago.edu).

This position is subject to the University's background check policy.

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

Tenure-Track Search in Sedimentary Geology

San Francisco State University, Department of Earth & Climate Sciences seeks applicants for a tenure-track Assistant (or Associate) Professor position in Sedimentary Geology beginning August 2016. Ph.D. in earth sciences or related discipline required. Salary commensurate with qualifications. Position description available at **http://tornado.sfsu.edu/PositionAnnouncement/TenureTrackSedimentology2015.pdf.** SF State serves a diverse student body with a mission to promote scholarship, diversity, instructional excellence and intellectual accomplishment. Faculty are expected to be effective teachers, demonstrate professional achievement and growth through research, publications and/or creative activities, and engage in service to the campus and community. Application review begins **November 13, 2015**, continues until filled. Submit letter of interest, CV, statements of research and teaching interests, and contact information of three references to **AcademicJobsOnline.org**. For questions, contact: **Dr. Leonard Sklar: leonard@sfsu.edu**

SAN FRANCISCO STATE UNIVERSITY

San Francisco State University is an Equal Opportunity Employer with a strong commitment to diversity. We especially welcome applications from members of all ethnic groups, women, veterans, and people with disabilities.

Solid Earth Geophysics

Brown University: DOF: Earth, Environmental, and Planetary Sciences

Tenure-Track Faculty Position in Geophysical Modeling

Location: Providence, RI

The Department of Earth, Environmental and Planetary Sciences at Brown University (http:// http://www.brown.edu/academics/earth-environmental-planetary-sciences/)invites applications for a tenure-track faculty appointment in Geophysical Modeling, including: mantle dynamics, thermo-mechanical properties of fluid/melt-rock systems, ice-sheet and glacier dynamics, and deformation of the crust and lithosphere. Candidates should complement and/or build on the Department's current strengths in solid Earth and planetary geophysics that integrate observations and theory from seismology, geodynamical modeling, experimental studies of physical and kinetic properties of rocks and minerals, and geochemistry/petrology. Candidates are also encouraged to highlight potential links with our excellent programs in Applied Math, Computer Science and/or Engineering Mechanics. The successful candidate will maintain an active, externally-funded research program and enjoy a commitment to teaching at both undergraduate and graduate levels.

Qualifications

Appointment will be at the Assistant Professor level. A Ph.D. degree is required, and postdoctoral experience is considered important.

Application Instructions

Applicants should forward a curriculum vita, descriptions of research and teaching interests, and contact information for at least three references to: apply.interfolio.com/31293 . Inquiries and other communications may be directed by email to: DEEPS@Brown.edu. Applications received by October 21st, 2015 will receive full consideration, but the search will remain open until the position is closed or filled. The start date for this position is July 1st, 2016. For more information visit http:// http://www.brown.edu/academics/earth-environmental-planetary-sciences/about/job-openings.

Interdisciplinary/Other

ASSISTANT PROFESSOR OF EARTH AND ATMOSPHERIC SCIENCES (Exploration Geophysics)

Applications are invited for a tenure track position as Assistant Professor in the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln. The successful candidate will be expected to participate in teaching and curricular development of undergraduate and graduate courses, to advise and direct graduate students, and to develop a rigorous research program that is supported by external funding. It is expected that the research program will include field and subsurface-based studies of exploration geophysics. Ability to contribute to growing petroleum geoscience-related teaching and research activities within the Department of Earth & Atmospheric Sciences will be considered as an advantage. The candidate should demonstrate strong potential for research and teaching and must hold a Ph.D. in Geology, Geophysics, or a related field at the time of appointment.

The Department of Earth and Atmospheric Sciences offers B.S. degrees in Geology and Meteorology-Climatology, as well as M.S. and Ph.D. degrees in Earth and Atmospheric Sciences. Primary research areas within the geological sciences include sedimentary geology, paleontology and paleobiology, petroleum geosciences and geobiology. Research in atmospheric sciences is focused on meterological hazards, climate change, and remote sensing. Additional active research areas include Climate System Science, Geoscience Education and Hydrological sciences. Additional information about our department can be found on our web site: http://eas.unl.edu.

To apply, go to http://employment.unl.edu, search for requisition #F_150159 and complete the "faculty/administrative form". Applicants must attach a cover letter, curriculum vitae, statements of research and teaching interests, and names of at least three references via the above website. We will begin to review applications on October 12, but the position will remain open until it is filled.

The University of Nebraska is committed to a pluralistic campus community through affirmative action, equal opportunity, work-life balance, and dual careers.

For further information, contact Dr. Chris Fielding, Search Committee Chair by email, phone, or mail at: cfielding2@unl.edu, 1-402-472-9801; Department of Earth & Atmospheric Sciences, University of Nebraska-Lincoln, 214 Bessey Hall, Lincoln NE 68588-0340.

ASSISTANT PROFESSOR OF EARTH AND ATMOSPHERIC SCIENCES (Hydrogeology/Groundwater Modeling)

Applications are invited for a tenure track position as Assistant Professor in the Department of Earth and Atmospheric Sciences at the University of Nebraska-Lincoln. The successful candidate will be expected to participate in teaching and curricular development of undergraduate and graduate courses, to advise and direct graduate students, and to develop a rigorous research program that is supported by external funding. It is expected that the research program will focus on the responses of groundwater systems to climate change. Ability to contribute to multidisciplinary water and climate research efforts within Department of Earth & Atmospheric Sciences and across the university will be considered as an advantage. The candidate should demonstrate strong potential for research and teaching and must hold a Ph.D. in Geology, Hydrogeology, or a related field at the time of appointment.

The Department of Earth and Atmospheric Sciences offers B.S. degrees in Geology and Meteorology-Climatology, as well as M.S. and Ph.D. degrees in Earth and Atmospheric Sciences. Primary research areas within the geological sciences include hydrogeological sciences, sedimentary geology, paleontology and paleobiology, petroleum geosciences, and geobiology. Research in atmospheric sciences is focused on meteorological hazards, climate change, and remote sensing. Additional information about our department can be found on our web site: http://eas.unl.edu.

To apply, go to http://employment.unl.edu, requisition # F_150187 and complete the "faculty/administrative form". Applicants must attach a cover letter, curriculum vitae, statements of research and teaching interests, and contact information for at least three references via the above website. We will begin to review applications on October 31, 2015, but the position will remain open until it is filled.

The University of Nebraska is committed to a pluralistic campus community through affirmative action, equal opportunity, work-life balance, and dual careers. See http://www.unl.edu/equity/notice-nondiscrimination.

For further information, contact Dr. Richard Kettler, Search Committee Chair by email, phone, or mail at: rkettler1@unl.edu, 1-402-472-0882; Department of Earth & Atmospheric Sciences, University of Nebraska-Lincoln, 214 Bessey Hall, Lincoln NE 68588-0340.

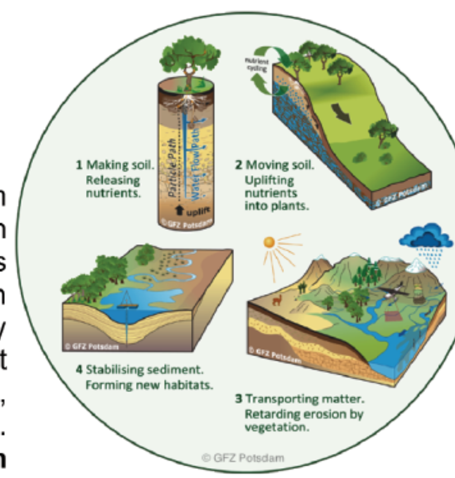
EARTH & ENVIRONMENTAL Sciences Lehigh University

Tenure Track Assistant Professor

Lehigh University invites applications for a tenure track position in

17 PhD Positions

***EarthShape: Earth Surface Shaping by Biota.* A German-Chilean Priority Program in the Chilean Coast Range**



The new German Priority Program (Schwerpunktprogramm der DFG) 1803 "EarthShape – Earth Surface Shaping by Biota" will explore how biologic processes form soil, influence topography, and thereby shape the Earth surface. You will work in a consortium of 13 interdisciplinary projects comprising **17 new PhD positions** and 3 Postdocs that encompass the fields Geology, Ecology, Soil Sciences, Geography, Microbiology, Geophysics, and Geochemistry. EarthShape research will be conducted at **four study sites within in the Chilean Coastal Range** that features one of Earth's most spectacular vegetation gradients and is controlled by climate ranging from hyper-arid to humid temperate. It is a natural laboratory to study how biology and topography interact. You will be trained in interdisciplinary methods and conduct joint field work and training workshops.

The program is coordinated by Todd Ehlers (todd.ehlers@uni-tuebingen.de) and Friedhelm von Blanckenburg (fvb@gfz-potsdam.de). Interested applicants should contact the supervisors at the potential host institutions (see list on web page). An MSc or Diplom degree is required for admission into PhD programs at German Universities. Projects will begin between January and March 2016 and are funded for three years. The application deadline for most positions is around October 15, 2015. Additional information about each position and contact information the supervisor is available on the "Positions open" link at www.earthshape.net earth and environmental sciences at the assistant professor level. Successful candidates will have a PhD, research expertise that contributes to department strengths through establishment of an internationally recognized externally funded research program, a commitment to teaching at both undergraduate and graduate levels, and a documented commitment to diversity and inclusion.

Applications should submit a cover letter, curriculum vitae, names and contact information of three references, statements of research and teaching interests, and a description of experience and vision for enhancing participation of traditionally underrepresented groups to https://academicjobsonline.org/ajo/jobs/5945. To ensure full consideration the application should be received by November 1, 2015.

For additional Information contact Anne Meltzer, Search Committee Chair, EES Dept., 1 West Packer Avenue, Bethlehem PA 18015-3001, ameltzer@lehigh.edu and see the EES department web pages, http://www.ees.lehigh.edu/.

The College of Arts and Sciences at Lehigh University is especially interested in qualified candidates who can contribute, through their research, teaching, and/or service, to the diversity and excellence of the academic community. Lehigh University is an Equal Opportunity Affirmative Action Employer. Lehigh University provides comprehensive benefits including partner benefits. Lehigh University is a recipient of a NSF ADVANCE Institutional Transformation award for promoting the careers of women in academic sciences and engineering.

GDL Foundation Fellowships in Structure and Diagenesis

The GDL Foundation supports study and research of chemical and mechanical interactions, structural diagenesis, in sedimentary basins. Practical applications are of particular interest.

We are currently seeking applications from M.S. and Ph.D. candidates, post-doctoral researchers, and scientists for fellowships, up to $10,000, based on specific proposals for research and participation in meetings and conferences to share results.

Submit applications (available at: www.gdlfoundation.org) by November 2, 2015.

POSTDOCTORAL POSITION IN PLANETARY SCIENCE PURDUE UNIVERSITY

Purdue University's program in planetary science has an opening for a PhD researcher to model the evolution of crater-generated porosity in the lunar crust using a crater terrain evolution model in conjunction with constraints from GRAIL gravity data. A PhD in physics, geophysics or planetary science and experience in modeling is required along with familiarity with computer languages such as FORTRAN or C in a LINUX environment. The position is available immediately and will run for approximately 1 year with the possibility of extension pending availability of funding. Please send a vita, bibliography and the names of three referees to Professor H. Jay Melosh, Earth and Atmospheric Sciences Department, 550 Stadium Mall Drive, West Lafayette, IN 47907, or to jmelosh@purdue.edu by October 31, 2015. A background check is required for employment in this position.

Purdue University is an EEO/AA employer fully committed to achieving a diverse workforce. All individuals, including minorities, women, individuals with disabilities, and protected veterans are encouraged to apply.

Tenure-Track Assistant Professor Position Available in Petrology and Geochemistry at the University of Puerto Rico - Mayaguez Campus

The Geology Department of the University of Puerto Rico at Mayaguez seeks to fill a tenure-track position in the fields of Petrology and Geochemistry, for January 2016. The appointment will be at the rank of an Assistant Professor. Candidates need to have a doctoral degree (PhD) at the time of appointment. Primary responsibilities for this position include teaching undergraduate courses in Igneous and Metamorphic Petrology, Geochemistry and basic level courses for majors and non-majors, as well as graduate level courses. Teaching responsibilities also include advising and directing undergraduate research and MS theses. The successful candidate will be expected to conduct research and obtain funding that will complement the department's strengths. Fluency in English or Spanish is required and fluency in both preferred. Interested candidates must submit a letter of interest/cover letter, curriculum vitae, undergraduate and graduate transcripts, a statement of research and teaching interests, copies of relevant publications, and the names, phone numbers and e-mail addresses of three professional referees to: Dr. James Joyce (james.joyce@upr.edu), Chairman Personnel Committee, Department of Geology, PO Box 9000, Mayaguez, Puerto Rico 00681-9017, USA. Details about the department are available in the website http://geology.uprm.edu. Review of completed applications will begin on October 15, 2015. The University of Puerto Rico is an equal opportunity employer.

Tenure-Track Position in Sedimentology or Geophysics at Texas Tech University

The Department of Geosciences at Texas Tech University seeks applicants for a tenure-track, assistant professor position in either sedimentology or geophysics to start Fall 2016. A PhD in an Earth Science or closely related discipline at time of appointment is required.

We seek a dynamic researcher and teacher who uses innovative field, laboratory and/or modeling approaches in either targeted area. For sedimentology, we seek candidates with expertise in sandstone, mudstone or carbonate sedimentary systems. For geophysics, we seek candidates with a specialty in seismology or CSEM/MT methods. The geophysics candidate's main area of research should be in imaging and interpreting crust and lithospheric features and whose interests include the basin scale. A letter of application including contact information for three references, vita, and short statements of research and teaching philosophies can be uploaded at http://www.texastech.edu/careers/ requisition #5155BR.

We seek candidates with strong records of scholarship who have the proven capacity or the clear potential to bring externally sponsored research to Texas Tech University. The department (www.geosciences.ttu.edu) has active research specialties in geology, geophysics, geochemistry, geography, and atmospheric science. We have ~400 undergraduate majors and ~85 graduate students. Texas Tech is located in Lubbock on the edge of the Permian Basin. The region appreciates the social and economic importance of geoscience research due to the importance of petroleum and groundwater resources to the national economy. Teaching duties include graduate and undergraduate courses in the candidate's specialty. Service to the department, university, and discipline is expected.

As an Equal Employment Opportunity/Affirmative Action employer, Texas Tech University is dedicated to the goal of building a culturally diverse faculty committed to teaching and working in a multicultural environment. We encourage applications from qualified candidates who can contribute, through research, teaching, and service, to the diversity and excellence of the academic community at Texas Tech University. The university welcomes applications from minorities, women, veterans, persons with disabilities, and dual-career couples. Evaluation of candidates will begin November 11, 2015 and continue until the position is filled. Department representatives will be available to discuss the position at the GSA Annual Meeting (1-4 November) in Baltimore, Maryland. Questions should be sent to Dr. Jeff Lee, Search Committee Chair: jeff.lee@ttu.edu.

Wiess Post-Doctoral Research Fellowship - Department of Earth Science, Rice University

The Department of Earth Science at Rice University is launching a Wiess Post-Doctoral Research Fellowship competition in the broad fields of Earth, atmospheric, and planetary sciences. The principal selection criteria for the fellow are scientific excellence and a clearly expressed research plan to address questions at the forefront of Earth science, broadly defined. Additional details about the fellowship and the department can be found at http://earthscience.rice.edu

Please send a cover letter, 3-pg research proposal, CV, and names of four references to esci-postdoc@rice.edu. The application deadline is November 1, 2015.

Equal Opportunity Employer—Females/Minorities/Veterans/Disabled/Sexual Orientation/Gender Identity

Student Opportunities

A Ph.D. Opportunity at Michigan Technological University

A Ph.D. research assistantship is available at the Earth Magnetism Laboratory of Michigan Tech focusing on the investigation of geomagnetic field strength during the Proterozoic. The position can start as early as January 2016; applications will be accepted from both US and international applicants until the position is filled. For detailed inquires, contact Dr. Aleksey Smirnov (asmirnov@mtu.edu).

Michigan Tech is an equal opportunity educational institution/equal opportunity employer.

PhD Student Opportunity in Hydrology, Washington State University

Four year RA available for student to work with an interdisciplinary team to understand the interactions between drought, forest management, and wildfire on forest ecosystem resilience. Students experienced with Linux/programming and/or ecohydrology will be competitive. The student will be co-advised by Jennifer Adam (WSU} and Christina Tague {UCSB}. Interested students should contact jcadam@wsu.edu for more information. Fall semester applications to WSU are due on 10 January for priority consideration.

Postcards from the Field

Greetings from the High North!

A lovely sunset? No, the sun doesn't set in the summer around here. We're approaching the Canadian High Arctic Research Station after a long day of sampling vegetation along a helicopter transect. Climate change is happening earlier and faster in the Arctic, and NASA is partnering with Canadian colleagues to better understand the consequences to society. Why? Because what's happening in the Arctic doesn't stay in the Arctic. Learn more about the Arctic Boreal Vulnerability Experiment at http://above.nasa.gov, and follow me on Twitter @NASA_ABoVE

—**Peter Griffith,** NASA

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

EARTH & SPACE SCIENCE

virtual poster showcase

Students Can Now Share Their Research—From Anywhere!

This is a new opportunity that allows undergraduate and graduate students to present their research virtually, without any need to travel.

Advantages of Virtual Presentations Over In-person Meetings

Less Time

Lower Cost

More Flexible Scheduling

3 Opportunities to Participate in Fall 2015

Virtual Poster Showcase #1
For Undergraduate Students

Virtual Poster Showcase #2
For Undergraduate Students

Virtual Poster Showcase #3
For Graduate Students

Students

- **Share** your research
- **Practice** your presentation skills
- **Review** the posters of your peers
- **Receive** quality feedback from peers and experts in your field
- **Build** your credibility

Faculty

- **Help students** develop their presentation skills and ability to evaluate science
- **Impact more students** with the funds you have
- **Incorporate Virtual Poster Showcases** in a capstone course

Sign up to receive e-mail alerts about upcoming Virtual Poster Showcases

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