College of Earth, Ocean, and Atmospheric Sciences

Research Highlights 2014–15

Oregon State University

About the College

The College of Earth, Ocean, and Atmospheric Sciences is an internationally recognized leader in the study of the Earth as an integrated system. It operates numerous state-of-the-art laboratories and two oceanographic research vessels, the 177-foot ocean-going *Oceanus* and the 54-foot coastal research vessel *Elakha*. The college has an annual budget of more than $50 million, with support coming from the National Science Foundation, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration and other federal agencies. It has more than 100 faculty, 200 graduate students and 600 undergraduate students. Graduate programs include master's and Ph.D. degrees in Ocean, Earth and Atmospheric Sciences; Geology; and Geography and a master's degree in Marine Resource Management. The college has undergraduate programs in Earth Sciences and Environmental Sciences, with several minors, options and certificate programs.

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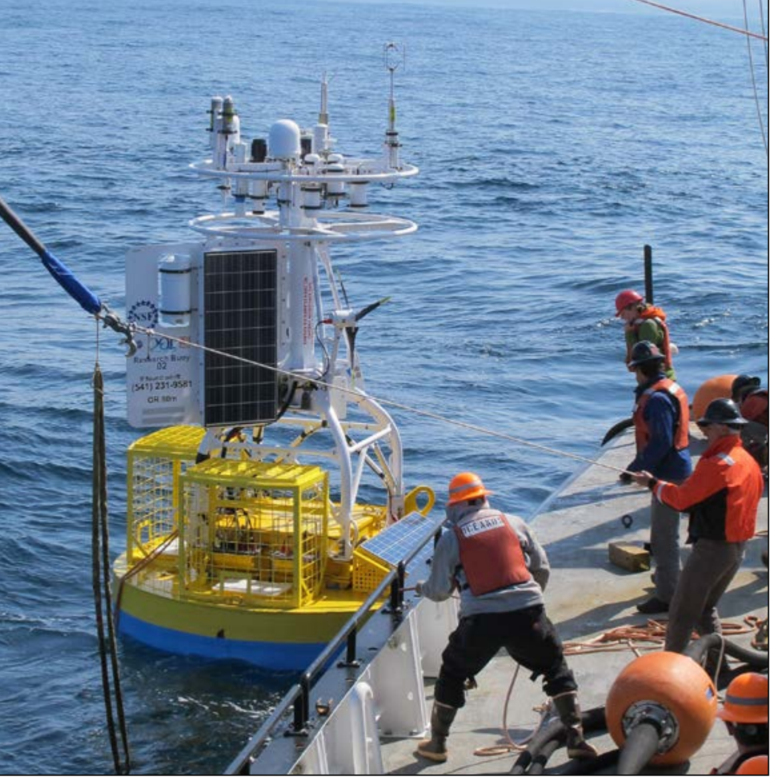
Photo courtesy of Dudley Chelton, College of Earth, Ocean, and Atmospheric Sciences. Includes cover, page 2 and back cover.

As the interim dean for the College of Earth, Ocean, and Atmospheric Sciences, I am honored to lead this internationally recognized institution in the Earth systems sciences. It's a good time to be dean. Oregon State University is ranked among the strongest Earth and environmental sciences programs in the world by the journal *Nature*, and we continue to publish research that breaks new ground or shapes the policy and management of our natural resources.

There are many examples of our impact throughout this publication. Chris Goldfinger's expertise on the Cascadia Subduction Zone and the seismic reality facing the Pacific Northwest recently garnered national attention and has helped to spur legislative action to improve our infrastructure (page 12). The Ocean Observatories Initiative made major headway on the "Endurance Array" that will give scientists and citizens unprecedented access to information about our oceans – from marine "dead zones" to wave energy potential (page 4). We have geographers and water experts who are using cutting-edge tools to understand insect outbreaks and ensuing landscape changes (page 14), and how pollution moves in streams (page 16).

As you can see, we have a lot going on at the College of Earth, Ocean, and Atmospheric Sciences. Thanks for your support.

Roy Haggerty, Interim Dean



The Oregon shelf surface mooring is lowered to the water using the crane on R/V Oceanus. (photo courtesy of Oregon State University)

OOI completes initial Pacific Northwest deployments

Oregon State University scientists deployed a sophisticated research buoy and two undersea gliders, all fitted with a suite of oceanographic instruments – a final piece of the "Endurance Array," a major component of the National Science Foundation's $386 million **Ocean Observatories Initiative**.

"This observatory opens up a new type of window to the sea, with environmental data available in 'real time' to researchers, educators, policy makers and ocean users," said **Ed Dever**, project manager for the Endurance Array. "In the short term, it will be a laboratory for the study of processes in one of the great coastal upwelling systems on our planet.

"In the long term, the information it collects will allow us, our children and our grandchildren to better understand the impacts of global climate change on the coastal ocean off Oregon and Washington."

The deployment of an inshore surface buoy about a mile off Nye Beach in Newport – in waters about 25 meters deep – is the third and final platform location in the array's "Newport Hydrographic Line." The line includes a shelf surface buoy in 80 meters of water, about 10 miles off the coast; and an off-shore surface buoy in 500 meters of water, about 35 miles out.

"For the first time, the science community will be able to monitor and assess all components of the ocean simultaneously, from the physics to the biology to the chemistry," said **Jack Barth**, an OSU oceanographer who has been a lead scientist on the Ocean Observatories Initiative since the early planning stages more than a decade ago.

The buoy will have an impressive array of instruments – at the surface, on the seafloor where it is anchored, and attached to a cable running up and down the water column. Various sensors will measure water velocity, temperature, salinity, pH, light intensity, carbon dioxide, dissolved oxygen, nitrate, chlorophyll, backscatter (or the measure of particles in the water), light absorption – and even populations of zooplankton and fish.

The other two buoys in the Newport Hydrographic Line will be paired with seafloor instruments that will be plugged into an underwater cable operated by the University of Washington. The cable will provide additional power for the instrumentation and high-bandwidth, two-way communications.

Barth noted that the instruments will constantly monitor the oceans and provide an incredible amount of data, whereas previously, scientists had to rely on intermittent shipboard data.

"These buoys are game-changers," he added. "We will be able to better monitor emerging hypoxia threats, toxic plankton blooms and ocean acidification. Fishermen can match oceanographic data with catch records and look at how temperature, salinity and other factors may affect fishing. The possibilities are endless."

Alejandra Sanchez

Dynamic Flows in the Upper Ocean

Alejandra Sanchez is a Ph.D. student in physical oceanography. Using data collected by underwater gliders, she is working with Associate Professor Kipp Shearman to understand processes that contribute to the mixing and transport of heat, salt and nutrients from the surface to the interior of the ocean. Sanchez has won numerous awards, including the OSU Women's Center Student Leader and the CEOAS Outstanding Service to the College.

Coastal and Near-Shore Oceanography

OSU to outfit undersea gliders to "think like fish"

Oregon State University researchers received a $1 million grant from the W.M. Keck Foundation to fund a pair of undersea gliders that will use acoustical sensors and predictive algorithms to respond to environmental cues and identify biological hot spots.

In other words, the scientists say, they want to outfit a robotic undersea glider to "think like a fish."

"We already have a basic understanding of the ecosystem," said **Jack Barth**, a physical oceanographer and principal investigator on the project. "Now we want to get a better handle of what kind of marine animals are out there, how many there are, where they are distributed, and how they respond to phytoplankton blooms, schools of baitfish or oceanic features. It will benefit a variety of stakeholders, from the fishing industry and resource managers to the scientific community."

Barth will work with marine ecologist **Kelly Benoit-Bird**, who specializes in the relationships among marine organisms from tiny plankton to large whales.

Using robot-mounted acoustic sensors, the OSU researchers will be able to identify different kinds of marine animals using their unique acoustical signatures. Diving seabirds, for example, leave a trail of bubbles through the water like the contrail left by a jet. Zooplankton show up as a diffuse cloud. Schooling fish create a glowing, amoeba-shaped image.

Programming a glider to spend weeks out in the ocean and then "think" when it encounters certain cues, is a challenge that falls upon the third member of the research team, **Geoff Hollinger**, from OSU's robotics program in the College of Engineering.

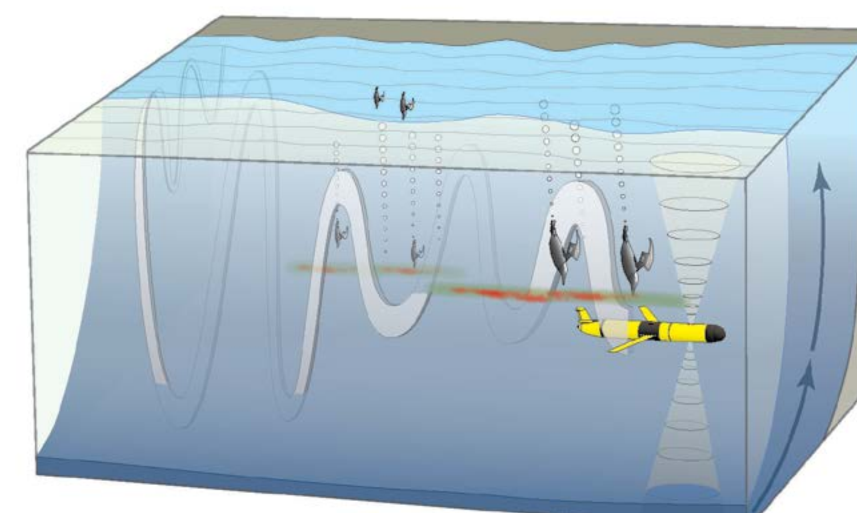
Hollinger will use predictive algorithms to make a glider dynamically respond to its environment. The right algorithm will essentially turn the glider into an autonomous vehicle that can run on autopilot.

"This project and the innovative technology could revolutionize how marine scientists study the world's oceans," Barth said.

Sandra Huynh

Marine Education and Engagement

Sandra Huynh is a master's student in Marine Resource Management (MRM) working with Kerry Carlin-Morgan at the Oregon Coast Aquarium. Her research focus is marine education and engagement, where she is studying visitor motivations for attending aquarium programs that highlight harbor seals, sea lions and the giant pacific octopus. Recently, she received an award from the Geoffrey Russell Dimmick Memorial Fund, in honor of a former MRM student.



A new vision for exploring ocean ecosystems: 1. An underwater glider launched near the coast swims out to find an ocean front separating cold, nutrient-rich water upwelled (arrows) near the coast from warm, offshore waters. 2. The glider then searches along the front to find a biological "hot spot," defined by increased concentrations of plankton (green), fish (red), and "contrails" from diving seabirds. 3. The glider further refines its sampling and delineation of the hot spot based on feedback from its onboard physical and bio-optical sensors along with an echosounder that can detect zooplankton, fish and diving seabirds. (image courtesy of Oregon State University)

Solid Earth

Climate-tectonic interactions on the Tibetan Plateau

The evolution of mountain ranges across the globe is governed by the interplay among climate, tectonics and erosion. Growing topography influences atmospheric circulation, generating spatial gradients in the magnitude and frequency of precipitation. These variations, in turn, drive differences in the potential for erosion and sediment transport out of rugged and deep canyons. Perhaps nowhere on Earth are these feedbacks as pronounced as the Himalaya-Tibetan orogen, where the growth of high topography in response to the collision of India and Eurasia has influenced the circulation of the Asian Monsoon for millions of years. The key to understanding the ways in which fluid and solid earth processes are linked is to develop robust records of both variations in monsoon intensity and uplift of the Tibetan Plateau.

Researchers at Oregon State University are exploring the connections between these systems using geologic records preserved in the landscapes of the Tibetan Plateau. Recent research on the age and distribution of ancient shorelines around Siling Co, a high-elevation saline lake in central Tibet, has shown that rapid, punctuated recession of the lake was associated with nearly 70 meters of lowering lake levels in the past 4,000 to 5,000 years.

"There are relatively few 'direct' measures of changes in precipitation. Most estimates of monsoon intensity rely on proxies, such as isotopes in cave stalagmites," said **Eric Kirby**, the R.S. Yeats Associate Professor of Earthquake Geology and Active Tectonics. "Our results provide a more direct estimate of changes in the balance between runoff and evaporation and imply a roughly three-fold reduction in precipitation in the region over the past few thousand years."

As it turns out, the change in the size of the lake was significant enough to have induced crust deformation beneath the Tibetan Plateau. During maximum lake levels, the weight of the water depressed the crust, and as the lake dried up, the crust rebounded.

"You can think of it like sitting on a mattress. The initial weight would cause a depression, but once you stood up, the mattress would spring back into place to reach equilibrium," Kirby said.

Shorelines formed during the highest lake levels. These "bathtub rings" above the modern lake (see figure) are normally horizontal, but they became deflected during the rebound. By measuring the deflections of shorelines from horizontal, researchers were able to determine the amount of rebound that has occurred, and, in turn, to develop estimates of the viscosity of the deep crust beneath the Tibetan Plateau. In a recent publication in *Earth and Planetary Science Letters*, Kirby and co-authors argue that the deep crust beneath the Tibetan Plateau is likely capable of viscous flow on geologic timescales.

"The exciting thing about studies like this is that we are able to observe how changes in climate directly drive deformation of the Earth's crust," said Kirby. "This is an encouraging result, in that it allows us to glean information about regions of the deep crust that are inaccessible to other means of study."

Joanna Rose

Marine Geology and Geochronology

Joanna Rose is an M.S. student in geology whose research focuses on marine geology and geochronology. She and her advisor, Anthony Koppers, are using high-resolution incremental heating ages of volcanic rocks to establish a chronology of the Cook-Australs, a volcanic island chain located in the South Pacific. She is the recipient of the 2015 Teaching Assistant Excellence Award.

More Online: Toba Animation

Learn more about the Toba supereruption and the process of resurgence by watching this animation online. See the eruption, watch the collapse and learn how magma pushes the earth back up to form a dome.

youtube.com/OregonStateCEOAS

Understanding resurgence at Lake Toba

Indonesia's Lake Toba is one of the world's largest calderas – the aftermath of a supereruption roughly 74,000 years ago that spewed ash across South Asia and left deposits nearly 2,000 feet thick near the main vent.

Researchers at Oregon State University, including graduate student **Adonara Mucek** and volcanologist **Shan de Silva**, are investigating what happened after the supereruption. In geologic terms, it's called resurgence, the process by which the floor of the caldera pushes back up and forms a dome. Knowing when and how resurgence occurs is crucial to understanding future volcanic activity.

"Resurgence is manifested through structural uplift at large calderas, as a result of remnant magma pushing up the caldera floor," Mucek explains. "We know this, but there are a lot of unanswered questions. When does it happen? When does it start? How long does it last? And why does it happen?"

Mucek is particularly motivated to answer those questions because the Indonesian government recently designated Lake Toba as a **UNESCO Global Geopark**. She is using surface process modeling to compute the evolution of Toba's topographic surface over time to understand the "ingredients" of resurgence. Basically, what mixture of landform development, processes and topographic features leads to resurgence?

Spatial distribution techniques will allow her to determine if the resurgent uplift on Toba's island can be detected from above. Combined with her field work, Mucek is using these methods to help tell the whole Toba story, now and in the years ahead.

"We can apply this research to other supervolcanoes. For example, Yellowstone also has resurgence, and other calderas across the world are going through the same process," she said. "It's important to understand these processes that are occurring today to figure out what will happen in the future."

*Graduate student **Adonara Mucek** in the field.*

Ocean/Air Fluxes, Flows

Researchers measure giant "internal waves" that help regulate climate

Once a day, a wave as tall as the Empire State Building and as much as a hundred miles wide forms in the waters between Taiwan and the Philippines and rolls across the South China Sea – but on the surface, it is hardly noticed.

These daily monstrosities are called "internal waves" because they are beneath the ocean surface, and though scientists have known about them for years, they had never been fully tracked from cradle to grave.

But a new study documents what happens to internal waves at the end of their journey and outlines their critical role in global climate. The international research project was funded by the Office of Naval Research and the Taiwan National Science Council.

"Ultimately, they mix heat throughout the ocean," said **Jonathan Nash**, an Oregon State University oceanographer and co-author on the study. "Without them, the ocean would be a much different place. It would be significantly more stratified – the surface waters would be much warmer and the deep abyss colder.

"It's like stirring cream into your coffee," he added. "Internal waves are the ocean's spoon."

Internal waves help move a tremendous amount of energy from Luzon Strait across the South China Sea, but until this project, scientists didn't know what became of that energy. A large fraction of energy dissipates when the wave gets steep and breaks on the deep slopes off China and Vietnam, much like breakers on the beach. But part of the energy remains, with waves reflecting from the coast and rebounding back into the ocean in different directions.

The waves have important global implications. In climate models, predictions of the sea level 50 years from now vary by more than a foot depending on whether the effects of these waves are included.

South China Sea internal waves seen from space. Photo: NASA and Global Ocean Associates.

Emily Shroyer

ONR Young Investigator Award

Assistant Professor Emily Shroyer received the 2015 Young Investigator Award from the Office of Naval Research for her research in small-scale processes that control the movement and mixing of heat and freshwater within the ocean. Specifically, her work investigates nonlinear internal waves, which propagate beneath the ocean's surface – redistributing energy and mass, influencing nutrient exchange and transporting sediment and larvae.

Scientists find deep-ocean evidence for Atlantic overturning decline

A new study has found evidence from the deep ocean that the Atlantic meridional overturning circulation (AMOC) – a system of currents that brings warm water from the tropics to the North Atlantic region and keeps its climate more moderate – declined at the end of the last ice age.

Some scientists have long suspected that was the case because the North Atlantic cooled at a time the rest of the planet was warming, but evidence to support the theory has been sparse or indirect. However, the new study, which utilized 25 deep ocean sediment cores and a corresponding computer model, determined that the AMOC not only declined – the process may have pumped more carbon dioxide into the atmosphere.

"There has long been a feeling that if the deep ocean was changing at the end of the last ice age, there should be evidence from the deep ocean to document it – and that has been lacking," said **Andreas Schmittner**, a climate modeling scientist at Oregon State University and lead author on the study.

"The Atlantic meridional overturning circulation enhances the biological pump, and if it declined it should have had an impact on primary productivity as well as the overall climate for the region," added Schmittner.

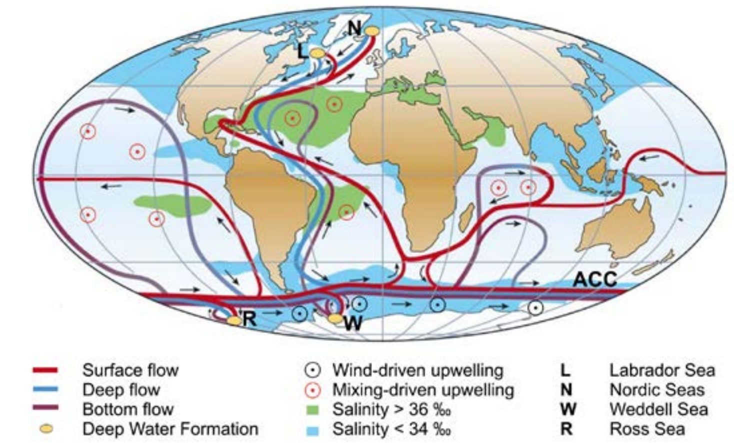


Figure 1. Strongly simplified sketch of the global overturning circulation system. In the Atlantic, warm and saline waters flow northward all the way from the Southern Ocean into the Labrador and Nordic Seas. By contrast, there is no deepwater formation in the North Pacific, and its surface waters are fresher. Deep waters formed in the Southern Ocean become denser and thus spread in deeper levels than those from the North Atlantic. Note the small, localized deepwater formation areas in comparison with the widespread zones of mixing-driven upwelling. Wind-driven upwelling occurs along the Antarctic Circumpolar Current (ACC). After Rahmstorf [2002].

Schmittner and his colleague David Lund from the University of Connecticut used evidence from 25 sediment cores taken primarily from the Atlantic Ocean, but also from the Indian and Pacific Ocean, which showed a change in the carbon isotope ratio over a period of 3,000 to 4,000 years that began some 19,000 years ago.

Schmittner and Lund's model matched ice core data from Antarctica, suggesting that the Atlantic meridional overturning circulation decline pulled carbon dioxide from the deep ocean and gradually released it into the atmosphere.

The researchers note that future global warming may again slow down the circulation because as surface waters warm, they become more buoyant and are less likely to sink – a key process to maintaining the system of currents in the Atlantic. The addition of fresh water from melting ice sheets may compound the slowdown.

Kate Faber

Melt Ponds on Arctic Sea Ice

Kate Faber is double majoring in Environmental Sciences and Fisheries and Wildlife Science with the University Honors College. In her second undergraduate year, she has been involved with the leadership for the new Environmental Sciences Club and is working on research with Jennifer Hutchings on melt ponds on Arctic sea ice. Faber recently received the Excellence in Environmental Science Award from CEOAS.

Elemental Cycles and Food Webs

Oysters at hatcheries in Oregon and Washington are showing the effects of ocean acidification.

New study finds "saturation state" directly harmful to bivalve larvae

A new study of Pacific oyster and Mediterranean mussel larvae found that the earliest larval stages are directly sensitive to saturation state, not carbon dioxide (CO_2) or pH. Saturation state is a measure of how corrosive the seawater is. It drops as CO_2 increases in the atmosphere, making it harder for early larvae to make their shells. The scientists utilized unique chemical manipulations of seawater to identify the direct sensitivity of larval bivalves to saturation state.

Larval oysters and mussels are so sensitive to the saturation state that the threshold for danger will be crossed "decades to centuries" ahead of when CO_2 increases (and pH decreases) alone would pose a threat to these bivalve larvae. Results of the study help explain commercial hatchery failures and why improving water chemistry in those hatcheries has been successful.

"Bivalves have been around for a long time and have survived different geologic periods of high carbon dioxide levels in marine environments," said **George Waldbusser**, an Oregon State University marine ecologist and biogeochemist and lead author on the study, "The difference is that in the past, alkalinity levels buffered increases in CO_2, which kept the saturation state higher relative to pH.

"In the present ocean, the processes that contribute to buffering the ocean cannot keep pace with the rate of anthropogenic CO_2 increase," added Waldbusser, "As long as the saturation state is high, the oysters and mussels we tested could tolerate CO_2 concentrations almost 10 times what they are today."

Scientists discover carbonate rocks are unrecognized methane sink

Since the first undersea methane seep was discovered 30 years ago, scientists have meticulously analyzed and measured how microbes in the seafloor sediments consume the greenhouse gas methane as part of understanding how the Earth works.

The sediment-based microbes form an important methane "sink," preventing much of the chemical from reaching the atmosphere and contributing to greenhouse gas accumulation. As a byproduct of this process, the microbes create a type of rock known as authigenic carbonate, which while interesting to scientists was not thought to be involved in the processing of methane.

That is no longer the case. A team of scientists has discovered that these authigenic carbonate rocks also contain vast amounts of active microbes that take up methane.

"No one had really examined these rocks as living habitats before," noted **Andrew Thurber**, an Oregon State University marine ecologist and co-author on the paper. "This goes to show how the global methane process is still rather poorly understood," Thurber added.

The study is important, scientists say, because the rock-based microbes potentially may consume a huge amount of methane. The microbes were less active than those found in the sediment, but were more abundant – and the areas they inhabit are extensive, making their importance potentially enormous. Studies have found that approximately 3-6 percent of the methane in the atmosphere is from marine sources – and this number is so low due to microbes in the ocean sediments consuming some 60-90 percent of the methane that would otherwise escape.

Now those ratios will have to be re-examined to determine how much of the methane sink can be attributed to microbes in rocks versus those in sediments. The distinction is important, the researchers say, because it is an unrecognized sink for a potentially very important greenhouse gas.

Oceans' most abundant organism has ability to create methane

The oxygen-rich surface waters of the world's major oceans are supersaturated with methane – a powerful greenhouse gas that is roughly 20 times more potent than carbon dioxide – yet little is known about the source of this methane.

Now a new study by researchers at Oregon State University demonstrates the ability of some strains of the oceans' most abundant organism – SAR11 – to generate methane as a byproduct of breaking down a compound for its phosphorus. These bacteria are so dominant that their combined weight exceeds that of all the fish in the world's oceans, scientists say.

"Anaerobic methane biogenesis was the only process known to produce methane in the oceans and that requires environments with very low levels of oxygen," said **Angelicque "Angel" White,** co-author on the study. "In the vast central gyres of the Pacific and Atlantic oceans, the surface waters have lots of oxygen from mixing with the atmosphere – and yet they also have lots of methane, hence the term 'marine methane paradox.'

"We've now learned that certain strains of SAR11, when starved for phosphorus, turn to a compound known as methylphosphonic acid," White added. "The organisms produce enzymes that can break this compound apart, freeing up phosphorus that can be used for growth – and leaving methane behind."

The discovery is an important piece of the puzzle in understanding the Earth's methane cycle, scientists say. It builds on a series of studies conducted by researchers from several institutions around the world over the past several years.

Coring for ice in Antarctica.

Iceberg influx into Atlantic during ice age raised tropical methane emissions

Huge influxes of fresh water into the North Atlantic Ocean from icebergs calving off North America during the last ice age had an unexpected effect – they increased the production of methane in the tropical wetlands.

Usually increases in methane levels are linked to warming in the Northern Hemisphere, but scientists have identified rapid increases in methane during particularly cold intervals during the last ice age.

These findings are important, researchers say, because they identify a critical piece of evidence for how the Earth responds to changes in climate.

"Essentially what happened was that the cold water influx altered the rainfall patterns at the middle of the globe," said **Rachael Rhodes**, a former research associate at Oregon State University and lead author on the study. "Our data suggest that when the icebergs entered the North Atlantic causing exceptional cooling, the rainfall belt was condensed into the Southern Hemisphere, causing tropical wetland expansion and abrupt spikes in atmospheric methane," she added.

Rhodes and her colleagues examined evidence from the highly detailed West Antarctic Ice Sheet Divide ice core. They used a new analytical method perfected in collaboration with Joe McConnell at the **Desert Research Institute** in Reno, Nevada, to make extremely detailed measurements of the air trapped in the ice. Utilizing the high resolution of the measurements, the team was able to detect methane fingerprints from the Southern Hemisphere that don't match temperature records from Greenland ice cores.

"It is a great example of how inter-connected things are when it comes to climate," Rhodes said.

Natural Hazards

Toppled building in Concepción, Chile, after its February 2010 earthquake.

Preparing for the next big one

Oregon State University scientists have been warning Pacific Northwest citizens for more than a quarter of a century about the potential of a major earthquake in the Cascadia Subduction Zone. The subduction of a tectonic plate beneath North America has the potential to trigger an earthquake ranging from magnitude 8.0, as happened in Chile in 2010, to 9.0 (or greater), which took place in Japan in 2011.

A *New Yorker* article that detailed the Pacific Northwest's grim seismic reality turned heads and drew fear from citizens across the region. **Chris Goldfinger**, a professor in OSU's College of Earth, Ocean, and Atmospheric Sciences and a leading expert on the Cascadia Subduction Zone, cautions that the furor in news reports and on social media about western Oregon becoming "toast" have been misconstrued.

He estimates that the chances of a major earthquake off the coast from northern California to just south of Astoria are about 24 percent in the next 50 years. "South of Cape Blanco, Ore., the chances increase to about 37 percent," he added.

As residents in Japan, Nepal, Chile and other countries have done, Northwesterners need to learn to live with the realistic threat of an earthquake and tsunami – not become paralyzed by fear and ignore the threat.

Fortunately, Oregon has been taking some of the first serious steps toward earthquake mitigation. Recent legislation has resulted in a large increase in funding for K-12 and emergency facility seismic retro-fitting, as well as the creation of a new position – the state's first Chief Resilience Officer. Oregon is also working on some of the first tsunami building codes, which likely will be implemented over the next few years.

Such planning is prudent, as scientists believe that a magnitude 9.0-plus earthquake, (the largest of the large) would likely trigger a tsunami that could devastate coastal communities, while the earthquake could destroy infrastructure throughout western Oregon and Washington, including roads, bridges, water and sewer lines, and the power grid.

However, the more probable scenario is an earthquake on the average side of large, where the damage is less. The best response isn't necessarily to flee the region but to become pro-active in preparing for a disaster.

Alyssa Schrems

Transport Networks and Evacuation Planning

Alyssa Schrems is an undergraduate in geography with research interests in transportation networks, resource conflicts, indigenous knowledge and tsunami evacuation planning. She is working with Professor Julia Jones to design the curriculum for an upcoming class that examines the effect of disasters on different community networks. In addition, she is the recipient of the 2015 Outstanding Geography Senior Award.

Volcano could house geothermal energy lab

Adam Schultz

Beneath Oregon's Newberry Volcano may exist one of the largest geothermal heat reservoirs in the western United States. Researchers are investigating the production potential of the volcano's west flank, an area outside of the protected National Volcanic Monument. The U.S. Department of Energy awarded $400,000 for the first of a possible three-phase program to Oregon State University, the Pacific Northwest National Laboratory and AltaRock to study Newberry's suitability for a geothermal observatory and technology testing facility that could pave the way for widespread carbon-free energy.

Newberry is one of several proposed FORGE sites (Frontier Observatory for Research in Geothermal Energy), an initiative spearheaded by the Department of Energy. The effort brings together scientists and engineers to develop, test and accelerate breakthroughs in enhanced geothermal systems (EGS). According to the Department of Energy, these systems could power up to 100 million homes in the United States.

Geophysicist **Adam Schultz** will serve as project lead for Oregon State University. He will apply his expertise in geological modeling and assimilating data from a variety of geophysical, geological and geochemical techniques to characterize the geothermal production potential of the west flank of Newberry Volcano. Schultz's lab specializes in magnetotellurics, a geophysical imaging method, to study enhanced geothermal systems and to optimize production. Magnetotellurics reveals contrasts in the electrical properties of the Earth. The resulting images illuminate the nature of subsurface structures, such as their geometry and possible composition, including the presence of geothermally heated fluids. When scientists apply this and other methods in the same location, they can improve interpretations of these features.

The Department of Energy will select three finalists in 2016 for further study.

Panorama of Newberry Volcanic National Monument, with obsidian flow on right. Image courtesy of USGS

GIS

Tracking insect outbreaks

Satellite mapping techniques have given scientists a bird's-eye view of landscape changes over time. Assistant Professor **Robert Kennedy** and his former graduate student Garrett Meigs (now with the University of Vermont) have taken advantage of this technology to assess insect outbreaks and their effect on western U.S. forests over the last few decades.

Two of the offending culprits — the mountain pine beetle and western spruce budworm — are native species whose population numbers depend on a number of factors, including host tree health and climatic variability.

Under the right conditions, the insects can cause pervasive tree mortality and ensuing changes in forest structure and composition. Until recently, studies had not been able to assess the cumulative impacts of these outbreaks on regional forests.

The researchers used new computational techniques to link satellite imagery from NASA and the U.S. Geological Survey with older data from airplane and ground surveys. Where old methods created the appearance of widespread, homogeneous insect activity, the new maps provide the fine spatial resolution necessary to better understand regional outbreaks since the 1980s.

Their analysis revealed that the budworm has affected a greater area and caused more total tree mortality than the mountain pine beetle, despite the beetle receiving more forest management attention. Beetle outbreaks also occurred in two phases — first during the 1970s and 80s in eastern and central Oregon and then later during the 2000s. Budworm outbreaks concentrated in northern Washington early on and spread from the eastern to central Pacific Northwest during the 1980s, returning to northern Washington during the 1990s and 2000s.

This new mapping framework is important, researchers say, because it will help scientists and land managers learn how insects shape forests, and in turn, how forests recover from outbreaks.

"Forests and insects dance to rhythms that are tricky to understand without good maps. We're excited to show how technology can blend with on-the-ground know-how to make those maps and lead to better management," Kennedy said.

In addition, the new mapping technique could be applied to the Pacific Northwest and other regions to assess when and where insect outbreaks result in substantial tree mortality. Kennedy said it makes way for additional research on the complex interactions between fire, insect outbreaks and climate change. For example, the team found recently that wildfire likelihood does not generally increase following mountain pine beetle outbreaks, despite popular sentiment to the contrary. In fact, wildfire likelihood appears to be lower following western spruce budworm outbreaks.

"Managing any natural resource under climate change requires knowledge of cause and effect. Maps like these provide us the tools to link the 'When?' and the 'Where?', and that's the first step toward understanding the 'Why?'"

View from Tam McArthur Rim of lodgepole pine and whitebark pine killed by mountain pine beetle within the prior 10 years, Deschutes County, Ore. in the Deschutes National Forest, September 2011. (Photo: Garrett Meigs, Oregon State University)

Atlas of Infectious Diseases

New Mapmaker Award

The Atlas of Infectious Diseases, an interactive atlas for the iPad, received the 2014 New Mapmaker Award from the British Cartographic Society. The atlas was created by a group of students in a computer-assisted cartography course. Also recently released is the Atlas of the Polar Regions. To download either atlas: cartography.oregonstate.edu

Gareth Baldrica-Franklin

Mapping Geology in National Parks

Gareth Baldrica-Franklin is a geography student and member of the University Honors College. In addition to his research in freshwater sustainability, he worked in the Cartography and Geovisualization Lab to create a series of maps for a course investigating the geology of national parks. Baldrica-Franklin is a recipient of the Arthur Parenzin Memorial Geography Scholarship and the 2015 Drucilla Shepard Smith Scholastic Award.

Climate Change

Global sea levels have risen six meters or more with just slight global warming

A review analyzing three decades of research on the historic effects of melting polar ice sheets found that global sea levels have risen at least six meters, or about 20 feet, above present levels on multiple occasions over the past three million years.

What is most concerning, scientists say, is that amount of melting was caused by an increase of only 1-2 degrees (Celsius) in global mean temperatures. Six meters does not sound like a lot, but a global mean sea level rise of 10 to 20 feet today could be catastrophic to the hundreds of millions of people living in coastal zones.

"Studies have shown that both the Greenland and Antarctic ice sheets contributed significantly to this sea level rise above modern levels," said **Anders Carlson**, an Oregon State University glacial geologist and paleoclimatologist. "Modern atmospheric carbon dioxide levels are today equivalent to those about three million years ago, when sea level was at least six meters higher because the ice sheets were greatly reduced.

Co-author **Peter Clark**, an OSU paleoclimatologist, said that because current CO_2 levels are as high as they were 3 million years ago, "we are already committed to a certain amount of sea level rise."

"The ominous aspect to this is that CO_2 levels are continuing to rise, so we are entering uncharted territory," Clark said. "What is not as certain is the time frame, which is less well-constrained. We could be talking many centuries to a few millennia to see the full impact of melting ice sheets."

Jon Edwards

Greenhouse Gases Trapped in Ice Cores

Jon Edwards is a Ph.D. candidate in Marine Geology and Geophysics doing climate research under Ed Brook. A first-generation college student, Edwards is studying past climates by measuring ancient gases trapped in small bubbles within ice cores. He is a recipient of the CEOAS Teaching Assistant Award and the Murray Levine Memorial Fund.

Scientists calculated the productivity of marine plankton during the last major global warming event, the end of the last ice age, by examining fossil diatoms buried in sediment off the coast of Oregon.

Ocean biota responds to global warming

The ocean absorbs carbon dioxide like a sponge; scientists say that about one-third of all CO_2 emitted historically by burning fossil fuels is now in the ocean. A major uncertainty has been how life in the ocean will respond to increasing CO_2 and global warming. A new study has found that as the Earth warmed coming out of the last ice age, plant growth decreased while carbon export increased.

Growth of phytoplankton (microscopic plants such as diatoms) near the sea surface converts carbon dioxide into organic matter. When the plankton die, their organic remains either decompose in the surface ocean, or sink into the abyss.

This sinking of plankton effectively pumps CO_2 out of the atmosphere. The so-called "biological pump" stores carbon in the deep sea, which is one way that biology influences global climate.

"It has been assumed that the amount of organic material that sinks to the sea floor would parallel that produced through photosynthesis near the sea surface," said **Alan Mix**, an Oregon State University oceanographer and co-author on the study. "Surprisingly, our study found that even as plant growth decreased, past warming actually enhanced the biological export of carbon to the deep sea, at least in the northeast Pacific."

The researchers say their findings don't necessarily mean that the ocean can continue to absorb increasing amounts of CO_2 indefinitely, but that computer models of the ocean's carbon cycle will need to take into account that plant productivity and carbon export are not always linked.

In addition, export of carbon to the deep sea may make some other impacts worse, the researchers point out. For example, as the extra sinking organic matter decomposes, it consumes oxygen dissolved in seawater – and loss of oxygen in the ocean is a growing concern.

Water Resources

A new way to measure nitrate removal in streams

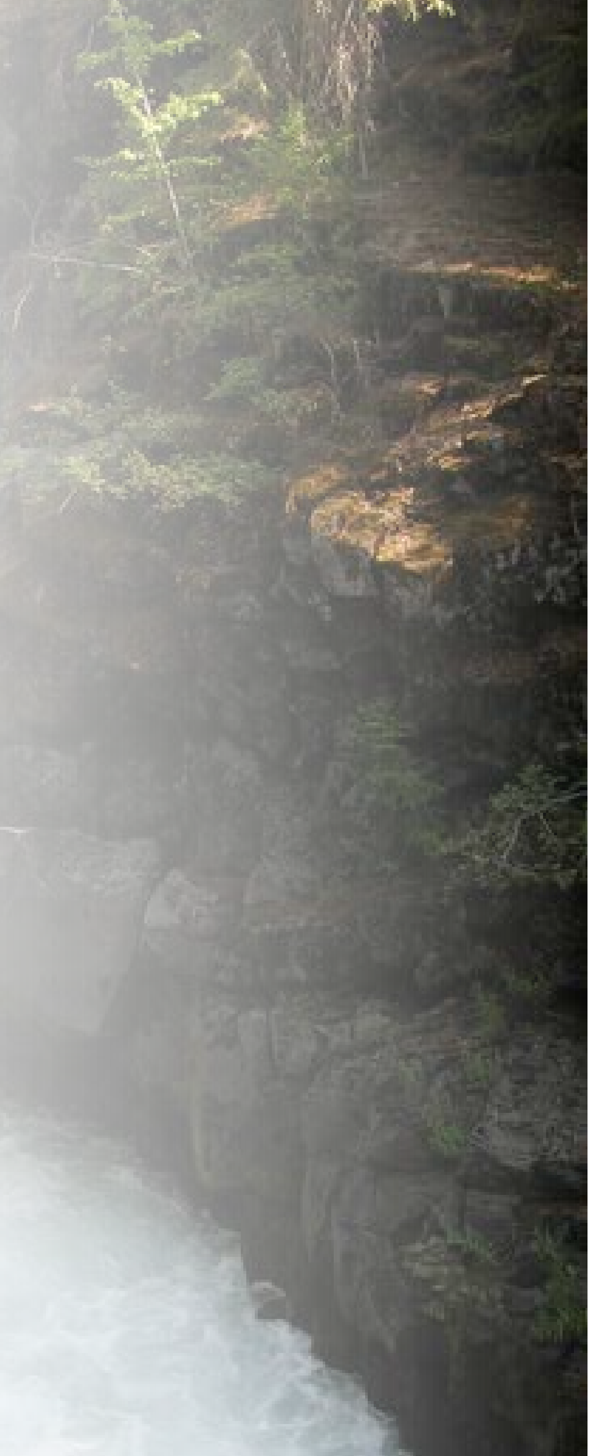
Excess nitrate from fertilizer runoff, wastewater discharge, rainfall and other sources can cause persistent problems in streams — including plant and algae growth that robs the system of dissolved oxygen. Denitrification, or the process that permanently transfers nitrogen from bioavailable forms to nitrogen gas, occurs in several locations in ecosystems. But scientists have been paying particular attention to a denitrification hot spot known as the hyporheic zone (HZ), the region beneath and alongside a steam bed. There, water has a longer residence time and is in contact with enormous numbers of bacteria, increasing the potential for reactions to occur that clear the system of bioavailable nitrogen and other excess inputs.

However, measuring the overall impact of hyporheic zones in removing nitrates at the reach and network scale is difficult. In addition, traditional methods inadequately characterize the role of these zones in the denitrification process.

To combat these shortcomings, **Roy Haggerty**, a professor of environmental geology, used two different measurements at different scales to paint a more holistic picture of the HZ-nitrate connection. He and colleagues characterized the reach scale with a specialized tracer experiment (a stable – i.e., non-radioactive – isotope of nitrogen) and solute-transport modeling to see how nitrates moved through the system. They then directly measured HZ conditions that enabled them to study nitrogen transformations in-situ. What they found is that the HZ accounted for about a third of the total denitrification. The results emphasize the key role of hyporheic zones in the nitrogen cycle and potential to improve water quality.

"For years, hydrologists and stream ecologists have hypothesized that the hyporheic zone of streams is a critical part of the terrestrial system for removing nitrate. This body of work by Jay Zarnetske and in collaboration with Steve Wondzell at the Forest Service provides some of the best evidence for that hypothesis," Haggerty said.

He added, "What we really need to do next is a big river. Rivers like the Mississippi deliver huge amounts of nitrate and other nutrients to the coastal ocean. The cost and complexity of doing experiments like these on a big river are large, but this is what needs to be done next."



Aaron Wolf

Heinz Award

Oregon State University's Aaron Wolf, an internationally recognized expert on water conflict resolution, has been named a 2015 recipient of the Heinz Award in the category of public policy. Wolf was cited for applying 21st-century insights and ingenuity to find common ground on water-centered conflicts.

Rogue River. Photo: Creative Commons license.

Academic Programs

Undergraduate Program

The college is committed to delivering outstanding undergraduate education that prepares tomorrow's science professionals. Bachelor's of Science degree programs in Earth Sciences and in Environmental Sciences provide the foundation for diverse careers that apply environmental science, geography, geology and earth system science in consulting, management, education, planning and research.

The majors provide a broad foundation in basic sciences, and specialization through options. All students complete practical, experiential learning through a combination of field courses, internships and research experience. The college also serves thousands of undergraduates through minors and general interest courses.

CEOAS undergraduates engage in a wide range of research through IDES (Increasing Diversity in Earth Sciences), REU (Research Experience for Undergraduates) and simply through working with CEOAS faculty on projects. Research positions for undergraduates are frequently written into federal grant proposals by faculty.

Earth Sciences

The Earth Sciences Bachelor's degree has options in Geography, Geology, and Ocean Science. A Climate Science option is under development.

The Geography option is designed for students interested in the interaction of society with natural processes and resources. A particular strength lies in the application of spatial techniques, such as GIS and remote sensing.

The Geology option is designed for students with interest in understanding earth processes, from deep causes of earthquakes and volcanoes to surface processes and climate change. This option emphasizes field experience.

The Ocean Science option is intended for students who are interested in the marine environment, from coastal mangroves in the tropics to the ice-covered Arctic Ocean, and how it interacts with and influences planet Earth. This option emphasizes field experiences, including ship time on a research vessel.

Environmental Sciences

The Bachelor's degree in Environmental Sciences encompasses the most diverse range of science options. It is designed for students who have a broad range of interests in the natural environment and the interaction of humans with the environment. The options allow exploration of environmental science policy, as well as environmental aspects of a wide range of sciences including biology, zoology, ecology, and earth, ocean and atmospheric sciences. Students sample courses in diverse colleges and departments, and may earn their degree on campus or through our Ecampus program. All majors engage in an internship or field experience.

Graduate Program

The college prepares students to seek out new ideas and innovative approaches to the complex issues of planetary-scale science. Original research, innovation and exploration are the focus. The college builds upon a strong tradition of analytical and computational technology that merges with collection of field and ship-board data to allow a wide range of fundamental and applied research. The ~200 graduate students interact with over 100 faculty to build new approaches to research, teaching and publishing.

Graduate students work closely with faculty advisors undertaking cutting-edge research, from proposals, to data collection, to publication. Many contribute to the college's teaching excellence as teaching assistants, themselves gaining important practical experience, while nearly all graduate students present at national or international professional meetings. Highlights of student research can be found throughout this publication.

Geography

Geography is the study of human use and interaction with the Earth and the identification of spatial and temporal variation in natural and human processes. The program has an applied orientation with three areas of excellence: 1) geospatial technologies and analysis; 2) water, climate and society; and 3) resources, planning and hazards.

Geology

Geology research addresses interactions of the solid Earth with the biosphere, atmosphere and hydrosphere in the past and today. Students pursue research ranging from study of the Earth's interior to paleoclimate, natural hazards, tectonics and Earth resources. The college has extensive analytical facilities in support of geochronology and geochemistry.

Ocean, Earth, and Atmospheric Sciences

The OEAS degree is an interdisciplinary program, integrating biological, chemical, geological and physical approaches to understanding the ocean and atmosphere. Areas of specialization include atmospheric sciences, biological oceanography, chemical oceanography, geological oceanography, geophysics and physical oceanography.

Marine Resource Management

Marine Resource Management (MRM) is a science-based, interdisciplinary master's program that combines the study of biological and physical science of the marine environment with the study of the social, economic, legal, educational and political processes that govern human uses of marine and coastal resources. Graduates from the program are trained to bridge the gap between science and policy.

Certificates

An undergraduate certificate in Geographic Information Science is also available. The college offers certificates at the graduate level for Geographic Information Science and Water Conflict Management and Transformation.

Field Experiences

Nearly all courses in the college include a lab, a recitation section or a field trip. All undergraduate degree programs require a substantive field or internship experience that helps students explore hands-on learning opportunities most appropriate for their future goals. The Board of Advisors consults on academic programs biannually and links academic programs with professional employment.

The Geology Field Camp, a rigorous multi-week field class, has been offered for more than 80 years.

The student Geosciences Club organizes seminars with professionals, social functions, and national and international field trips. Past international trips have included the Himalayas in Nepal, the Pyrenees, Costa Rica and India.

The Environmental Sciences club hosts a range of activities, including guest speakers from local agencies such as the EPA, a camping trip to the coast and a local restoration project.

New Faculty

Jessica Creveling joins Oregon State University as an assistant professor in Earth system history. She specializes in the use of sedimentological and stratigraphic field observations to study changes in sea level during ancient ice ages. She received her Ph.D. in Earth & Planetary Sciences from Harvard and was previously a postdoctoral fellow at Caltech.

Jamon Van Den Hoek joins Oregon State University as an assistant professor in geospatial intelligence and analytics. He specializes in the use of remote sensing and geospatial technologies to understand the relationship between large-scale environmental change and social interaction and conflicts. He received his Ph.D. in geography from the University of Wisconsin/Madison in 2012 and was previously a postdoctoral fellow at NASA Goddard.

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