A tale of two oceans, and the monsoons

Tiny seafloor shells could offer big clues to the forces that generate rainfall

By Fern Gibbons

Every summer, the continent of Asia takes a big breath. This inhalation pulls moisture-laden air from the Indian Ocean over India and Southeast Asia, causing torrential rains known as the monsoons. For as long as there have been people in India and Southeast Asia, lives have been set by the rhythm of the monsoons.

Some years, too much rain brings devastating floods and mudslides; in other years, too little rain causes droughts and famine. In 2007, flooding displaced about 30 million people from their homes. Over the past 200 years, several droughts have each caused more than 5 million deaths.

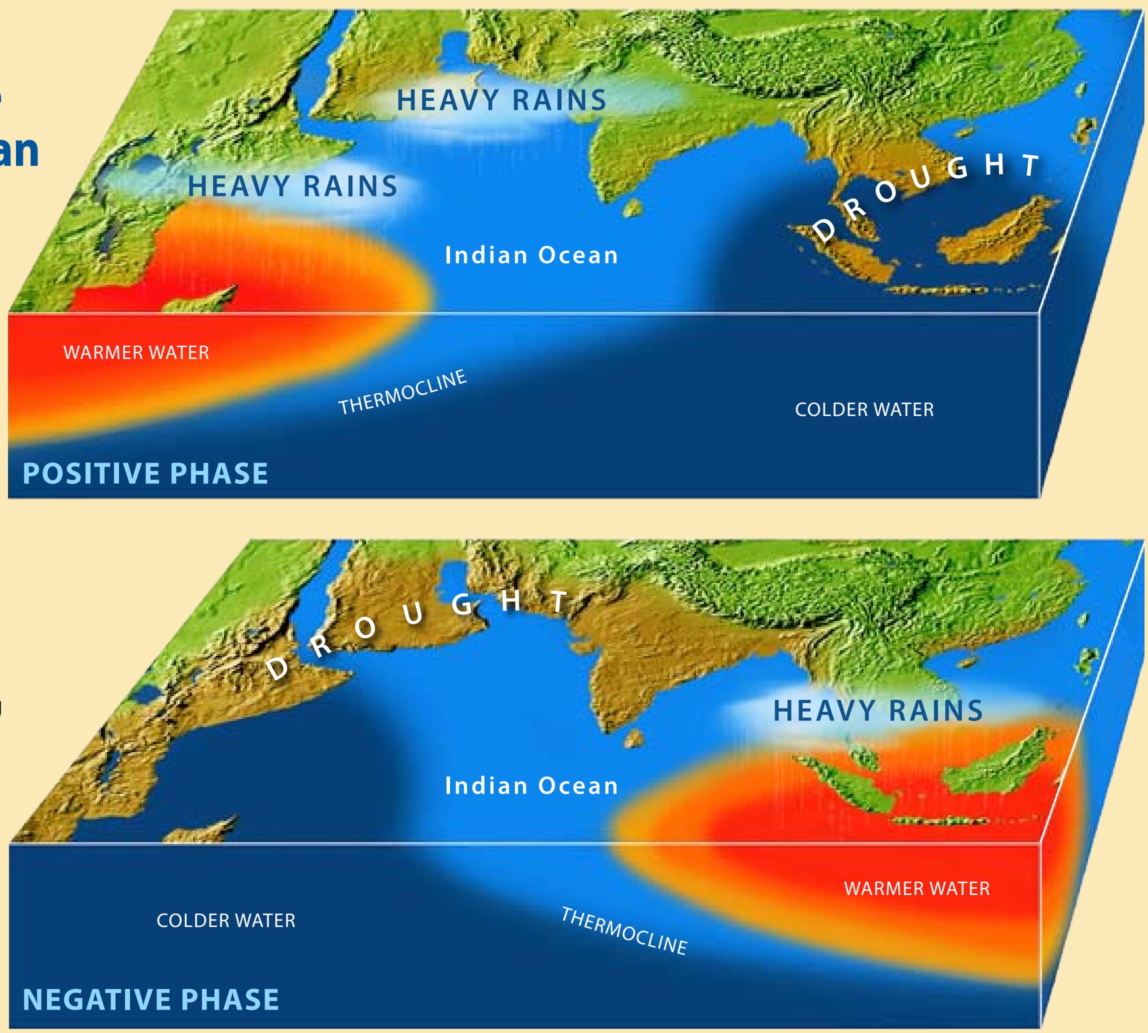
If we could forecast upcoming monsoon seasons, we could take steps to avoid death and destruction. But the monsoons have defied prediction so far, partly because they are generated by complex interactions among land, air, and two oceans. Predicting the monsoons will become even more difficult as global warming creates a climate that we have not experienced in recorded history. We won't be able to use our current climate as a guide to the future.

But we can use the past. One way to unravel the complexities of the monsoon system is to study how it has worked in the past. To do this, we use some very small shells, preserved in sediments at the bottom of the sea, to answer some very big questions about climate.

A seesawing ocean

During the summer, the huge landmass of Asia heats up like a brick in the sun; hot air rises over the continent, and cool ocean air, filled with moisture, flows in to replace it. During the winter, the air over the Indi-

Linking the Indian Ocean and the monsoons



Surface temperatures in the Indian Ocean naturally oscillate, a phenomenon called the Indian Ocean Dipole. During its positive phase, warmer waters in the western Indian Ocean bring heavy rains to East Africa and India, and colder waters bring drought to Southeast Asia. In the negative phase, ocean and monsoonal conditions reverse.

E. Paul Oberlander, WHOI

an Ocean is warmer than the air over land; the ocean air rises, drawing cool, dry air from Asia out to sea.

The size of the air mass that Asia breathes in depends, in part, on the temperatures of the Pacific and the Indian Oceans. And the temperatures of these oceans are influenced by two large-scale, dynamic patterns of winds and water temperatures that seesaw between two extremes: El Niño-Southern Oscillation (or ENSO) and the Indian Ocean Dipole.

During "normal" years in the Pacific Ocean, trade winds blow along the equator from Central America toward Indonesia, pushing warm surface water toward the western Pacific. In the eastern Pacific, cool water from the deep ocean is pulled up to the surface to replace the water blown to the west. The constant blowing of the trade winds maintains a Pacific Ocean with a tilted surface. So much warm water piles up in the west, the sea surface height there is about 7 inches higher than in the east.

Occasionally, the trade winds will weaken just for a bit. Without the winds holding the mound of warm water in place, it begins to slide back to the east. This is an "El Niño" event. As the pool of warm water from the western Pacific spreads eastward across the Pacific, it creates a cap of warm water in the east, effectively preventing the cool deep water from reaching the surface.

During El Niño years, the entire Pacific is warmer than usual. That can take Asia's breath away during the summer. A hotter Pacific Ocean can effectively compete with the hot Asian landmass, so that no cool, moist air is drawn landward, and ultimately, the monsoons do not fall over India.

Back and forth in the Indian Ocean

The Indian Ocean has its own seesaw behavior called the Indian Ocean Dipole. During a "positive" Indian Ocean Dipole event, warm waters in the east spread toward the west, somewhat as in an El Niño. The winds that blow along the equator also switch directions and blow toward the west. These westward-blowing equatorial winds enhance monsoon winds and create a more powerful monsoon.

India's largest rainfall in the past 150 years occurred during a positive Indian Ocean Dipole event. During negative In-

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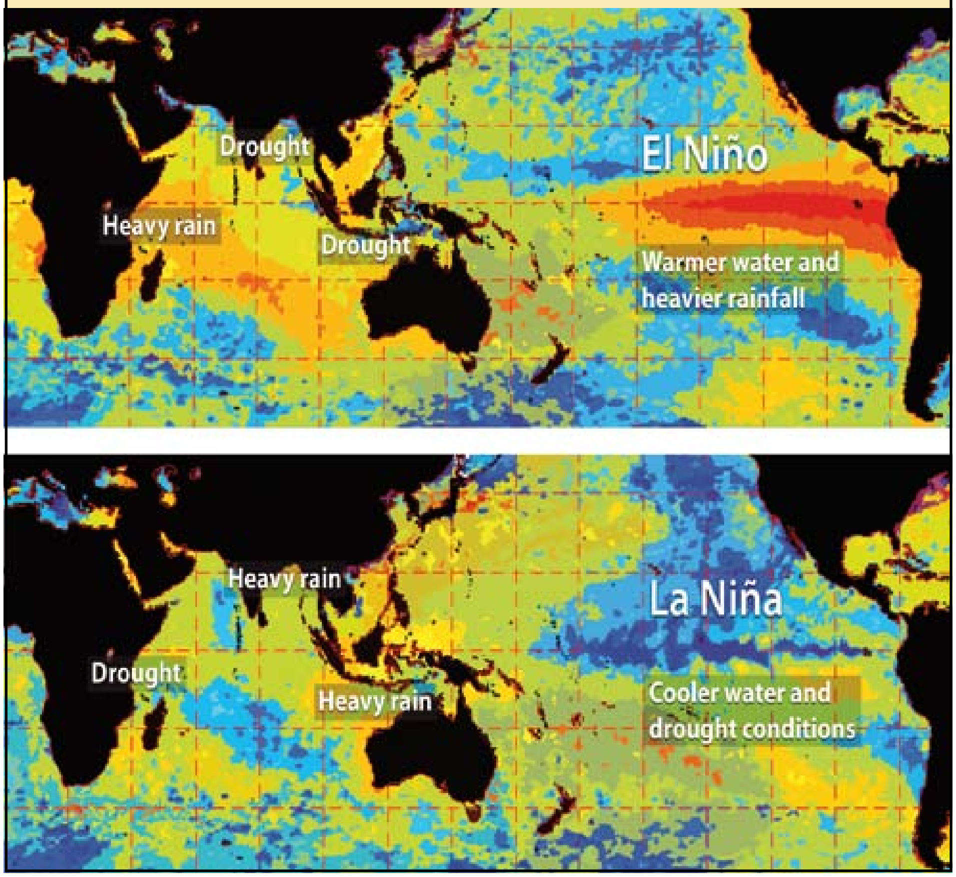
MIT/WHOI graduate student Fern Gibbons extracts tiny preserved shells of marine life from sediments cored from the seafloor. The shells hold chemical clues that reveal ocean conditions in the past and possible changes in the future.

How the Pacific influences rainfall in Asia

El Niño/Southern Oscillation periodically shifts Pacific Ocean temperatures. When surface temperatures in the eastern equatorial Pacific are warmer (orange) during an El Niño, there are heavy rains in East Africa and droughts in India, Indonesia, and Australia. When eastern Pacific waters turn colder (blue) during a La Niña, rainfall patterns flip-flop in Asia, Africa, and Australia.



dian Ocean Dipole events, ocean and monsoonal conditions reverse.

Predicting the monsoons is so difficult because ENSO and the Indian Ocean Dipole seem to take turns influencing the monsoons. In some years, an El Niño event has a strong influence on the monsoons, and the Indian Ocean Dipole has none. In other years, it is vice versa. The reasons for this trade-off are not entirely clear, but it probably has to do with the exact timing, strength, and positioning of the warm water pools during El Niño and Indian Ocean Dipole events.

The past holds clues to the future

In our quest to study past climate, our main clues come from foraminifera. These are amoebas, but unlike the tiny blobs you saw in the pond water in junior high school, these amoebas build shells around themselves, which they make from calcium carbonate. The shells contain evidence of what seawater conditions were like when the foraminifera were living and building their shells.

A foraminifer lives for about a month. When it dies, it sinks to the seafloor. It falls on top of the dead foraminifera from the previous year, and next year's foraminifera will fall on top of it. Research vessels can collect a core of these sediments, using a large tube inserted into the seafloor. From the core, we can extract and analyze foraminifera shells to reconstruct ocean conditions, and we can date the shells to determine when those conditions were occurring. Together, these let us create records of climate conditions that extend many thousands of years into the past.

Back on land, the cores are sliced open. We scope out slices of mud with a little spatula. When the cores are fresh, the mud they contain has a consistency similar to cake frosting. We rinse the mud in a sieve so that the remaining sample is mostly shells. With the naked eye, the shells look like grains of sand. Under a microscope, they are beautiful, shaped in spirals, disks, spheres, tubes, and cones. There are shiny shells and pitted shells and even the occasional pink shell.

From the core mud, I pick out two species of foraminifera, *G. ruber* and *P. obliquiloculata*, and move them to a separate dish with a very fine paintbrush. *G. ruber* lives right at the surface of the ocean, while *P. obliquiloculata* lives deeper, at approximately 300 feet. So measuring the isotopic and chemical composition of both of them is like having two thermometers in the water, one at the surface and one 300 meters deep.

If both foraminifera record warm temperatures, that means the layer of warm water on the surface was thick. If *G. ruber* records warm temperatures and *P. obliquiloculata* records cold temperatures, that means the warm surface layer was thin. While measuring two species is twice the work, knowing the temperature of both surface and subsurface waters is important if we want to understand how the mechanisms of the climate system interact.

Elementary evidence

We analyze the shells' chemistry in a mass spectrometer, investigating ratios of carbon, oxygen, calcium, and other elements that sometimes may take the place of calcium in the shell while it was growing. Variations in these elements can tell us about the temperature and salinity of the seawater that existed when the foraminifera were alive. They can also tell us about past levels of freshwater runoff into the ocean from rivers; increases indicate times in the past when monsoonal rainfall had risen.

With my Ph.D. advisor, Delia Oppo, I am examining sediments that have been cored from the seafloor in the eastern Indian Ocean, along the coasts of the islands of Java and Sumatra. In this location, ocean conditions are influenced by ENSO, the Indian Ocean Dipole, and the monsoons. By examining several cores from this region, we hope to tease out how these three systems interact.

Our goal is to create climate records for the past 25,000 years, a time span that encompasses many different climate conditions, including a time when much of North America was covered by an ice sheet and a time when the global climate was slightly warmer than it is today. That will give us the next-best way to understand how our climate system works under a variety of conditions, because we can run only one experiment at a time on Earth's climate—the one we are running now.

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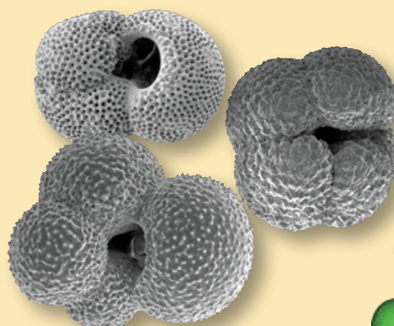
Fern Gibbons grew up in Cape May, N.J. Though she was raised at the shore and spent most of her free time sailing, she didn't seriously consider a career in oceanography until her third year at the University of Chicago. Perhaps she just needed to get away from the beach for a few years. In 2005, she began her graduate studies in the MIT/WHOI Joint Program, where she has pursued her interest in learning what the oceans were like in the past. In her free time, she hangs out with her husband, who is also a graduate student. Together they have a variety of pets, including a dog, a cat, fish, and bees. She enjoys gardening, though her lack of a green thumb suggests that she is probably smart to stay in a field where her study subjects are already dead.

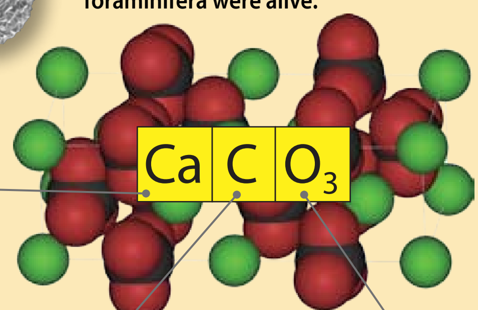
Chemical clues in tiny shells

Tom Kleindinst, WHOI

Seafloor sediments are full of fossilized shells, magnified here under a microscope.



The chemistry of calcium carbonate ($CaCO_3$) shells of tiny marine animals called foraminifera can tell scientists a lot about environmental conditions that existed thousands of years ago when the foraminifera were alive.



CALCIUM (Ca)

Other elements in seawater can substitute for calcium in the shells, giving scientists clues to how conditions changed.

Magnesium—The amount of magnesium in shells can tell scientists how water temperatures shifted over time.

Cadmium—The amount of cadmium in shells indicates the amount of nutrients in seawater at the time when the shells formed.

Barium—The amount of barium in shells can indicate how much runoff from rivers entered the oceans.

CARBON (C)

Most of the shells are made of one isotope of carbon, carbon-12, but the amounts of other carbon isotopes can be quite revealing.

Carbon-14 (radiocarbon)—The amount of carbon-14 in shells can help determine how old they are.

Carbon-13—The amount of carbon-13 in shells can reveal the levels of nutrients in seawater at the time the shells formed.

OXYGEN (O)

Scientists measure the amounts of two isotopes of oxygen in the shells, oxygen-16 and oxygen-18. The ratio of these isotopes helps them reconstruct a variety of past conditions: seawater temperatures, evaporation, precipitation, river runoff, and the volume of water on Earth that took the form of ice frozen in ice sheets and glaciers, rather than liquid in lakes and oceans.