Uncovering Prehistoric Hurricane Activity

Examination of the geological record reveals some surprising long-term trends

Kam-biu Liu

As a resident of hurricane-prone Louisiana, I was not particularly surprised as I watched the fence in my backyard being blown down when Katrina made landfall near New Orleans on August 29, 2005. (It was the second time this had happened in 13 years, my first fence having been toppled during Hurricane Andrew in 1992.) The wind speed in Baton Rouge, where I lived, was actually not that high, equivalent to that of a Category-1 hurricane. I reported the damage to my insurance company, and I was promptly compensated—no questions asked.

To insurers, the chance of property loss due to a Category-1 hurricane is a predictable matter, and they incorporate the costs of paying for such destruction in determining the rates that they charge their customers. After all, these companies, and the reinsurers that in turn insure them against catastrophic loses, hire lots of actuaries and risk managers to run computer models for calculating the probabilities that cities such as Baton Rouge or New Orleans will be hit by Category-1 hurricanes. These models are fairly reliable because they can be easily verified using empirical data from the historical record, there having been enough hurricanes of this magnitude during the past 150 years for statistical calibration.

I watched with much greater astonishment later as the levee system in New Orleans failed in the face of the remarkably large storm surge Katrina caused, resulting in the catastrophic flooding that eventually killed more than 1,300 people and laid waste to this low-lying coastal city. This calamity is a much less predictable event, at least to the U.S. Army Corps of Engineers, which built these structures back in the 1960s. The Corps designed the levees to withstand hurricanes of up to Category 3 in strength. The underlying assumption behind that fateful decision, apparently, was that it is extremely unlikely that New Orleans would be directly hit by a Category-4 or -5 hurricane—the likes of Camille (1969), Hugo (1989) or Andrew (1992)—or that a lesser storm might induce a surge commensurate with one of these larger catastrophes.

What exactly is the probability that a Category-5 hurricane would strike New Orleans? There is no clear answer to this question, because over the past 150 years, the period for which instrumental data exist, New Orleans has never been directly hit by a Category-5 or even a Category-4 hurricane. The two most recent intense hurricanes to inflict heavy damage on New Orleans—Katrinia and, in 1965, Betsy—were both only of Category-3 strength at landfall. Obviously, storms of greater intensities (here I call them "catastrophic hurricanes") are so rare that the historical record is not long enough to allow good judgments about their frequency at any particular place.

One must thus look elsewhere for assistance. The geological record can easily extend to thousands of years, increasing the likelihood of capturing evidence of these very rare, extreme events. The longer span can also reveal any temporal variations in the frequency of catastrophic hurricanes. It is well known from historical sources that Atlantic hurricane activity waxes and wanes, having experienced higher activity from the 1940s through the 1960s and during the years since 1995, with these active phases separated by a relatively calm period from 1970 to 1994. But are there longer-term variations, say, on timescales of centuries or millennia, superimposed on these multidecadal cycles?

Around 1989, my student Miriam L. Fearn and I started exploring the idea of trying to answer such questions by recovering geological records of past hurricane strikes. As a paleoecologist who specializes in using fossil pollen preserved in lake sediments as a means to determine ancient environments, I naturally thought of examining coastal lakes situated behind sandy barriers (for example, a beach with sand dunes) to look for evidence of prehistoric hurricanes. The basic assumption is that during landfall the waves and storm surge driven by the strong onshore winds may be high enough to reach over the barrier and drive sand into the lake, forming what geologists call an overwash fan along the lakeshore. An ancient overwash fan will appear as a sand layer, distinct from the fine organic mud that accumulates in a lake under normal conditions. Such a sand layer should be thickest along the side closest to the ocean and thinner toward the lake center.

With a series of sediment cores taken from a properly situated coastal lake, a geologist ought easily to be able to identify a number of sand layers, each corresponding to an intense hurricane strike in the past. The age of these events can be determined by radiocarbon analysis or by some other dating technique, such as measuring radioactive lead-210. Thus, a chronology of past hurricanes can be established, reaching back

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Figure 1. In 2005, Hurricane Katrina laid waste to a great swath of the Gulf coast near New Orleans. Among the wreckage was the flattened municipal building of Waveland, Mississippi, in front of which survived a sign commemorating a similar disaster that took place in 1969, when an even stronger hurricane (Camille) made landfall nearby. Just how often are catastrophic hurricanes likely to strike a particular locale? Because historical accounts cannot usually provide a definitive answer, the author and his colleagues have been probing the geological record in an attempt to chart variations in hurricane activity over the past few millennia.

hundreds or thousands of years. One can apply the same general strategy to uncover paleohurricane records from coastal marshes, shallow salt ponds or mangrove swamps in the tropics.

A Faithful Archive?

This approach was not without its skeptics, at least when I first started to pursue it. They asked: How do you know that the sand layers in these cores were not deposited by wind, which unceremoniously blows sand from beaches and dunes to the lakes behind them? The answer could be found in a detailed look at the sand and mud recovered in the cores. The sand layers are typically distinct and have sharp boundaries with the organic lake mud sandwiching them, indicating that they were formed by discrete events, not day-to-day winds or tides. Radiocarbon dates from some of these sand layers—for example, those from a well-dated core from Western Lake on the coast of the Florida panhandle—show that they formed a few hundred years apart. What kind of strong wind would deposit a layer of sand once every couple of hundred years except the kind that accompanies a hurricane?

Some doubters also pointed out that the sand in such cores might have been carried in by rivers. Several lines of evidence suggest that this was not the case. The sand layers my students and I uncovered in Western Lake, for example, are thicker and also more numerous in cores taken closer to the ocean than those from near the center of the lake, clearly indicating that the sand came from the beach in the front, not the rivers feeding into the back. We also looked at the microfossils contained in these sand layers, especially a variety called phytoliths, which are the remains of plants. The phytolith assemblages we found in these sands are similar to those produced by plants that grow near the beach (such as sea oats), which demonstrates that the material in these layers was washed in from coastal dunes and not carried in by rivers.

Some geomorphologists voiced other concerns when I first proposed this approach. They suspected that 2,000 or 3,000 years ago, when the sea level was lower, the position of the coastline must have been so different that these coastal lakes might not even have existed or might not have been close enough to the coast to record overwash events. Although no one knows precisely where the coastline was that long ago, the sed-

storm category	winds (miles per hour)	central pressure (millibars)	surge (feet)	damage
1	74–95	>980	4–5	minimal
2	96–110	965–979	6–8	moderate
3	111–130	945–964	9–12	extensive
4	131–155	920–944	13–18	extreme
5	>155	<920	>18	catastrophic

Figure 2. Since 1969, meteorologists have used the Saffir-Simpson scale to categorize Western Hemisphere tropical cyclones, in particular Atlantic hurricanes, which arise during late summer and fall. Storms are placed in one of five categories, determined by the maximum speed of their sustained winds. The depression in central air pressure, ocean surge height and extent of damage when they make landfall generally scale with wind speed and hurricane category.

imentary data from the cores my students and I have now collected show that the kinds of sediments these lakes held 3,000 years ago are similar to the material they are accumulating today. In particular, we often find microfossils indicating a coastal environment, such as obligate marine diatoms and dinoflagellates, in sediments dating to these ancient times. All these observations assure us that these lakes have been situated near the ocean for a few millennia and that they have functioned as repositories of hurricane-derived sand layers throughout this time.

What's Past Is Prologue

The general approach of using geological evidence to document ancient hurricanes has spawned the development of a new field of science called "paleotempestology," a word Kerry A. Emanuel, a meteorologist at the Massachusetts Institute of Technology, coined in 1996. During the past 15 years, my students and I have successfully used this methodology to determine the history of major hurricane strikes at scores of sites along the coast of the Gulf of Mexico, the U.S. Atlantic coast and in the Caribbean region.

A common pattern emerging from four of our Gulf coast sites, ranging from Louisiana to the Florida panhandle, shows that catastrophic hurricanes have hit each place about 10 to 12 times during the past 3,800 years, or approximately once every 300 to 350 years. In other words, at these locations, the probability of being directly hit by a Category-4 or -5 hurricane is approximately 0.3 percent per year.

Numbers like these are of great interest to reinsurance companies, because they need this kind of empirical

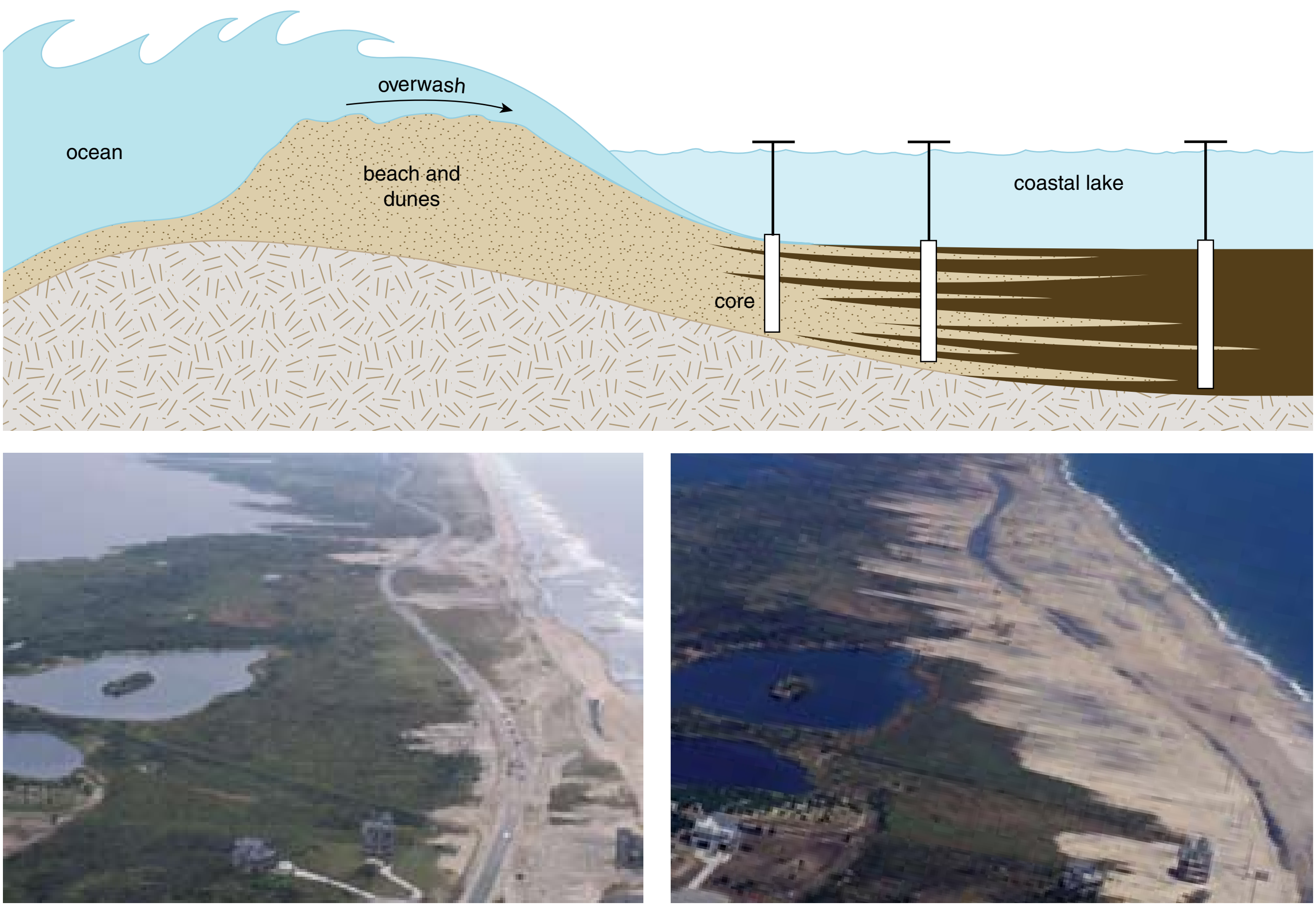

Figure 3. The author and his students have obtained sediment cores from different positions in various coastal lakes. The sand layers in these sediments constitute a record of ancient hurricane strikes, because the accompanying storm surges wash sand from the nearby beach into the lake *(diagram)*. This process was evident near Rodanthe, North Carolina, after Hurricane Isabelle struck in late September 2003 *(photographs)*. Before the storm *(left)*, beach sand was largely confined to the region between the ocean and the highway, whereas afterward sand is seen having been washed inland far enough to reach a small lake *(right)*. (Photographs courtesy of the U.S. Geological Survey.)

data to test and calibrate their computer models. Hence our paleotempestology work has garnered support from the Risk Prediction Initiative, a partnership between the reinsurance industry and hurricane scientists that is managed from the Bermuda Biological Station for Research. Even more important than the immediate business utility of these records is the geological perspective they provide. They show that coastal hurricane activity has varied at timescales of centuries to millennia.

Hurricane activity was generally low along the Gulf coast between 5,000 and 3,800 years ago and during the most recent millennium. During these two relatively quiet periods, each site was directly hit by catastrophic hurricanes only once every 1,000 years, equivalent to a landfall probability of 0.1 percent per year. However, in sediments laid down from 3,800 to 1,000 years ago, all the Gulf coast sites contain multiple sand layers, suggesting that this was a time of relatively high hurricane activity. During this hyperactive period, each site was visited by catastrophic hurricanes as often as once every 200 years, giving a landfall probability of 0.5 percent per year.

The good news, in a way, is that we are living in an era of relative calm. But the bad news is that the climate system is capable of delivering a lot more catastrophic hurricanes than what the Gulf coast has witnessed during the past 150 years.

What caused hurricanes to strike especially frequently between 3,800 and 1,000 years ago? One possible explanation calls on a shift in the position of the Bermuda High, a system of high pressure over the subtropical Atlantic Ocean that steers hurricanes from waters off the coast of West Africa toward North America. A shift in the position of the Bermuda High to the southwest would result in more hurricanes being channeled along a southerly course, some of which would then hit the Gulf coast. Conversely, a northeastward shift of the Bermuda High would result in more hurricanes colliding with the Atlantic coast of the northeastern United States.

According to this hypothesis, the Bermuda High moved southwestward toward the Caribbean during the interval between 3,800 and 1,000 years ago, resulting in more hurricanes impinging on the Gulf coast. This scenario is consistent with paleoclimatic evidence from the American Midwest and the Central Plains, which shows increased wetness during the period of hurricane hyperactivity on the Gulf coast. Presumably, the Bermuda High directed not only more hurricanes to the Gulf coast but also more moisture up the Mississippi River valley as well. At the same time, the climate of the northern Caribbean (places such as Haiti) and the southeastern United States became drier because this region was under the influence of the subsiding dry air that creates this persistent high-pressure system.

Additional support for the Bermuda High hypothesis comes from the Cariaco basin of coastal Venezuela, in the southernmost part of the Caribbean. The sedimentary record that other geologists have obtained from this basin shows that the climate there was becoming drier about 3,500 years ago, a change that paleoclimatologists believe arose because of a southward movement of something called the Intertropical

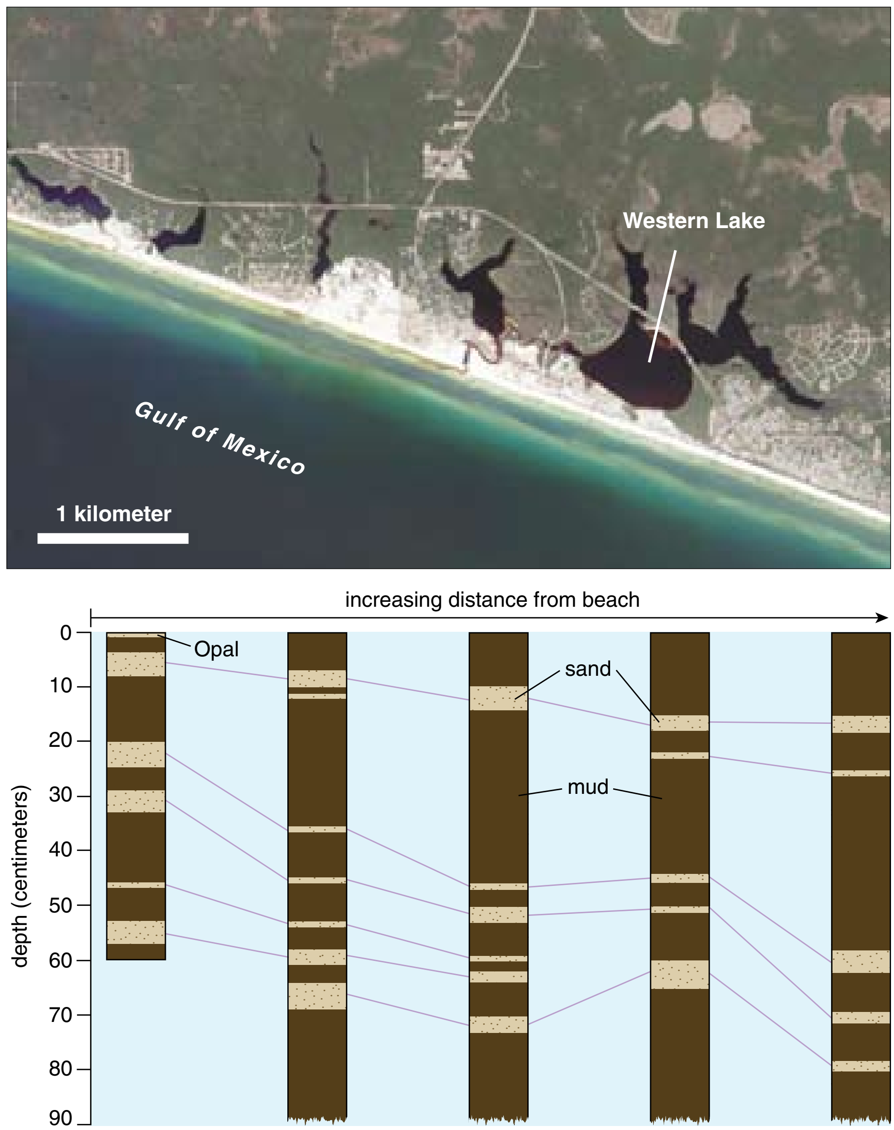

Figure 4. Western Lake is one of several small bodies of water situated near the coast of the Florida Panhandle within Grayton Beach State Park *(satellite image)*. Examination of cores taken from various positions in this lake *(diagram)* revealed past hurricane strikes, including that of Hurricane Opal in 1995, which was a Category-3 storm when it made landfall. Opal was only able to wash a small amount of sand to the seaward margins of the lake, whereas many of the prehistoric hurricanes documented in these cores carried considerably more sand toward the lake center, indicating that these earlier storms must have been far more devastating. Examination and radiometric dating of the longer cores obtained from Western Lake show that 12 such catastrophic hurricanes have hit this site during the past 3,800 years.

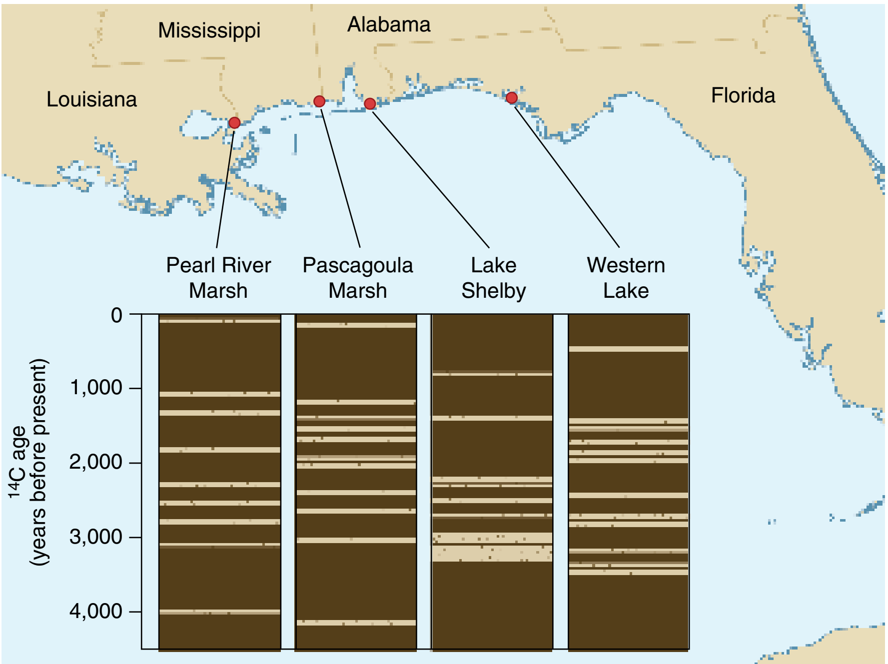

Figure 5. Sedimentary records from four coastal lakes show a distinct variation in hurricane activity in the Gulf region during the past few millennia. Whereas the interval between about 3,800 and 1,000 years ago was marked by frequent catastrophic hurricanes (typically one at each site every 200 years), the periods before and after were relatively quiet (with hurricanes striking any one locale just once every 1,000 years on average).

Convergence Zone, a belt of persistent cloudiness that roughly straddles the equator. This change was concurrent with the southwestward displacement of the Bermuda High, which sits to the north. The whole planetary pressure system must have shifted southward, though not necessarily in equal proportions, during the climatic transition between 3,000 and 4,000 years ago.

How can these ideas be tested? If a more southwesterly position of the Bermuda High was indeed responsible for steering more hurricanes to the Gulf coast between 3,800 and 1,000 years ago, fewer hurricanes would have been hitting the Atlantic coast at the same time, resulting in a quieter period there. Investigators can test this prediction by examining sedimentary records from appropriate sites in New England and other parts of the region. Jeffrey P. Donnelly, a coastal geologist from Woods Hole Oceanographic Institution, has made detailed examinations of material extracted from coastal marshes in the Northeast, although his studies are largely confined to documenting hurricane activity during the last 1,000 years, not long enough to shed light on what was going on during the hyperactive period. Fortunately, from coastal lakes my students and I have cored in Cape Cod, we were able to obtain records that go back almost 3,000 years.

The most compelling evidence comes from Nobska Pond, a small coastal lake in the town of Woods Hole. The Nobska Pond sediments show that the area was directly struck by intense hurricanes at least nine times during the past 2,500 years. However, six of these events happened during the past 1,000 years, whereas only three took place between 2,500 and 1,000 years ago. Thus, in Cape Cod at least, the most recent millennium has been much more active than the preceding period—exactly opposite to the pattern we had earlier established for the Gulf coast. This inverse correlation nicely supports the Bermuda High hypothesis.

South of the Border

Compared with both the Atlantic and Gulf coasts of the United States, the

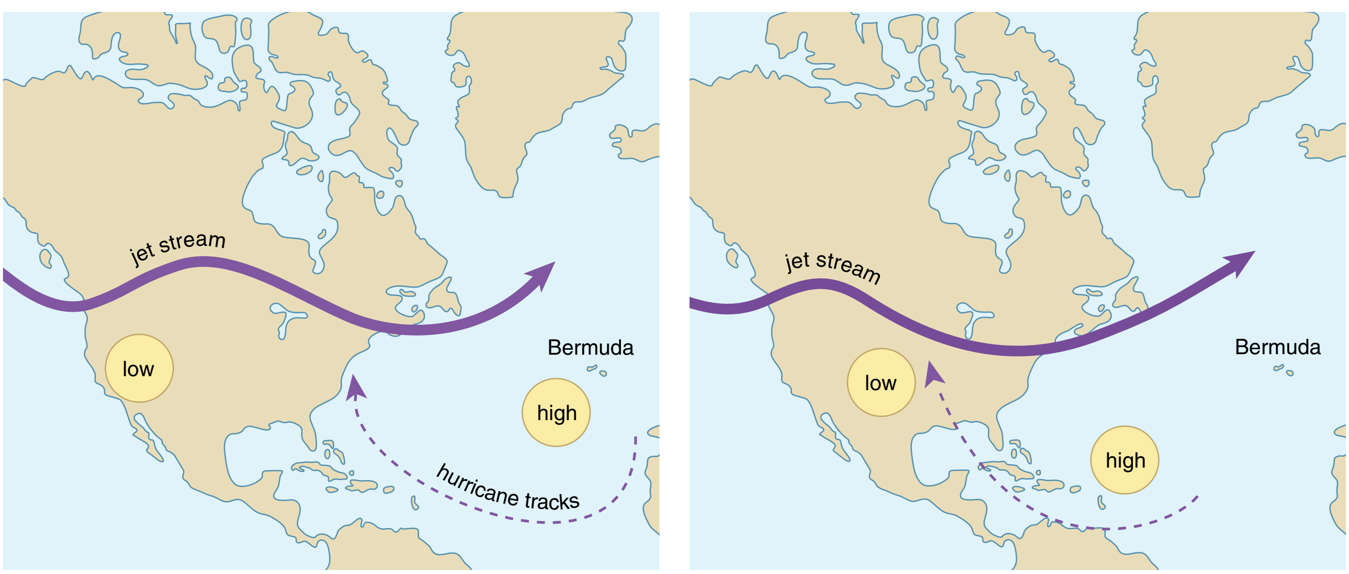

Figure 6. Changes in the position of the Bermuda High—a persistent atmospheric high-pressure system in the North Atlantic—might account for changes in hurricane activity over time. Today, the Bermuda High directs tropical storms from off of West Africa, where they originate, toward the East Coast of the United States *(left)*. Thus hurricanes strike the Gulf Coast relatively infrequently. But during the interval between 3,800 and 1,000 years ago, this high-pressure system may have been positioned more to the southwest, leading storms to strike the Gulf Coast more often *(right)*.

Caribbean region, including Central America, is hit by hurricanes not only more frequently but also with more devastating results. (Many hurricanes that end up making landfall in Florida or the Gulf coast actually come first through Cuba, Hispaniola or other islands in the Greater or Lesser Antilles.) Understanding the long-term pattern of hurricane activity is clearly important for risk prediction and disaster management in Caribbean nations. It is thus interesting to know, for example, whether hurricane activity in this region was in phase or out of phase with that of the Gulf coast during the hyperactive period. For this reason, the work I have been carrying out with my students has caught the attention of the Inter-American Institute for Global Change Research, which has recently funded us to study the paleotempestology of the Caribbean region in collaboration with investigators from four different nations in North and Central America.

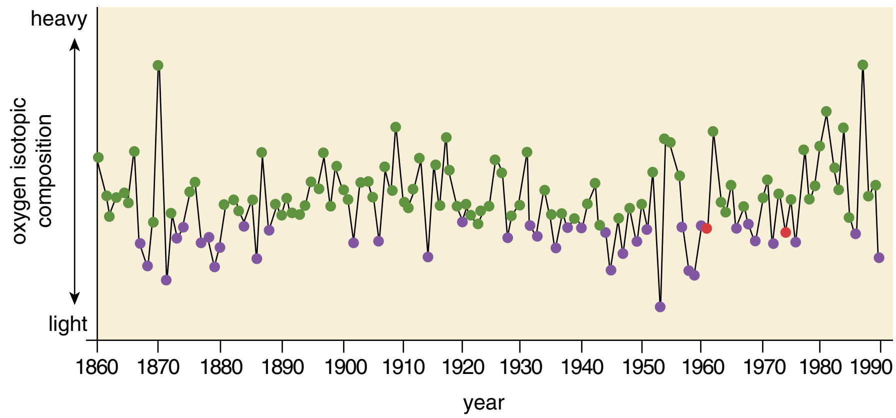

Figure 7. Examination of the isotopic composition of the oxygen atoms in tree rings can reveal past hurricanes. Here, analysis of cellulose produced late in the growing season in long-leaf pines located near Valdosta, Georgia, is compared with the historical record of hurricanes in the area. The tree-ring measurements show more light oxygen in wood laid down during years with documented hurricanes *(purple)*. Intermediate results were found for years during which hurricanes only took place more than 400 kilometers from the site *(red)*, whereas heavy oxygen-isotopic values correspond to years with no documented hurricanes *(green)*. Although the trees studied provided a 220-year record, the earlier portion is omitted here because historical documentation of weather events for the interval before the Civil War is relatively poor. (Adapted from Miller *et al.* 2006.)

For this project, we will use not only lake sediments but also newer techniques that are in their early stages of development, such as the study of corals, tree rings and speleothems (cave deposits). Our conviction that such materials can record hurricanes is based on the discovery that the rainwater associated with these great storms is strongly depleted in the heavy isotope of oxygen (oxygen-18), which makes it distinct from other forms of precipitation or from ordinary groundwater. When corals, trees or stalagmites absorb this isotopically light water, it is recorded in their growth bands. Recent work, spearheaded by Claudia I. Mora and her research group at the University of Tennessee, has demonstrated the promise of these isotopic techniques by using tree rings to produce a 220-year record of historic hurricanes in southern Georgia. Amy B. Frappier of Boston College and colleagues at the University of New Hampshire have had similar success using stalagmites from limestone caves in Belize.

Although the various methods of paleotempestology can look back thousands of years, they can also provide clues to past hurricane strikes and their environmental consequences over shorter time spans, on the order of decades to a few centuries—the time period for which historical evidence or even oral histories overlap the geological record. In some remote parts of Central America, the history of hurricanes prior to the 20th century is very poorly known, there being few written records (such as local newspapers). One such area is the Mosquito Coast of eastern Honduras around Laguna Ibans, a large coastal lake separated from the Caribbean Sea by a long and narrow sand barrier.

I have been recently funded by the U.S. National Science Foundation to produce a record of hurricanes on the Mosquito Coast. What makes this project particularly interesting is that this culturally diverse place is perfect for studying the response of different groups to hurricane hazards. On the sand barrier fringing Laguna Ibans and several other lagoons adjacent to it are a handful of villages occupied by people of three different ethnic backgrounds—the indigenous Miskito, the Afro-Caribbean Garifuna (also known as the "black Caribs") and the Hispanic Ladinos.

In 1998, Hurricane Mitch brought torrential rainfall and triggered massive flooding and landslides in Honduras and Nicaragua, killing more than 12,000 people in these two nations. Mitch was a Category-5 hurricane at sea, though it was much weakened before it made landfall to the west of Laguna Ibans. The effects of this destructive storm on the landscapes and especially on the society of the Mosquito Coast are little known to the outside world. Just how vulnerable were these communities? More important, how do the different populations perceive the continuing risk? And in the aftermath of a natural disaster, do different ethnic groups respond by making different decisions concerning relocation or rebuilding?

To probe these questions, I have worked collaboratively with David M. Cochran, a human geographer at the University of Southern Mississippi, using the standard methods of ethnographic research, including interviews and participatory group meetings, to study the cultural adaptations and societal resilience along the Mosquito Coast. We also took sediment cores from Laguna Ibans and a smaller lagoon next to it to examine the history of past hurricane strikes in the area. We were in a fortunate position in that we can use what we learned from oral histories to help decipher the geological record, a project that is still ongoing. Our hope is to integrate paleotempestology with the established methods of the social sciences so as to help inform these remote coastal communities about their hurricane risk and, ideally, to help prepare residents for the next disaster.

Getting Fired Up

There is no doubt that hurricanes are the greatest natural hazard confronting the U.S. Gulf coast, but wildfire can be a significant danger too. For example, in the dry summer of 1998, half a million acres of forest burned, with some fires disrupting traffic along interstate

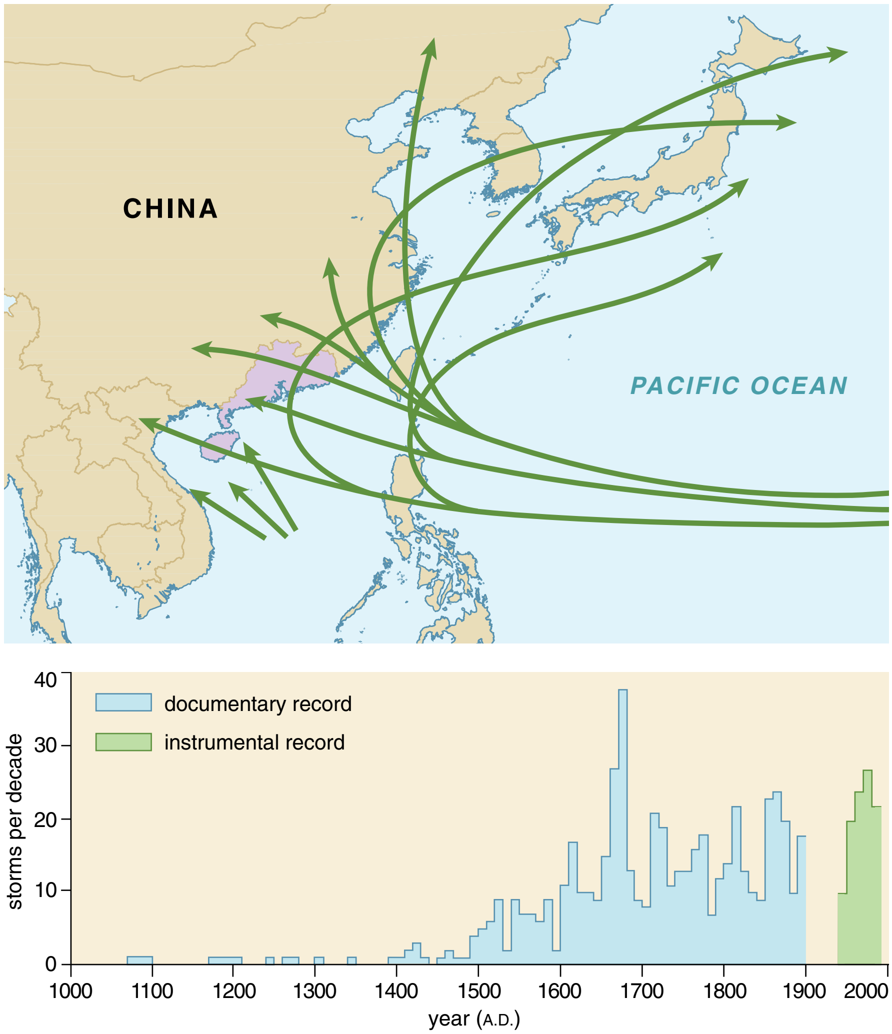

Figure 8. China, like the United States, is frequently subject to the ravages of tropical cyclones, which in that region are called typhoons. But China offers a much longer historical record from which to judge variations in storm activity over time—some 4,000 years' worth. The author has compiled a millennium-long chronology of typhoon strikes *(bar graph)* for Guangdong Province *(purple area on map)*. He postulates that the increasing frequency of typhoons there reflects a diminishing propensity for these great storms to turn north or northeast as they cross the western Pacific, a tendency that still exists to some extent, as can be seen in the generalized storm tracks for this region during recent times *(green arrows on map)*.

highways. The Gulf coast region from eastern Louisiana to the Florida Peninsula has among the highest incidences of thunderstorms and lightning strikes in North America. For a major fire to start, all it takes is a spell of dry weather plus a lot of fuel on the ground. This combination is common. The prevalence of pine savanna or pine forest in the southeastern United States—a fire-adapted ecosystem—is testimony to the frequency of fire in prehistoric times.

Ecologists have long suspected that there is a link between hurricanes and fire, because hurricanes blow down lots of trees, which sooner or later turn into massive amounts of dry fuel waiting to go up in flames. For this reason, big fires are expected to follow major hurricanes. However, this notion is not easy to test empirically in modern societies, because after a major hurricane lumber companies and local fire departments usually work hard to remove the salvageable timber and other dead wood before this material is engulfed by wildfires. The methods of paleotempestology can, however, probe times before human actions began altering the natural state of affairs.

In a core from Little Lake, Alabama, my students and I found seven sand layers, indicating seven strikes by intense hurricanes during the past 1,200 years. We then examined these sediments for microscopic charcoal particles (to reveal the history of wildfires) and fossil pollen (which show changes in the surrounding vegetation). Interestingly, we found a prominent charcoal peak immediately above each of the thicker sand layers, which suggests that fires indeed erupted after each of these major hurricane strikes. The pollen above the sand layers also shows that following these hurricanes, salt-tolerant plants increased in abundance, presumably because of an influx of saltwater from the storm surge. What's more, we found indications that the local pines took considerable time to recover from the damage that storm and fire inflicted on them.

Not Written in Stone

The examination of such geological materials can indeed provide extraordinarily rich records going back thousands of years, but information about past hurricanes can also be retrieved from historical documents archived in libraries and museums. For most regions of the world, however, the length of such observations rarely exceeds a few centuries. In the United States, written accounts can be found, for example, in old newspapers dating back to the colonial period, in personal diaries or in daily weather records kept at some plantations. In addition, the captains of ocean-going vessels often made detailed notes about weather conditions during their voyages, and these mariners' logbooks can provide a wealth of information about storms encountered at sea.

In the hurricane-prone Caribbean region, local governments of the former Spanish colonies often kept official records pertaining to hurricane strikes and other natural disasters. Voluminous collections of these colonial historical records are now kept in several archives in Seville and Madrid, waiting to be deciphered by historians and paleotempestologists alike.

In the Far East, missionaries from the West kept written records of local observations including weather events such as typhoons. One such priest, the Spanish Jesuit Miguel Selga (who served as director of the Manila Observatory between 1926 and 1946), compiled an inventory of typhoon activity around the Philippines covering the period from 1348 to 1934.

But by far the world's longest documentary record of typhoons comes from China, where the written history goes back nearly 4,000 years. Growing up in typhoon-ravaged Hong Kong in the 1950s and '60s, I developed a keen personal interest in such typhoons and their effects on Chinese society. I remember vividly the excitement, mixed with fear, I experienced during my boyhood as I fled my wind-shaken old house to a shelter during the landfall of Typhoon Wanda in 1962.

Being a history buff in addition to a paleoecologist, I naturally turned to the immense Chinese documentary record to piece together the history of typhoon activity in China. Among the various official and unofficial documents of relevance, the richest and geographically most complete data sources are the local gazettes *(fang zhi)*, which were kept at the county, administrative-district or provincial level. These semi-official records, written by local scholars under the auspices of the governments, contain information about unusual or remarkable cultural and natural phenomena that took place locally.

The voluminous local gazettes contain descriptive and sometimes vivid accounts of typhoon strikes. For example, the following paragraph is an excerpt from the gazette of Zhenhai County, Zhejiang Province, in southeastern China.

> In the 6th lunar month of the 6th year of Emperor Chongzhen [1633 A.D.], typhoon struck. Torrential rain fell for 10 days. Houses collapsed. Naval battleships were drifting in the sea; 8 or 9 out of 10 were destroyed, drowning numerous soldiers. Since the first year of Chongzhen, there was no year without typhoon strikes. The damage was especially serious this year. It was widely believed that the culprit was a mischievous dragon.

From *fang zhi* records like this, I have produced a 935-year time series of typhoon landfalls for the Guangdong Province of southern China, running from 975 to 1909 A.D., the longest record of tropical cyclones in the world. A striking feature is that typhoon activity in Guangdong ran in cycles of approximately 50 years. Two of the intervals of highest activity, around 1660–1680 and 1850–1880, coincide with two of the coldest periods in the past millennium in the Northern Hemisphere (during a time known as the Little Ice Age), when conditions in central and northern China were cold, windy and dry.

A possible explanation is that the typhoon tracks generally shifted to the south during these frigid periods, resulting in more typhoons hitting Guangdong and fewer hitting Japan and eastern China. A statistical analysis of the modern record of typhoon landfalls in China supports the notion that an anti-phase pattern exists between Guangdong in the south and other coastal provinces to the north. Historian Kin-sheun Louie of the Chinese University of Hong Kong and I are now examining the *fang zhi* records from Fujian and other coastal provinces to test this hypothesis of north-south shift.

Over the Horizon

Over the past decade, paleotempestology has become a burgeoning area of inquiry, one that seems to have an ever-expanding frontier. The development of new research tools offers an opportunity for results of many different kinds to be compared and correlated so that a more complete picture of the ancient environment can be brought into focus. For example, the long documentary record from China, speleothem isotopic signatures from Belize or tree rings from the southeastern United States could be used to complement the examination of sediment cores obtained from these areas.

The environmental consequences of recent hurricanes, such as Katrina and Ivan, should be studied in greater detail so that these events can be used as modern analogues to help specialists interpret paleoecological observations. These recent episodes of destruction might, for example, provide a basis for determining the intensity of ancient hurricanes from such parameters as the thickness of the sand layers deposited. But above all, investigators need to produce more records—certainly from the United States, but also from other cyclone-prone regions of the world.

Each such record functions something like a paleoweather station, one that is only sensitive to hurricanes for which the eye of the storm makes landfall within about 100 kilometers of the sampling locale. So far, fewer than a dozen well-dated and well-validated records are available from the entire Unites States, from Texas to Maine. How accurate could our normal weather forecasting be if we had only a dozen weather stations along our entire coastline?

Their paucity notwithstanding, these paleoweather stations have so far provided an invaluable window on the distant past. Just as a few fossil skulls from Africa have allowed anthropologists to piece together the history of human evolution, these natural archives have provided climatologists with a broad perspective on changes in hurricane activity—something that is precious, however crude and incomplete that knowledge may still be.

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