

# TREE-RING CIRCUS

## *Using Trees to Reveal Earth's Environmental History*

*by Gordon C. Jacoby*

*Z*ealously seeking any clues that could teach them something new about the Earth, Lamont scientists would leave no stone unturned. It was inevitable that one day the observatory would look up from the Earth and into the trees.

Throughout most of the world's temperate zones and certain tropical regions, trees form one growth ring each year. The size, density, anatomy and chemistry of each ring reflects the environmental conditions in the year in which it grew. So like ancient scribes, long-lived trees can sensitively record the environmental history of a given time and place.

Silent though they are, the trees, it turns out, can speak volumes. They can chronicle temperatures, year by year, hundreds of years into the past, long before thermometers and other meteorological instruments were set out in places where humans seldom traveled or kept records. The trees' long, precise record of annual changes can help us figure out if recent global warming has been caused by humans and help us assess the ecological effects of such warming. They can even leave telltale signs of where and when great earthquakes occurred, when glaciers advanced or retreated, when volcanoes erupted and when forest fires raged.

The study of tree rings, or dendrochronology, is a relatively new field. It was pioneered at the University of Arizona, which was the main (and almost only) tree-ring laboratory in existence when I earned my Ph.D. in geology from Columbia in 1971. I had focused my research there

on how the geology of regions affected the water supplies that flowed within. As a hydrologist in the early 1970s, I participated in a large-scale study to assess the impacts of major projects to dam, divert and redistribute water from the mighty Colorado River in the southwestern United States. Instruments had recorded a recent history of the region's renewable water supply, but a much longer-term perspective was essential. I learned that trees, whose growth depends on water, might be able to provide some hydrological history. So I began working with Charles Stockton at the Arizona tree-ring lab—looking over his shoulder, taking tree core samples, examining specimens and learning about tree-ring analysis.

We put together a 400-year record from the trees, which showed that the shorter-term recorded data did not provide a full understanding of the renewable water supply. Our tree-ring data showed that the available supply was likely to be significantly less than the recorded data suggested. In fact, our study indicated that the proposed water development and consumption could lead to hydrological bankruptcy. Many people didn't want to hear that there wasn't enough water for all the desired projects, but in the face of concerns about limited water supplies and other environmental considerations, the pace of some of the proposed developments has slowed.

By this time, I had become fascinated by the potential of trees as a tool for unraveling natural environmental history. In one of my visits to the tree-ring lab in Tucson,

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TWELVE PERSPECTIVES ON THE FIRST FIFTY YEARS

I learned that my old alma mater was proposing to enter the field of dendrochronology and to establish its own lab. But no one at Lamont knew very much about the field, so its proposal to the National Science Foundation had some obvious flaws. This was opportunity not only knocking, but breaking and entering.

I called Wally Broecker, the principal investigator of the NSF proposal, and volunteered to rewrite it with a more solid dendrochronological foundation. Broecker invited me to Lamont to give its first tree-ring seminar and to visit NSF to help introduce and promote the project to scientists there. When NSF funded Lamont's proposal, I was offered the job of launching Lamont's tree-ring lab, along with a promise of having our own building. I immediately hired Ed Cook, a bonafide dendrochronologist trained at Tucson, and the seed was sown.

134 | The building we had been promised turned out to be a ramshackle, somewhat smelly former private house on property adjacent to the original Lamont estate. It did have a scientific history, however. The former owner was a physician who apparently had used the place to conduct experiments on mice in an effort to create smokeless cigarettes.

That wasn't the only smoke that had been blown about the place. Rooms in the house had also been promised to other Lamont researchers. In typical Lamont tradition, the building had been divvied up by researchers hungry to find any available space. But the tree-ring lab soon established the alpha position and we overtook the whole house. Mind you, our quarters—in terms of location and condition—did not exactly induce jealousy among our colleagues, and because it was off-campus and off the beaten track, we didn't get many visitors. So for many years we lived a sort of wilderness existence, which perhaps is only fitting for a tree-ring lab.

It was a sapling of a tree-ring lab, but Lamont proved fertile soil. Like most everyone else, Lamonters did not know much about dendrochronology. But unlike at some other places, I just couldn't get away with anything at Lamont. Scientists here would challenge nearly every statement I made, no matter how simplistic or fundamental

it seemed to me. I could always expect someone to say, "Well, how do you know that?" and I had to explain why a particular procedure or concept was valid. And that was very healthy, because it made me think a lot more and sharpened my understanding of the science.

At the same time, Lamonters have always been open to taking some chances and trying new applications to a technology or a science. And that suited me well because I was keenly interested in exploring whatever the tree rings could reveal about the natural environment.

As a general rule, a wide tree ring indicates that a tree thrived that year because it had warm temperatures and/or adequate water. Narrow rings indicate that growth was inhibited by cold temperatures and/or drought.

To get these tree-ring records, we core the trees, extracting a pencil-thin cross section extending from the newest rings at the bark to the oldest rings at the center of the tree. The process does not cause permanent injury to the trees. Not all trees are suitable because they don't live long enough to take us sufficiently far back in time, or because they don't produce usable annual growth rings.

We routinely sample ten to forty trees from the same site to derive the communal response of the trees' ring widths in a given location. We sand and polish the cross-sections to bring out the rings' detailed anatomy. Then by means of pattern matching and statistical analyses we assign correct years to each ring, a process called cross-dating. On live trees the outermost ring represents the year we took the sample. Preserved dead trees can be cross-dated if living trees nearby are old enough to provide overlap. For older trees we establish approximate dates with radiocarbon dating and use cross-dating to establish exact relative dates between samples.

Multiple sampling also allows us to cross-date the rings of many trees to ensure that our dating is accurate, and to compensate for occasionally false or missing rings. And just as in humans, trees' growth rates change over their lifetimes, so we have to filter out the effects of aging on the tree rings. It is not a trivial endeavor, but we have developed statistical analyses that we can run on multiple samples from the same site.

As a additional check, we compare what our tree rings indicate about temperatures or water supplies, for example, with actual records of these environmental conditions taken by thermometers, rain gauges and other meteorological instruments stationed in the region over the past twenty to 100 years. If the trees and the instruments tell a similar story we can more confidently estimate the meteorological record back to times long before instruments were installed.

One of our major achievements has been to use trees to reconstruct a record of annual temperatures across the entire Northern Hemisphere over the past 400 years. We have taken advantage of trees at high-latitude tree line and some northern elevational tree lines. These trees are at the limit of their ability to survive, and small changes in temperatures stress them and leave a distinct and measurable signal in their rings. To collect our Northern Hemisphere temperature records, we have sampled boreal tree line forests of Canada, Alaska, Mongolia, Norway, Siberia and Kamchatka.

Essential for getting a long, untarnished record is finding trees that have never been disturbed by humans. Getting to our sampling sites typically requires hiking, kayaking rivers or using small planes. During field seasons, we are itinerant and live out of tents—not unlike a traveling circus. Our research expeditions are nothing if not memorable, as Rosanne D'Arrigo, the lab's first graduate student and now a colleague, will tell you in an accompanying chapter. To sample climatically sensitive hemlocks in the Himalayas in Nepal, Ed Cook and Paul Krusic have trekked to some relict stands that were thirteen days' walking from the nearest trail head—though even these trees were endangered by unregulated logging, fire and other natural hazards.

Some of the data from this network of trees we have sampled has combined to create an emerging picture of Earth's temperature over the past centuries. It provides a long-term perspective to help scientists determine what factors may be driving the higher temperatures of recent decades and whether global warming may be related to human activity, or may just be part of natural climate variation. By comparing

the tree rings with other long-term evidence, scientists will better understand whether the buildup of industrial greenhouse gases in the atmosphere is causing the recent warming trend, or whether other factors, such as solar or volcanic activity, play critical roles in Earth's climate.

The general trend reflected in the tree-ring record includes cooler conditions in the early 1700s, followed by warming that started mid-century. An abrupt cooling occurred in the late 1700s and early 1800s, varying for different geographical areas. The coldest period was between the 1830s and the 1870s, after which a steadily increasing warming trend began. Temperatures in the 1900s have been higher than in any other period captured by the tree rings from all over the Northern Hemisphere. The ten highest growth intervals are all after 1920. The highest twenty-five-year growth period was between 1944 and 1968, with additional warming in the last two decades.

Scientists are already using the emerging tree-ring records of annual temperature changes to search for the critical factors—working cumulatively or counteractively—that affect Earth's climate. In general, warmer temperatures recorded by the trees correspond with periods of increased solar irradiance before the Industrial Revolution. But solar irradiance alone cannot account for the steadily rising and unusually high warming that began in the late 1800s when large amounts of industrial greenhouse gases began to build up in the atmosphere. Volcanoes and aerosols also play a role by sending up particles that block sunlight and cool temperatures—the way the eruption of Mount Pinatubo in the Philippines did in the early 1990s. The cold trend in late 1700s and early 1800s coincides with several major volcanic eruptions.

Our research also provides insights on how ecosystems may respond to global warming—a subject of interest to forestry management officials. Many people have speculated that warmer temperatures would spur growth in the great forest belts stretching across Alaska, Canada and Siberia. But a study I did with D'Arrigo showed that such thinking might be too simplistic and that global warming

may produce complex side effects that cause ecosystems to respond in unanticipated ways.

Analyzing Alaskan tree rings dating back to the 1680s, we found that starting in the 1930s, temperatures became unusually warmer and tree growth increased. But since the 1970s, that growth has declined. Continuing warming conditions may be increasing evaporation and slowing tree growth by making trees more prone to moisture stress. Warm temperatures may also be promoting increases in insect populations and diseases.

Meanwhile, Ed Cook has been pursuing a similar tree-ring temperature record for the Southern Hemisphere, which poses more challenges for dendrochronologists. The Southern Hemisphere has far less land, with little of it located in temperate (rather than tropical) zones in which trees have annual growing seasons that produce the best annual growth rings.

But Ed Cook found a species of tree, the huon pine, that grows at high elevations near the windswept timberline of Mount Read in the outback of western Tasmania. Not only do the huon pines record reliable and detailed signals of temperatures fluctuations, they produce a natural pesticide, methyl eusinol, that also makes them highly resistant to rot. Sampling live and dead trees (some burned by forest fires but still usable for tree-ring analysis), he has reconstructed an annual temperature record reaching back 4,000 years.

The record shows an abrupt temperature rise since 1965. It also reveals above-average warmth from A.D. 1,100 to 1,190, which coincides with what is known as the Medieval Warm Epoch, a well-documented era of warmer temperatures in some regions of the Northern Hemisphere. But huon pine records also reveal a period even warmer than now, which occurred in pre-Industrial Revolution times 1,500 years ago.

Cook also discovered huon pines that were buried by sediments, and thus preserved, around the Stanley River in Tasmania. Some of these trees are up to 10,000 years old, giving Cook an unparalleled opportunity to extract an annual temperature record extending to times when the Earth was emerging from its last ice age.

Cook, D'Arrigo and Brendan Buckley are extending dendrochronological research in the Southern Hemisphere, sampling in New Zealand and southern South America. And D'Arrigo, working with colleagues in Thailand and Indonesia, is exploring whether some tropical trees such as teak might be new candidates for tree-ring research. They might be used to reveal records of past monsoons and El Niños, which regulate rainfall in the region. Back in the Northern Hemisphere, Cook has also put together a tree-ring record of drought across the continental United States, which nicely chronicles the Dust Bowl era, among other periods.

But water and temperatures are not the only possible factors that can affect trees' growth. We discovered that other traumatic events could also severely diminish trees' ability to grow and would also leave telltale marks in the rings: earthquakes, landslides, surging glaciers or volcanoes that spewed out sulfurous gases that blocked out sunlight during a growing season.

In the 1980s, working with Paul Sheppard and Kerry Sieh of CalTech, we sampled nine conifer trees growing within twenty meters of a segment of the San Andreas Fault near the town of Wrightwood, California. In all nine, we found significantly suppressed tree rings—all starting between the growing seasons of 1812-1813. In all of these trees, something happened that winter that affected their growth more than anything else during their entire life spans. It took four trees more than half a century to recover.

But farther from the fault, trees of the same species and in the same environment showed no similarly abnormal rings. We believe the root systems of the nine trees, growing on the surface rupture of the fault, were severed by the effects of a major earthquake. In several cases the trees' tops were broken off by quake-related accelerations and displacement.

The trees provided the first evidence that a major earthquake took place at that time and place. Such information is more than just of historical interest: It extends farther into the past the limited track record of that segment of the San Andreas, giving seismologists a better understanding of

how long it takes for strain to accumulate along the fault and how often major earthquakes may occur on it.

In 1992, we uncovered evidence for another great earthquake in a locale that had not been considered susceptible to major earthquakes until recently. Sonar surveys of Lake Washington, within the city limits of Seattle, had revealed that large landslides had occurred in the past, carrying Douglas fir trees to the lake bottom. The trees were preserved in the oxygen-poor sediments, and a private logging company had sought to make some money by salvaging the great trees with barge cranes. We cut a deal with the company and sampled seven trees recovered by the barge. The trees were so well-preserved, they still retained some bark and the last annual ring that they had grown before they were drowned in the lake.

We cross-dated the trees with samples taken of our submerged trees by scuba divers. The cross-dating was aided by matching fire scars, because Douglas firs' unusually thick bark can survive repeated fires that can cause nonfatal scarring or distinct signs of trauma in subsequent rings. All seven samples died in the same year about 1,000 years ago (estimated by radiocarbon analysis). Each had a completely intact outer ring and there was no indication that the next year's growth had started. So all the trees must have died in the fall, winter or early spring.

We then analyzed a bark-bearing Douglas fir log that had been partially buried on a tidal marsh about ten miles northwest of Lake Washington. The log was buried by sand deposited by a tsunami originating from Puget Sound, according to Brian Atwater of the United States Geological Survey. The tidal wave also caused the marsh to subside by three feet and sediments rushed in to partially bury and preserve the log.

Radiocarbon dating could estimate only that the log was between 1,000 and 1,300 years old and that the sand around the log was deposited between 1,100 and 1,000 years ago. But our tree-ring analysis revealed that the log and the seven submerged Lake Washington trees all died in the same season of the same year. The landslide and the tsunami were triggered by the same great prehistoric

earthquake. The tree-ring results made an important contribution to the documenting of this event, one of the major findings showing that the Pacific Northwest is a region of potential seismic hazard.

There are more arboreal detective stories to tell. Sampling trees across all of North America, we showed the pervasive effects of a great volcanic eruption in Tambora, Indonesia, in 1815-16, which was so cold that colonists on the Eastern Seaboard called it "The Year with No Summer." We found that volcanic gases had probably blocked sunlight and cooled temperatures over an unexpectedly extensive area, though there were substantial geographical variations and some regions experienced little effect from the eruption.

Our former colleague Gregory Wiles, now at The College of Wooster in Ohio, has chronicled the advance and retreat of the Columbia Glacier (and by extension climate changes) in Alaska by dating trees that had been overrun and killed during advances, and exposed again during retreats. We have found evidence of past forest fires and insect infestation. We have even tracked down the date and stand of trees from which a famous covered bridge over the Housatonic River at Cornwall, Connecticut, was built in Colonial times.

And there will be more stories that the trees will tell us. In 1995, we were invited to leave our isolation ward and enter a fully renovated on-campus building that had been the observatory's original machine shop. Our new state-of-the-art laboratory has microscopes with computerized measuring machines, based on our own design, that can measure rings to a precision of 0.001 millimeters. We have an X-ray densitometry system for analyzing seasonal and annual density variation in growth rings. We use Lamont mass spectrometers for chemical analysis of wood and plant material. We have microtomes and precision saws for sample preparation and a climate-controlled storage facility to archive our vast collection of wood samples from around the world. Lamont's new interest in terrestrial ecology has spawned new applications for tree-ring analysis.

Dendrochronology at Lamont has taken root and is branching out.