



Part 1 of Coring for Clues covered the basic principles and methods used to estimate climate variability before the modern period of instrumental records. Part 2 discusses how such analysis has been used at two especially appropriate locations for paleoclimate research and finishes with descriptions of three other proxy data types.

CASE STUDY: THE CARIACO BASIN

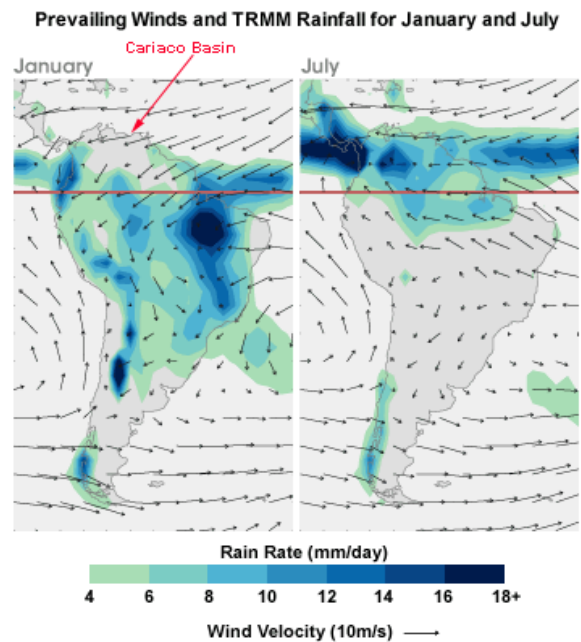
The easterly trade winds of the Northern and Southern Hemispheres converge near the Equator in the *Intertropical Convergence Zone (ITCZ)*. This convergence corresponds to rising air masses and frequent thunderstorms. The seasonal movement of the ITCZ from its northern (July) position towards its southern (January) position drives the cycles of rainy and dry seasons in different locations of the tropics. Over South America, the January position is around 15 degrees South and the July position is around 5 degrees North. Because the ITCZ is a key component of global circulation, changes in its behavior over longer time periods can reflect global climate change.

The Cariaco Basin off the Venezuelan coast receives riverine input that varies along with the position of the ITCZ. Peak flows occur during the rainy season in the Northern Hemisphere summer and fall and minimum flows during the Northern Hemisphere winter and spring. The position of the ITCZ also controls the position of the winds that “pull” ocean waters from the depths to the surface, resulting in maximum and minimum ocean bottom water upwelling seasons. The upwelling minimum, when ocean waters are the least productive, occurs during the rainy season. The upwelling maximum, when ocean waters are the most productive, occurs during the dry season.

These seasonal phenomena leave distinct signatures in the sediment that accumulates on the bottom of the basin at the relatively rapid rate of about 0.4 mm per year. Additionally, and crucially for paleoclimatic reconstructions, sea floor topography restricts the movement of oxygen-rich waters into the bottom of the basin, leading to anoxic conditions there that inhibit living organisms from disturbing the site. This lack of disturbance allows for distinct varves, or seasonal delineations much like tree rings, to develop in the sediment layers.

Core samples taken from the Cariaco Basin have been used to make estimates about past states and average locations of the ITCZ. Because the region also receives large amounts of dust from the Sahara, which like most dust sources has a distinctive fingerprint, the amount of Saharan dust present in the basin’s samples may be used to estimate past conditions in North Africa, with less dust indicating wetter periods there. Analysis of the samples indicates that during cold periods of Earth’s past, such as the Younger Dryas period between 12,800 and 11,500 years ago and the Little Ice Age from 1500 to about 1900, there was reduced sedimentation in the basin and probably reduced rainfall in the Cariaco watershed, suggesting a more southerly average position of the ITCZ. Warmer periods experienced more rainfall and featured a more northerly average position of the ITCZ.

Land use changes over the last century, particularly clearing land for agriculture and building dams and levees for water conservation and flood control, have altered the flow of the rivers feeding the Cariaco Basin. This means that the relationships that exist today amongst rainfall, marine productivity and sedimentation may have been different in the past. Other paleoclimate records from the region, such as lake core records, however, have been used to corroborate the story told by the Cariaco sediments. For example, an abrupt drying around 4,000 years ago captured in lake sediments in Colombia also appears in the Cariaco accumulations.



Above: The difference in South American winter and summer rainfall distributions, which follows the movement of the ITCZ. Image: NASA.



CASE STUDY: LAKE TITICACA

Estimating how terrestrial ecosystems respond to climate variability on glacial-interglacial (10 to 100,000 year) time scales has been impeded, especially in the Southern Hemisphere, by lack of suitable sediment coring sites. An exception is Lake Titicaca, which sits at an elevation of 12,500 feet on the border of Peru and Bolivia. The lake covers 3,200 square miles (about one-third the size of Lake Erie), is fed by four main rivers and has limited outflow. This near-balance between water input and water loss by evaporation means that water levels are closely coupled to climate variability, which is recorded in lake sediment layers. Strong seasonality of the basin's rainfall makes these sediments effective indicators of South American Summer Monsoon (SASM) behavior. The SASM is connected to the Andean low-level jet (LLJ), which transports moisture from the equatorial latitudes into the southern Amazon and Andes. The strength of the LLJ varies with Earth's precessional orbital cycle, a 26,000 year oscillation in the direction of Earth's rotational axis. Other factors influencing millennial scale precipitation variability in the Titicaca Basin include Atlantic sea surface temperatures, the El Niño–Southern Oscillation (ENSO) and global ice volume. Lake levels exert a strong influence on the local climate, with areas near the lake today being nine degrees Fahrenheit warmer and three times wetter than other Andean locations of similar altitude and latitude.



Above: Lake Titicaca from the Space Shuttle Endeavor in 1993. Note the surrounding highlands on both sides of the lake basin. Image: NASA.

Water inputs from the surrounding landscape are full of pollen. Pollen-rich sediment layers have been analyzed to reconstruct the composition of the vegetation that surrounded the lake during different points in the past. Titicaca's sediment cores, which go back 370,000 years, show significant sensitivity to climate. The lake was a fraction of its current size and featured extensive salt marshes during a warm period 130,000 years ago when global temperatures were around 3.6 degrees warmer than present. Droughts were more frequent between 9,000 and 4,400 years ago, and lake levels then were about 280 feet lower than those today.

OTHER PROXY DATA SOURCES

Peat Accumulation: *Ombrotrophic peatlands*, lands at middle and high latitudes where rainwater accumulates in low-lying, hydrologically-isolated areas, develop soil layers of partially decayed organic matter called peat. Peatlands are useful for paleoclimate analysis because they are sensitive to decadal changes in local hydrologic regimes. Analysis of seeds, leaves, shells and even fossils contained in peat can be used to determine the species that lived at a given location when the peat accumulated. Organic matter in peat can be dated precisely using radiocarbon isotope analysis. Annual resolution of layers is usually not possible, but sub-centennial inferences regarding climate can be made from peat analysis. Peat also accumulates in tidal zones. Analysis of the types of fossils and plant remains that are contained in different peat layers can help determine whether the peat accumulated in salt or freshwater zones, which is useful for reconstructing past sea levels.

Borehole Archives: The surface air temperature propagates into the Earth's subsurface, driving the ground surface temperature over long time periods. Borehole archives indicate changes in the ground temperature with depth, which reflects surface temperatures of the past. Departures from the expected geothermal gradient – the normal rate at which temperature increases with depth due to heat flowing from the Earth's molten interior – are indicative of past temperature regimes. Borehole data is best for analyzing long-term temperature changes, as this record is of very low resolution. Individual climate events may be apparent in borehole archives if the event duration was at least 60 percent of the time since its occurrence. In other words, a cooling event 2,000 years ago will show up as an individual event if it lasted at least 1,200 years. The average ground surface temperature change over the mid-latitudes since 1850 is approximately 1.2 to 1.6 degrees Fahrenheit, which is similar to the increase in surface air temperatures estimated from the instrumental record. The first 300 to 600 feet below Earth's surface store climate data of the past millennium. Events like the post-glacial warming 10,000 years ago are over 3,300 feet down.

Leaves and Needles: Buried leaves and needles are useful for estimating past carbon dioxide (CO₂) concentrations. Plants exchange gas with the atmosphere through tiny openings in their leaves or needles called *stomata*. Experiments show how stomatal frequency varies in modern plants as CO₂ levels fluctuate, which allows for evaluation of past CO₂ levels based on analysis of buried leaves and needles. Western Hemlock trees, for example, grow needles with fewer stomata per millimeter of needle length as ambient CO₂ levels rise. Analysis of needles has enabled CO₂ reconstructions back to the year 860. Absolute cell numbers in leaves and needles, inferred from epidermal cell density, can also be used to evaluate past temperature and precipitation variability. Florida's Swamp Laurel Oaks grow leaves with fewer cells following wet winters compared to dry winters; winter precipitation variability is largely determined by ENSO. Oak leaves contained in layers of swamp peat can be used to reconstruct past wintertime rainfall patterns and estimates of ENSO's behavior.

Special thanks to Bob Henson and Joe Witte for their contributions to this paper.

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