The Amazon Reveals Its Secrets—Partly

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The amount of solar irradiation received at any one time and place on Earth's surface, or insolation, is determined by long-term cyclical changes in the rotation and orbit of Earth around the sun. These insolation changes are thought to play an important role in driving global climate change, but little is known about their effects at high versus low latitudes. Did climate change in the tropics lead or lag ice volume changes at higher latitudes during global ice age cycles? And is tropical climate variability caused by changes in seasonal insolation at low latitudes, or do insolation changes at high latitudes affect the tropics indirectly through long distance effects of large-scale climate features such as El Niño–Southern Oscillation?

To answer these questions, we require reliable temperature and hydrological records for the tropics. Many tropical ocean and land records show that during ice ages, the tropics cooled by about 5°C (*1–4*), but tropical land records are often poorly dated and temperature and precipitation effects can seldom be distinguished. Atmospheric methane concentrations from polar ice cores are therefore frequently used as an indirect proxy for tropical paleohydrology, under the assumption that this methane comes mostly from microbial processes in tropical wetlands (*5*, *6*). Methane is also produced by sources outside the tropics, however, and the relative contribution of these different sources to past methane concentrations remains unclear.

Several recent studies have tried to reconstruct long-term changes in the South American Summer Monsoon from lake sediments (*7*, *8*), ice cores in the tropical Andes (*9*), and grassland invasions into the Atacama Desert at the southwestern limits of the tropical rainfall belt (*10*). The hope was that the Summer Monsoon's history could be used to test the validity of the tropical signals derived from the ice-core methane record, but no clear pattern emerges from these studies. Discrepancies are likely to arise from regional differences in climate over an area continental in scale.

What is clearly needed is a proxy that integrates hydrology over the entire South American tropics. Such a proxy is now provided by Maslin and Burns on page 2285 of this issue (*11*). The authors exploit the vastness of the Amazon's reach. The river drains more than 6×10^6 km^2, discharging about 20% of all fresh water that makes it into the world's oceans. It carries nearly 1 gigaton of sediment per year across the breadth of the continent and dumps it in a delta 3.3×10^5 km^2 in area with fan sediments up to 5 km in thickness. Most of the sediment originates in the Andes, but most of the water that discharges into the ocean comes from low-lying areas in the basin (*12*).

Maslin and Burns (*11*) attempt to reconstruct the past 14,000 years of the river's outflow from the oxygen isotope composition of foraminifera (single-celled marine organisms that construct calcite shells) in sediments at Ocean Drilling Program Site 942 (see the figure) (*13*). Located on the western edge of the Amazon Fan, the site is ideal for monitoring mixing of Amazon fresh water with the North Brazil Coastal Current (NBCC), the only surface water current to cross the Equator. The NBCC exports heat and salinity from the South to the North Atlantic, eventually influencing surface waters that reach the Nordic seas through the Gulf Stream. During glacial periods (and short, cold events such as the Younger Dryas), enhanced zonal winds in boreal summer could have deflected the NBCC to the southeast, shutting off cross-equatorial heat transport.

In an earlier study, Maslin *et al.* (*14*) measured the oxygen isotope composition of six foraminiferal species in the upper 4.5 m of sediment. To reconstruct Amazon outflow, Maslin and Burns (*11*) now focus on *Neogloboquadrina dutertrei*, a species that favors cooler, deeper waters and is therefore isolated from local changes in salinity. The oxygen isotope composition of *N. dutertrei*

The author is with the U.S. Geological Survey, Tucson, AZ 85745, USA. E-mail: jlbetanc@usgs.gov records global ice volume, ocean temperature, and the mixing ratio of fresh water and seawater. To separate out the freshwater input, Maslin and Burns removed the ice volume and ocean temperature components by subtracting an independent planktonic oxygen isotope record south of the Amazon and upstream in the NBCC. The residual was further adjusted for the effects of temperature and rainfall amount on the oxygen isotope composition of river water.

The net result is an indirect measure of Amazon River outflow that is broadly consistent with the global methane curve from the Greenland Ice Sheet Project 2 (GISP2) ice core (see the figure) (*5*, *6*). The best match is during the Younger Dryas (13,000 to 11,600 years ago), when ice-core methane and reconstructed Amazon discharge both dropped to 60% below modern values (*2*, *11*). Both records exhibit anomalous peaks, which occur 11,600 years ago in the methane record and 11,800 years ago in the Amazon outflow. The latter was probably due to increased rainfall in the lowlands rather than meltwater from Andean glaciers.

Retrieving sediment and ice cores. The JOIDES Resolution drilling ship took the core analyzed by Maslin and Burns (*11*). **(Inset)** The site of GISP2, one of the Greenland ice cores used to measure past methane concentrations.

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The overall trend in Amazon outflow tracks summertime solar insolation at 10°S, which reached a minimum between 12,000 and 10,000 years ago and a maximum in the past 3000 years. These insolation differences are thought to regulate the intensity of convection over the Amazon Basin and the Central Andes, which in turn affects westward penetration of Atlantic moisture and southern extension of the Intertropical Convergence Zone (ITCZ). On page 2291 of this issue, Mayle *et al.* (*15*) also summon increasing summer insolation at 10°S to explain southern expansion of Amazonian rainforests in eastern Bolivia during the past 3000 years.

Maslin and Burns' elegant study is probably not the final word. The authors make several key but unproven assumptions to quantify Amazon discharge from the foraminiferal record. For example, the dependence of the oxygen isotope composition of rainfall on temperature and rainfall amounts over the Amazon Basin can be complicated by changes in the position of the ITCZ, which may push isotopically depleted moisture inland (*16*). Trade wind intensities along the northern South American coastline, which changed dramatically during deglaciation (*17*), also could have modulated the position and width of the Amazon freshwater plume, affecting its mixing with the NBCC (*18*). Furthermore, little attempt has been made to allow for the effects of rising sea level on the extent of Holocene wetlands. During the last ice age, when sea level was 100 m below that of today, the increased gradient caused the Amazon and its tributaries to incise tens of meters below their floodplains. Ten thousand years ago, sea level was still 25 m below modern levels, and it rose only gradually throughout the Holocene. Incised valleys slowly backfilled with sediment, but tributaries originating in sediment-starved lowlands could not keep up with the rising water, resulting in large freshwater lakes (*19*). These lakes are only now being drowned in sediment, implying that the maximum extent of methane-producing wetlands in the Amazon Basin may depend more on rising sea level than on increasing rainfall.

Finally, it remains unclear how orbital modulation of seasonal insolation might force tropical precipitation. During the past 1 million years, increases in lowland Amazon Basin precipitation have coincided with ice-melting events and maximum June insolation at 65°N (*20*), not maximum January insolation at 10°S. Physical mechanisms for high-latitude forcing of the tropics could involve changes in oceanic heat transport, as well as remote teleconnections with the Asian Monsoon and Pacific climate (*21*, *22*).

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