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# Two millennia of Mesoamerican monsoon variability driven by Pacific and Atlantic synergistic forcing

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ABSTRACT

The drivers of Mesoamerican monsoon variability over the last two millennia remain poorly known because of a lack of precisely-dated and climate-calibrated proxy records. Here, we present a new high resolution (~2 yrs) and precisely-dated (± 4 yr) wet season hydroclimate reconstruction for the Mesoamerican sector of the North American Monsoon over the past 2250 years based on two aragonite stalagmites from southwestern Mexico which replicate oxygen isotope variations over the 950–1950 CE interval. The reconstruction is quantitatively calibrated to instrumental rainfall variations in the Basin of Mexico. Comparisons to proxy indices of ocean-atmosphere circulation show a synergistic forcing by the North Atlantic and El Niño/Southern Oscillations, whereby monsoon strengthening coincided with a La Niña-like mode and a negative North Atlantic Oscillation, and vice versa for droughts. Our data suggest that weak monsoon intervals are associated with a strong North Atlantic subtropical high pressure system and a weak Intertropical convergence zone in the eastern Pacific Ocean. Population expansions at three major highland Mexico civilization of Teotihuacan, Tula, and Aztec Tenochtitlan were all associated with drought to pluvial transitions, suggesting that urban population growth was favored by increasing freshwater availability in the semi-arid Mexican highlands, and that this hydroclimatic change was controlled by Pacific and Atlantic Ocean forcing.



## 1. Introduction

### 1.1. Climate and paleoclimatology of the Mesoamerican monsoon

The objective of this study is to present a precisely-dated and climate-calibrated wet season rainfall proxy record over the past two millennia in the Mesoamerican summer monsoon region. We have identified an ideal location in the heart of the monsoon that has stable cave climate characteristics and drip water infiltration that is representative of monsoon rainfall that allows us to replicate and robustly document climate variability over the past two millennia, constrain forcings of Mesoamerican climate change, and establish temporal correlations between hydroclimate and population change in highland Mexico. Specifically, this study advances previous work via 1) the replication of the climate signal from two precisely-dated stalagmites; 2) the attribution to specific climate forcings of the El Niño/Southern Oscillation and the North Atlantic Oscillation, which improves future climate projections; 3) quantification of the lengths and magnitudes of wet and dry hydroclimatic events over the last two millennia, and 4) demonstration that each major population expansion at Tula, Tenochtitlan, and Teotihuacan were associated with a switch from dry to wet conditions.

The North American Monsoon System (NAMS) is one of Earth's major monsoons (Higgins et al., 1999; Liebmann et al., 2008; Metcalfe et al., 2015; Trenberth et al., 2000; Wang et al., 2014), but it has received less attention than the Asian, Indian, and South American monsoons. The NAMS (Fig. 1) impacts climate in Central and North America from a latitude of 9° to ca. 36°N and affects the entirety of Central America, Mexico, and the southwestern United States (Liebmann et al., 2008). We focus on the Mesoamerican monsoon sector (Lachniet et al., 2013) of the larger NAMS, encompassing the region of southwestern Mexico from west of the Isthmus of Tehuantepec to the Sierra Madre Occidental at roughly 20° north latitude. The monsoon in northwestern Mexico and the southwestern United States is often called the Mexican monsoon (Douglas et al., 1993) or the "core" NAMS (Gutzler, 2004), and is

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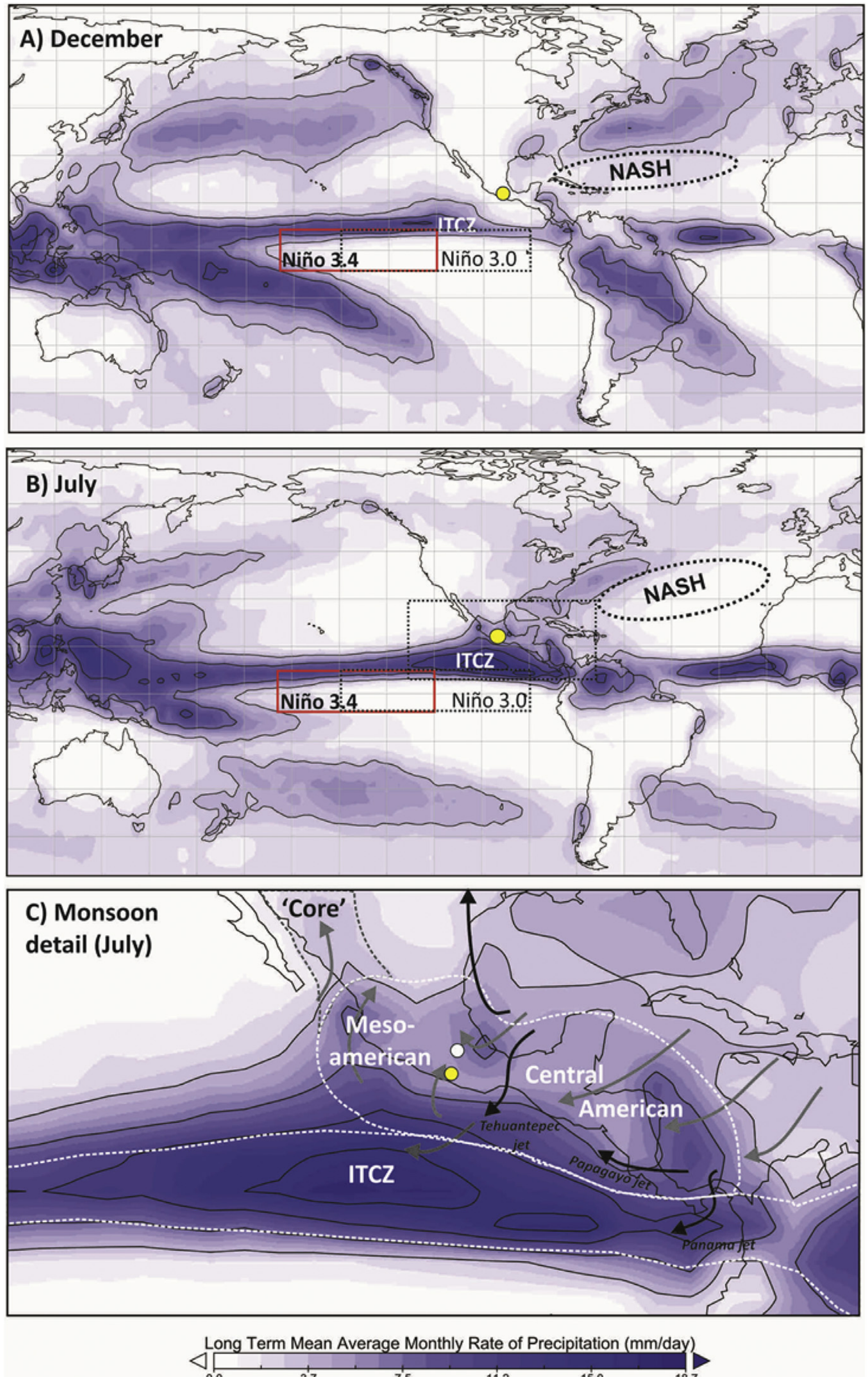


**Fig. 1. Location map and climatological features**. Yellow circle is Juxtlahuaca Cave, white circle is the Basin of Mexico region, and purple shading is monthly December and July precipitation rate showing the seasonal migration of the ITCZ. Red box is the Niño 3.4 region, dotted box is the Niño 3.0 region, and dashed black ellipse shows the core location of the North Atlantic subtropical high pressure cell. C) Is detail of monsoon boundaries in Mexico and Central America. Arrows indicate wind vectors, with black indicating climatological jets. The North Atlantic Subtropical High (NASH) and ITCZ migrate northward in the boreal summer rainy season when moisture is advected northward to southwestern Mexico. Black square indicates Basin of Mexico.

dominated by diurnal land surface heating and advection of moisture from the Gulf of California (Hu and Feng, 2002; Stensrud et al., 1995). Monsoonal circulation is associated with heating of the land surface during boreal summer which produces convection and divergence aloft (Trenberth et al., 2000). The seasonal cycle is dominated by a wet season between June and November (Lachniet et al., 2012b; Liebmann et al., 2008) when rainfall typically exceeds 1200 mm/year.

Today, monsoon rainfall supports 74 million residents of the Mexican agricultural heartland, and in the past it watered the cradle of new-world agriculture and highland civilizations including those at Teotihuacan, Tula, and the Basin of Mexico (Fig. 1). The archeological and historical data document population expansions and movement, notably when Basin of Mexico populations reached one million around Spanish contact in 1519 CE, a level not reached again until the 20th century. The possible links