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# A mid-Holocene paleoprecipitation record from Belize

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ABSTRACT

Understanding past climate may contribute to a better understanding of future climate change, allowing for adaptations to changing water resources. High latitude paleoclimate reconstructions reveal a warmer northern hemisphere during the mid-Holocene, yet paleoclimate records from tropical Central America are lacking, especially seasonally resolved reconstructions needed to resolve seasonal shifts. Here we reconstruct mid-Holocene precipitation using high-resolution (sub-annual to biannual) stable isotope ratios (oxygen and carbon) extracted from a speleothem recovered from Belize to investigate the frequency and magnitude of precipitation variability. We found a slight increase in precipitation during the mid-Holocene in Belize with less variability compared to the late-Holocene. This increase in precipitation may be a result of the expansion of the North Atlantic Subtropical High (NASH), which strengthens the Caribbean Lower Level Jet, enhancing westward advection of atmospheric moisture to Belize. The decrease in precipitation variability could be derived from a northward movement of the Intertropical Convergence Zone (ITCZ) placing Belize within the bounds of the ITCZ for a longer period each year. Time series analysis reveals periodicities of 200–250 years which correspond to the Suess solar cycle. The additional periods of ~100 and ~50 years also have origins in solar irradiance. The North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Variability (AMV; also known as the Atlantic Multidecadal Oscillation (AMO)), long recognized as important drivers of precipitation variability in the region, are present but only at the 90% significance level. We posit that the reduced influence of the NAO and AMV could be caused by the northerly migration of the ITCZ during the mid-Holocene.



## 1. Introduction

The recent report by the Intergovernmental Panel on Climate Change (IPCC) highlighted Central America as a region highly likely to experience precipitation changes in the coming decades due to greenhouse gas warming (IPCC, 2013). The Mid-Holocene was a period of enhanced warming in the high northern hemisphere (e.g., Dorale et al., 1992; Koc and Jansen, 1994; Korhola et al., 2000; Rosen et al., 2001; Solovieva et al., 2005) with temperature changes similar to those predicted by the IPCC due to anthropogenic climate change (IPCC, 2013). The larger increase in temperature in the Polar Regions compared to the tropics results in a weaker tropics to poles temperature gradient (Fu, 2015). An increase in boreal solar irradiance during the mid-Holocene strengthened the regional influence of the summer North Atlantic Subtropical High (NASH), a finding based on climate models (Bartlein et al., 1998), changing lake levels in NE USA (Shuman and Donnelly, 2006) and higher summer precipitation in West Virginia (Hardt et al., 2010). It has been determined that this same process is occurring today (Mayewski et al., 2004; Li et al., 2011; Li et al., 2012). The NASH, also referred to as the Bermuda High, is an area of high pressure centered on Bermuda that influences precipitation in North and Central America (Zishka and Smith, 1980). For example, a more intense NASH enhanced the influx of moist air from the Gulf of Mexico into the east-central portion of the USA during the mid-Holocene (Hardt et al., 2010). An investigation into mid-Holocene precipitation variability for northern Central America would provide insight into the precipitation response to increased temperatures and decreased latitudinal temperature gradient (Davis and Brewer, 2009; O'ishi and Abe-Ouchi, 2011). This investigation will contribute to better predictions of future precipitation so that governments are able to prepare for potential water supply and management issues.

There have been a number of paleoclimate studies on late-Holocene in Central America (e.g., Covich and Stuiver, 1974; Leyden et al., 1994; Hodell et al., 1995; Rosenmeier et al., 2002;; Lachniet et al., 2007; Bernal et al., 2011; Kennett et al., 2012; Lachniet et al., 2012; JGR; Medina-Elizalde et al., 2010; Medina-Elizalde and Rohling, 2012; Frappier et al., 2014) but very few studies exist for the mid-Holocene period (e.g., Covich and Stuiver, 1974; Leyden et al., 1994; Hodell et al., 1995; Lachniet et al., 2004; Metcalfe et al., 2009). Of the latter period, all except Lachniet et al. (2004) are based exclusively on lacustrine

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sediments, predominantly from the Yucatan peninsula, with most showing increased precipitation during the mid-Holocene. The study of Hodell et al. (1995) found evidence for higher lake levels during the mid-Holocene than the present in their Lake Chichancanab, Mexico sediment record. Similar evidence is present in sediment cores from Lake Quexil, Guatemala (Leyden et al., 1994) and Lake Coba on the Yucatan Peninsula (Whitmore et al., 1996). The mid-Holocene sediment core records from Lake Salpetén and Lake Petén Itzá in Guatamala reveal evidence for increased surface and groundwater flow (Rosenmeier et al., 2002). The evidence of Metcalfe et al. (2009) shows a moist and relatively stable climate in the New River Lagoon, Belize from the early Holocene to 5.6 ka. The limitations of these lake reconstructions is their lower resolution (centennial to decadal) and limited number of dates to constrain their chronologies. Costa Rican stalagmite V1 showed a stable $\delta^{18}O$ trend (~6‰) across the mid-Holocene from 7.5 to 4.9 ka, suggesting increased precipitation in Central America relative to the early Holocene (Lachniet et al., 2004).

To understand what drives mid-Holocene precipitation variability in Central America requires a temporally high resolution proxy that is sensitive to changes in rainfall; variations in the oxygen isotopic ratio ($\delta^{18}O$) within tropical speleothems meet this criterion. Precise $^{234}U$-$^{230}Th$ ages in conjunction with sampling calcite at the micron resolution, allows the production of paleoclimate records that can be subjected to time series analyses with statistical confidence. Such analyses can provide insights into which of the various teleconnections, each with its own periodicities, may be the drivers of this precipitation variability.

The $\delta^{18}O$ in speleothems are controlled by cave temperature, the isotopic composition of the drip waters derived from surface precipitation, seasonal changes in the source of precipitation and potential evaporation in the vadose zone (Fleitmann et al., 2003; Lachniet et al., 2004; Asmerom et al., 2007; van Beynen et al., 2007; Lachniet and Patterson, 2009; Baker et al., 2010). In the tropics, relatively low speleothem $\delta^{18}O$ values are indicative of more precipitation and vice versa, via the amount effect (Lachniet, 2009; Shah et al., 2013). Speleothem growth rates vary between 0.01 and 1.00 mm/year with the highest value giving calcite samples at annual or sub-annual resolution (McDermott, 2004). This resolution allows for seasonally resolved reconstructions of past precipitation. Interpretation of the carbon isotopic ratio ($\delta^{13}C$; ratio of $^{13}C/^{12}C$) variability in tropical speleothems is more complex. The $\delta^{13}C$ isotopic composition of speleothems can be influenced by a variety of factors. One such factor is changes in carbon fixation in photosynthesis pathways ($C_3$ vs $C_4$ plants) which can be related to water stress adaptations in vegetation (Yonge et al., 1985; Fairchild et al., 2006) but also changes in atmospheric $pCO_2$ (Schubert and Jahren, 2012). Controls derived from soil include the decomposition of roots and organic matter in the soil/epikarst (Ünal-İmer et al., 2015) and climate impacts on soil moisture content (Wong and Breecker, 2015). The contribution from limestone can provide “aged carbon” to speleothem calcite (Breecker et al., 2012). Degassing of $CO_2$ at various stages from the surface to when the calcite is deposited within the cave are also important (Dulinski and Rozanski, 1990; Fairchild et al., 2006) as well as the rate of this deposition (Lončar et al., 2015). For a more detailed discussion, see Wong and Breecker (2015).

Here we present a high-resolution (sub-annual to biannual) speleothem record of mid-Holocene precipitation for the western Maya Mountains of Belize. This location is considered representative of broad precipitation patterns in northern Central America based on the understanding of modern regional climate influences (Jury et al., 2007; Gamble and Curtis, 2008; Cook and Vizy, 2010; Karmalkar et al., 2011). The sub-annual to biannual resolution of this Belizean Maya Mountains reconstruction provides the most detailed paleoprecipitation reconstruction to date for the mid-Holocene.

Our main questions are how the magnitude and variability of mid-Holocene precipitation compares to that of modern precipitation and if differences are apparent, what atmospheric-oceanic mechanisms could drive this change? To address these questions, our research objectives are to: 1) determine stable isotopic variability in a speleothem that formed during the mid-Holocene; 2) compare mid-Holocene precipitation to the present; and 3) assess possible drivers of mid-Holocene precipitation amount and variability.

## 2. Site description

The climate of our study site, which lies on the Vaca Plateau of Belize, is controlled by both the Pacific Ocean and the Caribbean Sea, the latter being more influential due to the dominant easterly trade winds. The Intertropical Convergence Zone (ITCZ) and NASH both influence the climate of Belize (Fig. 1) (Gamble and Curtis, 2008; Cook and Vizy, 2010). During the boreal summer, the ITCZ's northward migration brings precipitation to Belize and the opposite occurs during the winter (Waliser and Gautier, 1993). The NASH impacts tropical American precipitation via the Caribbean Low-Level Jet (CLLJ), which is a regional manifestation of the easterly trade winds (Gamble and Curtis, 2008; Cook and Vizy, 2010). Summer expansion and intensification of the NASH strengthens the CLLJ (Gamble and Curtis, 2008; Wang et al., 2008). This leads to decreased precipitation in the eastern Caribbean due to an increase in moisture flux divergence and increased precipitation and lower level jet convergence in the western Caribbean and coastal Central America (Gamble and Curtis, 2008; Taylor et al., 2011).

In addition to the influence of NASH and the CLLJ, interactions between the low latitude Pacific and Atlantic Oceans contribute to the Central American climate. Jury et al. (2007) found a stronger influence of El Niño Southern Oscillation (ENSO) in the western Caribbean while the influence of the North Atlantic Oscillation (NAO) is more evident in the southeastern Caribbean. Decadal variability in North Atlantic SSTs, termed Atlantic Multidecadal Variability (AMV) (originally coined the Atlantic Multidecadal Oscillation (AMO)) (Enfield et al., 2001), impacts seasonal precipitation with warm phases generating more winter precipitation in the western Caribbean and Central America and vice versa (Knudsen et al., 2011).

Our study site (Chen Ha Cave) lies within the Cayo District of Belize and the closest weather station is ~50 km away at Spanish Lookout (Fig. 2). The average annual temperature is 26 °C (average monthly temperatures varies from 21 to 31 °C) with wet summers and dry winters (Belize Meteorological Weather Service, 2014). The orographic effect of the Maya Mountains leads to precipitation in excess of 3800 mm/year on the windward side compared to the leeward side where the study area receives 1500 mm/year (Belize Meteorological Weather Service, 2014).

The speleothem used in this study (CH04-02) was collected in 2004 from Chen Ha Cave located on the Vaca Plateau (17°N, 89°W, 550 masl; Fig. 1) in the Mayan Lowlands of southwestern Belize. A second speleothem, CH04-03, was collected from the same cave to compare with CH04-02. The Vaca Plateau is comprised of Cretaceous Campur limestone, which is highly karstified and heavily brecciated (Reeder et al., 1996). The recharge on the Northern Vaca Plateau is entirely autogenic and thin soils permit rapid infiltration of precipitation (Reeder et al., 1996; Webster et al., 2007). The Vaca Plateau has insufficient rainfall for its forests to be classified as tropical rainforest and is considered tropical moist broadleaf forest (Douglas et al., 2012).

Chen Ha Cave has a progressively narrowing vertical shaft 55 m deep (reducing to 2 m wide, just above the main chamber) that terminates in a horizontal chamber measuring 20 m by 7 m with a height that varies from 1 to 7 m. Constrictions in the shaft reduce the exchange of air between the cave and the surface, which have been found to promote high humidity and elevated $CO_2$ levels in caves (physical effects experienced by cavers - Williams, 1958; Smith, 1993) within the cave. Other caves with similar depth within the study area have relative humidity of 93 to 95% (Webster et al., 2007). CH04-02 was chosen for its size (CH04-02 is a calcitic stalagmite is ~1 m in length, diameter between 75 and 10 mm and there is little deviation in the growth axis) and location in