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Drought in the northern Bahamas from 3300 to 2500 years ago

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ABSTRACT

Intensification and western displacement of the North Atlantic Subtropical High (NASH) is projected for this century, which can decrease Caribbean and southeastern American rainfall on seasonal and annual timescales. However, additional hydroclimate records are needed from the northern Caribbean to understand the long-term behavior of the NASH, and better forecast its future behavior. Here we present a multi-proxy sinkhole lake reconstruction from a carbonate island that is proximal to the NASH (Abaco Island, The Bahamas). The reconstruction indicates the northern Bahamas experienced a drought from ~3300 to ~2500 Cal yrs BP, which coincides with evidence from other hydroclimate and oceanographic records (e.g., Africa, Caribbean, and South America) for a synchronous southern displacement of the Intertropical Convergence Zone and North Atlantic Hadley Cell. The specific cause of the hydroclimate change in the northeastern Caribbean region from ~3300 to 2500 Cal yrs BP was probably coeval southern or western displacement of the NASH, which would have increased northeastern Caribbean exposure to subsiding air from higher altitudes.

1. Introduction

Multiple proxy-based climate archives document significant hydroclimate variability in the tropical North Atlantic region during the Holocene. These include oxygen isotopic variability in speleothems (Mangini et al., 2007; Medina-Elizalde et al., 2010; Winter et al., 2011; Fensterer et al., 2013) and microfossils (Hodell et al., 1991, 2001), compound-specific stable isotope analysis (Lane et al., 2014), lake-level records (Holmes, 1998; Fritz et al., 2011; Burn et al., 2016), microfossils and sedimentology of inland saline ponds (Teeter and Quick, 1990; Teeter, 1995b; Dix et al., 1999), coastal lagoon sedimentology, mineralogy, and water level variability (Hodell et al., 2005a; Malaizé et al., 2011; Gregory et al., 2015; Peros et al., 2015), terrestrial landscape change through pollen analysis (Kjellmark, 1996; Leyden et al., 1998; Higuera-Gundy et al., 1999; Kennedy et al., 2006; Lane et al., 2009; Slayton, 2010; Torrescano-Valle and Islebe, 2015), the Ti flux into the Cariaco Basin (Haug et al., 2001), among others. The Holocene-scale hydroclimate records that are available generally document increased precipitation during the Holocene Climatic Optimum when boreal summer occurred near perihelion (~8000–6000 years ago), which was followed by an overall drying pattern over the last ~5000 years (Hodell et al., 1991, 1995; Higuera-Gundy et al., 1999; Haug et al., 2001; Fensterer et al., 2013). Superimposed upon this long-term trend, the Caribbean has experienced multiple centennial-scale droughts whose regional expression can be variable.

Previous droughts on the Yucatan Peninsula in Mexico are well documented. In the current climate regime, there is a regional precipitation gradient from the dryer northern region (~900 mm yr^{-1}, ~21°N) to the wetter south (1700 mm yr^{-1}, ~17°N)(Hodell et al., 2005b). This gradient is driven by seasonal migration of the Intertropical Convergence Zone (ITCZ), where oceanic warming during the boreal summer displaces the Atlantic

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ITCZ and the tropical rain belt northward (Hastenrath, 1976, 1984; Hu et al., 2007). As such, droughts on the Yucatan Peninsula that are documented by lake level, pollen, and geochemical reconstructions at 4700-3600 Cal yrs BP, 3400–2500 Cal yrs BP, 2300–2100 Cal yrs BP, 1900–1700 Cal yrs BP, 1400–1300 Cal yrs BP, 730 Cal yrs BP, and 560 Cal yrs BP (Hodell et al., 2005a, 2005b; Torrescano-Valle and Islebe, 2015) are likely linked to meridional ITCZ displacements. However, the ITCZ is just one component of the Hadley Cell, so other areas in the tropical North Atlantic may experience different hydroclimate changes if Hadley circulation moves meridionally. As such, the spatial pattern, ocean-atmospheric forcing, and specific timing of Yucatan droughts on other Caribbean islands remains under investigation (Lane et al., 2014).

Compared with the Yucatan, knowledge of Holocene hydroclimate variability on Little Bahama Bank and Great Bahama Bank is still limited. A pollen-based reconstruction of landscape change on Andros Island (Church's Bluehole) indicates a dominance of salt- and drought tolerant shrubs typical in modern open and rocky sites (e.g., *Piscidia*-type, *Dodonaea*) from 3000 to 1500 years ago, which then shift to hardwoods and palms, and a final transition to the modern pine-dominated landscape by ~750 years ago (Kjellmark, 1996). In a pollen record from Emerald Pond (sinkhole) on Abaco, an increase in *Pinus* and a decrease in palm pollen during the last ~700 years was the most significant floral change over the last ~8000 years (Slayton, 2010), which was also noted by van Hengstum et al. (2016) in the pollen record from Blackwood Sinkhole. However, an increase in grass on the landscape from ~3200 to 2300 Cal yrs BP led Slayton (2010) to suggest this was a possible arid period in Abaco.

Here we present evidence for a megadrought from ~3300 to ~2500 years ago on the Little Bahama Bank (Fig. 1). This is documented through a multi-proxy (i.e., microfossils, geochemistry, sedimentology) sinkhole-lake level reconstruction using sediment cores from No Man's Land (NML) on Abaco Island (26.592°, −77.279°). The potential climatological forcing of this drought is also discussed, given that other Caribbean localities (e.g., Yucatan, Dominican Republic) have experienced synchronous aridity and Abaco Island is geographically far removed from precipitation caused directly by ITCZ convective activity (Fig. 1C and D). In contrast, the geographic position of the Little Bahama Bank makes it a key geographic locality to monitor the long-term behavior of the NASH (Fig. 1B).

2. Regional rainfall

Many large-scale ocean and atmospheric influences in the Pacific and Atlantic region impact Caribbean rainfall and evaporation (Hastenrath, 1976, 1984; Enfield and Alfaro, 1999; Gamble and Curtis, 2008), such as: the intensity and position of the North Atlantic Subtropical High (Davis et al., 1997; Giannini et al., 2000; Li et al., 2011, 2012a, 2012b), the position of the Caribbean Low Level Jet (Wang, 2007; Whyte et al., 2008; Martin and Schumacher, 2011a; Herrera et al., 2015), the Madden-Julian Oscillation (Martin and Schumacher, 2011b), seasonal migration of the ITCZ (Hastenrath, 1976), El Niño/Southern Oscillation (Nyberg et al., 2007; Jury, 2009), the North Atlantic Oscillation (Jury et al., 2007), hurricane activity, orographic effects (e.g., Cuba, Hispaniola) (Jury et al., 2007; Gamble and Curtis, 2008; Martin and Fahey, 2014), and sea surface temperatures in the North Atlantic warm pool (Wang et al., 2006).

On millennial timescales, meridional displacements of the ITCZ are thought to be important drivers of Caribbean rainfall. The ITCZ is a band of strong convective activity and precipitation caused by the convergence of the trade winds, which oscillates seasonally between ~0° N and 13°N (see Fig. 2G in Hu et al., 2007). The zonally-averaged ITCZ position is suggested to have only moved <2° latitude during the Holocene based on time-sliced estimates of cross-equatorial atmospheric transport (McGee et al., 2014). However, there is evidence for Caribbean megadroughts across 18°N to 26°N during the Holocene. Therefore, regional ocean-atmospheric drivers of rainfall must be considered for understanding Caribbean hydroclimate variability on Holocene timescales.

In general, annual Caribbean rainfall is bimodal with dry season from November through April and a wet season from May to October. However, the wet season is interrupted by a rainfall decrease known as the ‘Mid-Summer Drought’ (Magaña et al., 1999; Jury et al., 2007; Gamble et al., 2008). It is thought that the Mid-Summer Drought is caused by seasonal intensification and southwestern displacement of the NASH in the Caribbean region during boreal summer (Hastenrath, 1976, 1984; Gamble et al., 2008), in addition to potential amplifying effects from local vertical wind shear and atmospheric dust from Africa (Angeles et al., 2010). Gamble and Curtis (2008) presented a 5-part conceptual model to describe synoptic scale atmospheric drivers of annual and regional Caribbean rainfall patterns: (1) summertime expansion of the NASH, which decreases rainfall especially in the northeastern Caribbean, (2) large-scale subsidence concentrated at 70–75°W that decreases local precipitation [Zone 2 in Fig. 1B, see Fig. 4a Magaña and Caetano (2005)], (3) the Caribbean Low Level Jet that impacts the north coast of South America and the Lesser Antilles, (4) vertical wind shear, and (5) localized divergence of surface winds near Jamaica. Hastenrath (1976) observed that an early southward displacement and intensification of the NASH, stronger Trade Winds, and an equator-ward shift of the east Pacific ITCZ occurs during the winter preceding a particularly dry Caribbean summer. Likewise, the anomalously dry Caribbean decade from 1979 to 1989 CE has been attributed to intensification of the NASH (McLean et al., 2015).

Still further, the timing and amplitude of rainfall across the western tropical North Atlantic margin is also variable. In the northeastern-most Bahamian Archipelago (e.g., Little and Great Bahama Banks) and northwestern Cuba, annual rainfall exceeds 1300 mm yr^{-1}, as do the islands of Hispañiola, and those in the northern Lesser Antilles. However, Jury et al. (2007) documented that the southern Bahamian Archipelago, eastern Cuba, and Jamaica (Zone 2, Fig. 1B) receive only ~870 mm yr^{-1} of rainfall. It is thought that reduced annual mean precipitation in the central Caribbean (Zone 2) relates to local subsidence caused by large-scale divergence as the anticyclone flow splits between an axis south of Cuba and one re-curving towards Florida (Jury et al., 2007; Gamble and Curtis, 2008). The Mid-Summer Drought occurs in July, August, and September in the northern Bahamas; but it happens in June, July, and August in the lower Bahamian Archipelago (Fig. 1E).

3. Study site

The Bahamian Archipelago is a group of carbonate islands and banks along the western tropical North Atlantic margin that began forming in the late Jurassic, and this region has since weathered into a mature karst landscape (Mullins and Lynts, 1977; Mylroie and Carew, 1995; Mylroie et al., 1995a, 1995b). Sinkholes and blueholes are an important source of paleoenvironmental and paleohydrological information because sediment and fossils deposited into these systems can remain protected from subsequent bioturbation or physical reworking (Crotty and Teeter, 1984; Kjellmark, 1996; Alverez Zarikian et al., 2005; Steadman et al., 2007; van Hengstum et al., 2016).

No Man's Land on Great Abaco Island is one of the largest diameter inland lakes in the northern Bahamas (Fig. 2). In its