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The combined influence of Pacific decadal oscillation and Atlantic multidecadal oscillation on central Mexico since the early 1600s

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ABSTRACT

Periodic droughts have been one of the most serious environmental issues in central Mexico since the earliest times. The impacts of future droughts are likely to become even more severe as the current global warming trend increases potential evaporation and moisture deficits. A full understanding of the mechanism underlying climate variability is imperative to narrow the uncertainty about future droughts and predict water availability. The climatic complexity generated by the combined influence of both Atlantic and Pacific forcings, however, causes considerable difficulty in interpreting central Mexican climate records. Also, the lack of high-resolution information regarding the climate in the recent past makes it difficult to clearly understand current drought mechanisms. Our new high-resolution $\delta^{18}O$ record from Hoya Rincon de Parangueo in central Mexico provides useful information on climate variations since the early 1600s. According to our results, the central Mexican climate has been predominantly controlled by the combined influence of the 20-year Pacific Decadal Oscillation (PDO) and the 70-year Atlantic Multidecadal Oscillation (AMO). However, the AMO probably lost much of its influence in central Mexico in the early 20th century and the PDO has mostly driven climate change since. Marked dryness was mostly associated with co-occurrence of highly positive PDO and negative AMO between ∼1600 and 1900.

1. Introduction

Central Mexico has been one of the most populous regions in the world for a long time. However, its dense population often undermined ecological resilience and increased the vulnerability of societies to climate shifts (e.g. De Tapia, 2012). In particular, periodic drought conditions have been serious threats faced by poor people in the region, who consistently suffered from environmental degradation and consequent subsistence deficit (Liverman, 1990; Enfield and O'Hara, 1999). Today's situation is not much different from the past. Drought is still one of the main environmental problems in central Mexico (Ortega-Gaucin and Velasco, 2013; Aguilar-Barajas et al., 2016). There is an urgent need for a better approach to this issue since central Mexican states, including Guanajuato, Mexico, and Puebla, only have about 12% of the water in the nation despite containing ∼60% of the total population (Enge and Whiteford, 1989; Liverman, 1992). Urban development and intensive agriculture have substantially lowered the groundwater table, exacerbating the outcomes of drought (Barker et al., 2000). Current global warming is also believed to increase potential evaporation and thus decrease moisture availability in central Mexico (Seager et al., 2009).

A full understanding of the mechanisms underlying climate variability seems to be imperative to reduce the uncertainty of future droughts and better predict water availability (e.g. Dai, 2011). However, the climatic complexity generated by the combined influence of both Atlantic and Pacific forcings causes considerable difficulty in interpreting central Mexican climate records. Most of all, the lack of high-resolution information regarding climate change in the recent past does not allow us to clearly understand current drought mechanisms. Short and incomplete rainfall observations also contribute to the difficulty.

Several tree ring records from central Mexico have contributed to developing an understanding of climate dynamics (Therrell et al., 2006; Stahle et al., 2011, 2012). Climate variation in central Mexico appears to be mainly driven by the Pacific Decadal Oscillation (PDO)/El Nino Southern Oscillation (ENSO) and Atlantic Multidecadal Oscillation (AMO)/North Atlantic Oscillation (NAO) (Stahle et al., 2012). In addition, the Pacific forcing over central Mexico has been suggested to be more dominant during the late

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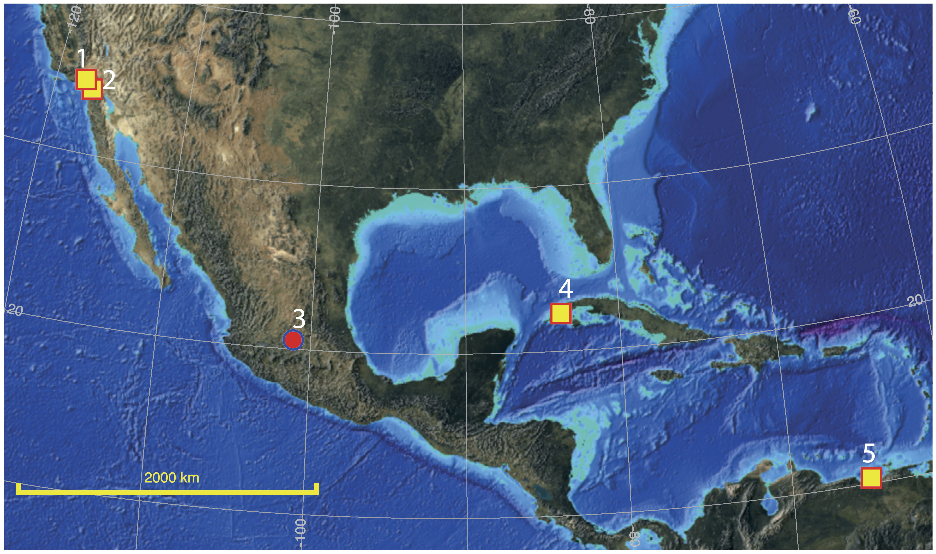

Fig. 1. The location of the study site and paleoclimate proxy records discussed in this study. (1) and (2) Southern and Baja California (MacDonald and Case, 2005; Biondi et al., 2001), (3) La Hoya Rincon de Parangueo, this study, (4) Dos Anas cave system in Northwestern Cuba (Fensterer et al., 2012), and (5) Cariaco Basin, Venezuela (Black et al., 1999). This map was modified from UNAVCO map tool (UNAVCO Inc., jules.unavco.org).

Holocene since AMO signals shown in these data are relatively weak. The AMO influence on central Mexico, however, should also be substantial given its intermediate position between two oceans. It is indeed generally agreed that the Atlantic forcing plays a major role in regulating summer rainfall over central Mexico (Méndez and Magaña, 2010). The difficulty in detecting the AMO may have to do with the PDO/ENSO influence, which complicates the pattern of AMO-related climate shifts (Mo et al., 2009; Hu and Feng, 2012). Also, regional/local SST variability might not be represented well by the AMO index since the latter is defined as annual mean SST anomalies averaged over the entire North Atlantic basin.

Detecting the AMO and PDO separately in central Mexican climate data would be important for a clear understanding of past drought that apparently have predictive potential. Also, the drought hypothesis for past societal events could be more objectively tested once these two major drivers are better understood. Temporal correlation between climate variation and social upheavals has been vigorously attempted in central Mexico (Therrell et al., 2006; Stahle et al., 2011; Lachniet et al., 2012; Bhattacharya et al., 2015) but their causal links still seem rather weak for wide acceptance (e.g. Cowgill, 2015).

In this paper, we provide a new high-resolution δ^{18}O record from Hoya Rincon de Parangueo, a maar lake in the Valle de Santiago area of Guanajuato, Mexico. This study aims to 1) reconstruct climate change since 1610 in central Mexico, 2) find past temporal patterns of dryness/wetness, and 3) separately detect the influence of the Pacific and Atlantic forcings from our records.

2. Study area

La Hoya Rincon de Parangueo, hereafter referred to as Rincon, is a maar crater located near Valle de Santiago in southern Guanajuato, Mexico (Figs. 1–2). Its age has not been determined, but Hoya San Nicolas and Hoya Alberca, two other maars located ca. 4 km to the south and south-east of Rincon (Fig. 2), have respectively produced Potassium/Argon ages of 1.2 Ma and 0.37 Ma (Murphy, 1986). As recently as the 1980s, there was a 30 m + deep lake at Rincon. Lowering of the regional water table due to ground water extraction for irrigation, however, has since caused the lake to desiccate (Alcocer et al., 2000; Escolero-Fuentes and Alcocer-Durand, 2004).

The Valle de Santiago area is one of several lowland areas in this section of the Rio Lerma watershed. Collectively they are known as the Bajío. The Bajío has been one of Mexico's most important agricultural areas since the second half of the 16th century, and thus, the vegetation of the area has been heavily disturbed by human activities. At present, most of the Valle de Santiago area is agricultural, especially the alluvial plain that borders the Rio Lerma. On the volcanic uplands, the vegetation is subtropical deciduous woodland and scrub, and most of it is disturbed by woodcutting and browsing of domesticated animals. The more inaccessible Rincon crater contains a floristically rich remnant of subtropical woodland (Aguilera Gómez, 1991).

The present climate of the area is temperate with a strongly seasonal pattern of rainfall. Mean monthly temperatures range from 14.7 °C in January to 22.8 °C in May (Servicio Meteorológico Nacional). Eighty percent of the precipitation falls between April and November as the Bermuda high shifts northward and tropical easterlies move on to the Mexican plateau (Mosiño Alemán and García, 1974). During the winter and spring months, the area is under the influence of high pressure and monthly rainfall totals are minimal. Instrumental data indicate that PDO and AMO are important drivers of the central Mexican climate during the summer season (Sutton and Hodson, 2005; Pavia et al., 2006; Méndez and Magaña, 2010). Warm ENSO/PDO and cold AMO (Atlantic SSTs) are suggested to cause persistent drought in central Mexico while cold ENSO/PDO and warm AMO cause relatively wet conditions (Seager et al., 2009; Méndez and Magaña, 2010).

3. Materials and methods

In 2004 we recovered a 4 m-long sediment core (UC2004) from Rincon (20°23′N/101°15′W) with a 5 cm diameter Livingstone corer equipped with butyrate liners (Park et al., 2010). In this study, undisturbed upper sediments between depths of 85 and 155 cm were used to investigate recent climate variability. According to local informants, the marl reef that surrounds the lake was fractured during the Mexico City earthquake of September 19, 1985. We assumed therefore that the slump deposit extending from the surface to 84 cm was deposited during that event (Fig. 3). Lead 210 dating and tephrochronology have since confirmed this assumption.