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Proglacial lake sediment records reveal Holocene climate changes in the Venezuelan Andes

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ABSTRACT

Lake sediment records from the Cordillera de Mérida in the northern Venezuelan Andes document the history of local glacial variability and climate changes during the Holocene (~12 ka to the present). The valleys that contain these lakes have similar bedrock compositions and hypsometries, but have different headwall elevations and aspects, which makes them useful for investigating the magnitude of past glaciations. There was widespread glacial retreat in the Venezuelan Andes during the early Holocene, after which most watersheds remained ice free, and thus far only valleys with headwalls higher than ~4400 m asl contain evidence of glaciation during the last ~10 ka. There was a pronounced shift in sediment composition for the Montos (headwall: ~4750 m asl) and Los Anteojos (headwall: ~4400 m asl) records during the middle Holocene from ~8.0 to 7.7 ka when conditions appear to have become ice free and drier. There is tentative evidence that the glacier in the Mucubají valley (headwall: ~4609 m asl) advanced from ~8.1 to 6.6 ka and then retreated during the latter stages of the middle Holocene. Clastic sediment accumulation in other nearby lake basins was either low or decreased throughout most of the middle Holocene as watersheds stabilized under warmer and/or drier conditions. In the Montos record, there was another major shift in sediment composition that occurred from ~6.5 to 5.7 ka, similar to other regional records that suggest conditions were drier during this period. Overall, the late Holocene was a period of warmer and wetter conditions with ice extent at a minimum in the northern tropical Andes. There were also punctuated decadal to multi-centennial periods of higher clastic sediment accumulation during the last ~4 ka, likely in response to periods of cooling and/or local precipitation changes. In watersheds with headwalls above 4600 m asl, there is evidence of glacial advances during the Little Ice Age (~0.6–0.1 ka). The pattern of glacial variability is generally similar in both the northern and southern tropics during the Little Ice Age, suggesting that ice margins in both regions were responding to colder and wetter conditions during the latest Holocene. The observed pattern of Holocene climate variability in the Venezuelan Andes cannot be explained by insolation forcing alone, and tropical ocean influences were likely associated with the observed glacial and lake level changes.

1. Introduction

The response of tropical climate systems to shifting boundary conditions and short-term perturbations is a central question of earth-systems science. Millennial-scale insolation changes likely drove the broad pattern of Holocene climatic changes identified by proxy records from both the northern and southern Andes (e.g.

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Abbott et al., 1997; Koch and Clague, 2006). Superimposed upon the millennial-scale trends are century-scale variations, (most notably glacial and lake-level fluctuations) driven by regional-scale temperature and precipitation changes that are not directly controlled by orbital processes (e.g. Seltzer et al., 2000; Polissar et al., 2013). For example, a clastic-rich sediment profile from the Laguna Mucubají watershed (Fig. 1) illustrates that multiple Holocene glacial advances occurred in Venezuela (Stansell et al., 2005; Polissar et al., 2006b). It remains unknown, however, if the timing of changes observed at Mucubají is representative of glacial advances in the region, or how the timing of the multi-centennial glacial advances and retreats compares to that of other tropical Andean locations. Given the range of headwall elevations and different geomorphic conditions for valleys that were potentially glaciated, there should be detectable variability in the timing of sedimentological changes in lakes between watersheds in the Venezuelan Andes. These differences, in turn, should provide information about the magnitude and timing of distinct glacial events.

Here we present three independently dated lake sediment records from different watersheds in the northern tropical Cordillera de Mérida of the Venezuelan Andes in order to evaluate the timing and extent of glaciations in each valley. These valleys have similar bedrock compositions and hypsometries, but different headwall elevations that span ~350 m across what is thought to be a critical elevation threshold in the Venezuelan Andes (Montos 4750 m asl, Mucubají 4609 m asl, and Anteojos 4400 m asl). This allows for comparison of the timing of shifting sediment characteristics across a vertical gradient. We applied a multi-proxy approach to characterize changes in fine-grained clastic (non-biogenic) sediment concentrations to infer past changes in glacial activity. We also analyzed indicators of past changes in lake productivity, including biogenic silica and organic matter, and incorporated lake level records from nearby sites into our analysis as corroborating evidence of past climate changes. Combined, these archives indicate considerable glacial and lake level variability occurred during the early, middle and late Holocene that must be influenced by forcing mechanisms other than insolation alone.

2. Study site and modern climate

Today in the Venezuelan Andes the majority of precipitation falls during boreal summer, and humidity is high year-round (Azocar and Monasterio, 1980). Precipitation originates mostly from the Atlantic Ocean and is transported over the continent by the easterlies (Garreaud et al., 2009). The amount of precipitation that falls in Venezuela is affected by sea surface temperatures (SSTs) in both the Atlantic and Pacific Oceans; tropical North Atlantic SSTs are positively correlated, and tropical Pacific SSTs are negatively correlated with Andean rainfall (Pulwarty et al., 1992; Polissar et al., 2013). Likewise, temperature variability in the northern tropics is driven by changes in both the tropical Pacific and Atlantic Oceans (Vuille et al., 2000). The relationships between tropical ocean conditions and Andean climate change are further detailed in the discussion section below.

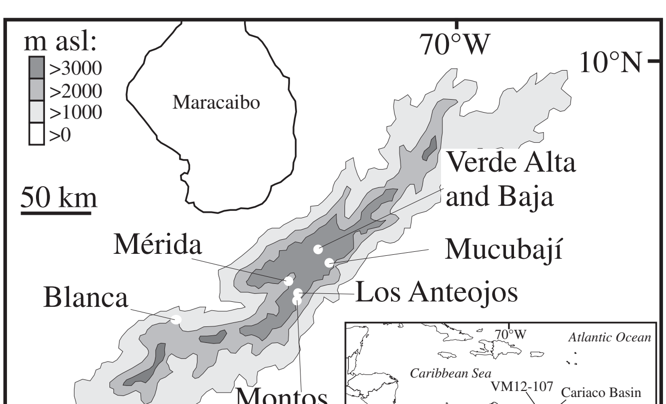

Fig. 1. Map identifying the location of Mérida Andes, and the locations of other paleoclimate records discussed in this manuscript.

The wet and generally cloudy conditions make glaciers in this part of the Andes more sensitive to temperature than to precipitation changes (Kaser and Osmaston, 2002; Stansell et al., 2007b). In A.D. 1952 only four glaciated peaks remained in Venezuela, with elevations of 4979 m asl (Pico Bolívar), 4922 m asl (Pico La Concha), 4942 m asl (Pico Humboldt) and 4883 m asl (Pico Bonpland) (Schubert, 1998). Today, the only watersheds with remaining ice are Pico Humboldt and Pico Bolivar, and it is projected that all glaciers will melt in the Venezuelan Andes within the next few decades (Braun and Bezada, 2013). These catchments, however, were extensively glaciated in the past; thus lake basins in these valleys preserve evidence of shifting ice margins during at least the last ~12,000 years (Stansell et al., 2005; Polissar et al., 2006b).

2.1. Laguna de Montos

Laguna de Montos (N 8.512°, W 71.086°, 4050 m asl) has a headwall elevation of ~4750 m asl and is located in the Cordillera de Mérida on the southeast-facing side of the valley below the peaks of El Toro and El Leon (Fig. 2). The catchment is currently ice free, and the overflowing lake was 12.7 m deep in February, 2011. Glaciers do not exist in the watershed today, but ice on the flanks of El Toro (4728 m asl) was up to 16 m thick in A.D. 1868 (Jahn, 1925; Schubert, 1992). Ice existed below El Leon (~4750 m asl) until ~A.D. 1910 (Jahn, 1925), and below El Toro until A.D. 1931 (Schubert, 1992). Meteorological data are not available for the Montos valley, but precipitation amounts are likely similar to that described below for Laguna de Los Anteojos (~1550 mm/yr). The Montos catchment contains a well-defined cirque basin surrounded by a steep, bowl-shaped depression that keeps the lake protected from wind mixing. The protected conditions, combined with the relatively large depth for the basin size, result in a depositional environment with minimal lake sediment mixing. There is no well-established direct inflow to the lake, and it is fed mostly by on-lake precipitation and secondary surface runoff (and presumably groundwater inflow) from the catchment. The catchment bedrock is predominantly high grade meta-sedimentary rocks that are high in silicate minerals (Schubert, 1972; Hackley et al., 2005). There are prominent moraines below the lake and, although less pronounced, there are also moraines and polished bedrock glacial landforms in the watershed above the lake (Schubert, 1987). The vegetation is limited mostly to small shrubs and grasses, typical of the super páramo plant types common to the region (Berg and Suchi, 2001).

2.2. Laguna de Los Anteojos

The valley that contains Laguna de Los Anteojos (N 8.538°, W 71.074°, 3920 m asl) has a headwall elevation of 4400 m asl and is adjacent to Pico Espejo and the Pico Bolivar Massif (Fig. 2). Weather stations in the region have operated intermittently since at least the 1980's, and indicate that precipitation in the area around Los Anteojos is high (1550 mm/yr) (Monasterio and Reyes, 1980; Rull