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Holocene climatic variations in the Western Cordillera of Colombia: A multiproxy high-resolution record unravels the dual influence of ENSO and ITCZ

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A B S T R A C T

The Páramo de Frontino (3460 m elevation) in Colombia is located approximately halfway between the Pacific and Atlantic oceans. It contains a 17 kyr long, stratigraphically continuous sedimentary sequence dated by 30 AMS 14C ages. Our study covers the last 11,500 cal yr and focuses on the biotic (pollen) and abiotic (microfluorescence-X or μXRF) components of this high mountain ecosystem. The pollen record provides a proxy for temperature and humidity with a resolution of 20–35 yr, and μXRF of Ti and Fe is a proxy for rainfall with a sub-annual (ca. 6-month) resolution.

Temperature and humidity display rapid and significant changes over the Holocene. The rapid transition from a cold (mean annual temperature (MAT) 3.5 °C lower than today) and wet Younger Dryas to a warm and dry early Holocene is dated at 11,410 cal yr BP. During the Holocene, MAT varied from ca. 2.5 °C below to 3.5° above present-day temperature. Warm periods (11,410–10,700, 9700–6900, 4000–2400 cal yr BP) were separated by colder intervals. The last 2.4 kyr of the record is affected by human impact. The Holocene remained dry until 7500 cal yr BP. Then, precipitations increased to reach a maximum between 5000 and 4500 cal yr BP. A rapid decrease occurred until 3500 cal yr BP and the late Holocene was dry. Spectral analysis of μXRF data show rainfall cyclicity at millennial scale throughout the Holocene, and at centennial down to ENSO scale in more specific time intervals. The highest rainfall intervals correlate with the highest activity of ENSO. Variability in solar output is possibly the main cause for this millennial to decadal cyclicity. We interpret ENSO and ITCZ as the main climate change-driving mechanisms in Frontino. Comparison with high-resolution XRF data from the Caribbean Cariaco Basin (a proxy for rainfall in the coastal Venezuelian cordilleras) demonstrates that climate in Frontino was Pacific-driven (ENSO-dominated) during the YD and early Holocene, whereas it was Atlantic-driven in Cariaco (ITCZ-dominated). From ca. 8000 cal yr BP, climate in both areas was under the dual influence of ENSO and ITCZ, thereby showing existing teleconnections between the tropical Pacific and Atlantic oceans.

The Frontino record is to date the highest-resolution Holocene study in NW Colombia. An implication of these results is that new records should be analyzed with multiproxy tools, in particular those providing high resolution time series, such as μXRF.

1. Introduction

Records of climate change are particularly important in the tropics, where major thermal energy interchanges take place between oceans and atmosphere. Climatic events like the migration of the Intertropical Convergence Zone (ITCZ, e.g., Haug et al., 2001, 2003; Petersen and Haug, 2006; Yancheva et al., 2007; Wanner

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et al., 2008) and the El Niño-Southern Oscillation (ENSO, e.g., Thompson, 2000; Moy et al., 2002; Riedinger et al., 2002; Flantua et al., 2016a) are typically associated with the tropics but influence the global climate. The here studied high-altitude site, the Páramo de Frontino at the northern termination of the Colombian Western Cordillera (Fig. 1), is ideally located because it is exposed to the climatic influence of both the Atlantic and Pacific oceans.

In the last 50 years, Colombia has been one of the best-studied tropical countries with respect to Quaternary climate change and associated variations in the distribution of vegetation (Flantua et al., 2015). Palynology has been the main tool for these investigations: Van der Hammen and González (1960a,b), González et al. (1965), Van der Hammen et al. (1973), Van Geel and Van der Hammen (1973), Van der Hammen et al. (1980/1981), Hooghiemstra (1984), Kuhry (1988), Mommersteeg (1998), Thouret et al. (1996), Wille et al. (2001), Van der Hammen and Hooghiemstra (2003), Groot et al. (2011), among others. The period since the last glacial maximum is the best covered by pollen-based records from a variety of biomes (páramo, montane forest, savana, rainforest, dry forest), which were used to unravel the dynamic history of these ecosystems (e.g., Marchant et al., 2001, 2002, 2006; Flantua et al., 2015). In montane areas, the Eastern Cordillera of Colombia is palaeoecologically best studied, whereas the history of ecosystems in the Western Cordillera (where the Páramo de Frontino is located) is poorly known. Nevertheless, information about the ecology and biotic diversity of montane forests and tropical alpine grasslands (called "páramos"), including those of the Western Cordillera, can be found in Cuatrecasas (1958), Rangel (1995), Gentry (1995), Rangel et al. (1997), Van der Hammen et al. (2005) and Rangel (2010), among others.

High-resolution pollen records over the last 15,000 years, which can provide reliable proxies for climate variations, are rare in the South American tropics (Flantua et al., 2015, 2016a,b; Urrego et al., 2016). Outside of Colombia, pollen records reflecting the Holocene have been well studied in Venezuela (Bradbury et al., 1981; Rull et al., 2005), Ecuador (Niemann et al., 2009; Brunschön and Behling, 2010), Peru (Weng et al., 2006) or Yucatan (Leyden, 2002). Although Colombia probably presents the largest number of palynological publications of all tropical countries (Flantua et al., 2015), very high-resolution studies (i.e., those with a time

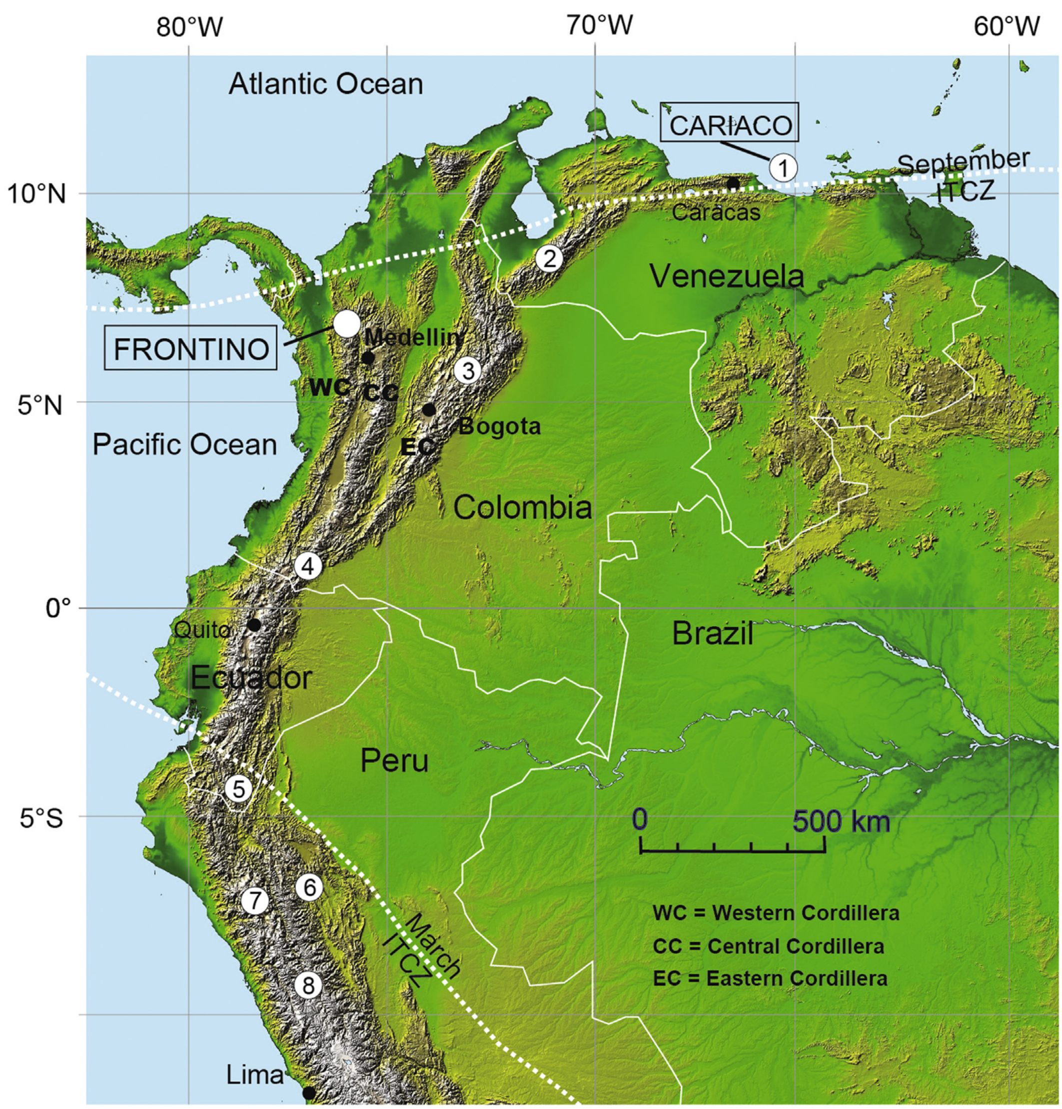

Fig. 1. Location map of the Páramo de Frontino at the northwestern termination of the Western Cordillera in Colombia and seasonal positions of the present-day Intertropical Convergence Zone (ITCZ). Locations numbered 1 to 8 show sites mentioned in the text: 1) marine Cariaco Basin, Venezuela (Haug et al., 2001); 2) Laguna Los Anteojos, Venezuela (Stansell et al., 2010); 3) Lake Fúquene, Colombia (Bogotá-Angel et al., 2011); 4) Laguna La Cocha, Colombia (González-Carranza et al., 2012); 5) Laguna Rabadilla de Vaca, Ecuador (Niemann et al., 2009); 6) Laguna de Chochos, Peru (Bush et al., 2005); 7) Laguna La Compuesta, Peru (Weng et al., 2006); 8) Huascaran ice core, Peru (Thompson et al., 1995).