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Earth and Planetary Science Letters 242 (2006) 375 – 389
EPSL
www.elsevier.com/locate/epsl

Holocene hydrologic balance of tropical South America from oxygen isotopes of lake sediment opal, Venezuelan Andes

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Received 8 June 2005; received in revised form 21 December 2005; accepted 21 December 2005

Editor: E. Boyle

Abstract

Precipitation in the South American Andes is derived from Atlantic Ocean evaporation which is modified by passage over lowland South America. The isotopic composition of Andean precipitation reflects evaporation conditions over the Atlantic Ocean, moisture recycling during advection across the South American lowlands and uplift to the Andes. Records of the oxygen isotope composition of precipitation in the Venezuelan Andes, derived from lake sediment diatom $\delta^{18}O$ measurements, show a 2.4‰ decrease during the past 10,000 yr. A simple model of the evaporation, advection and uplift processes is used to understand the cause of the isotope shift. The data and model suggest that the decreasing $\delta^{18}O$ reflects a decrease in the fraction of moisture entering South America that reaches the Andes. Ice cores from Peru and Bolivia exhibit similar isotope trends indicating that the shift occurred in both hemispheres. An isotopic record of Amazon River discharge is consistent with the Andean records, indicating increasing continental runoff was associated with the decreasing export of water vapor. Orbital changes in solar insolation cannot explain the synchronous trends in both hemispheres. Changing climate in the tropical Pacific is an attractive explanation for the trends because modern interannual variability in this region has similar effects in both hemispheres.

Keywords: oxygen isotopes; biogenic opal; hydrologic balance; Holocene; Venezuela; Amazon Basin; South America

1. Introduction

The tropical rainforests of South America flourish because of the abundant precipitation they receive. Water balance calculations indicate that approximately 40–50% of the annual precipitation is lost as runoff and the remaining moisture returned to the atmosphere by evaporation and transpiration [1,2]. Transpiration accounts for most of the recycled water vapor [3], intimately linking the hydrologic balance of lowland South America to the vegetation. This interplay between vegetation and climate creates an internal feedback that makes it difficult to predict the impact of external perturbations such as orbital insolation cycles, solar variability and increasing carbon dioxide on the climate of the region. Indeed, the Quaternary evolution

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doi:10.1016/j.epsl.2005.12.024

of the lowlands and their susceptibility to land-use changes and global warming are topics of considerable interest and debate [4–7]. Accordingly, proxy records of past changes in the hydrologic balance of lowland South America are valuable for understanding the ecological and climatic sensitivity of the region.

The isotopic composition of precipitation and atmospheric water vapor is a sensitive indicator of moisture recycling and the atmospheric water balance [8]. Unfortunately there are no long proxy records of the isotopic composition of precipitation in lowland tropical South America. However, atmospheric flow from east-to-west (Fig. 1) transports water vapor from the low elevation tropics to the high Andes where it falls as precipitation, leading to the potential for reconstructing the lowland water balance from proxy records in the Andes. The composition of Andean precipitation integrates the isotopic effects of oceanic evaporation, lowland moisture recycling and orographic uplift. If the impacts of oceanic evaporation and orographic uplift can be constrained, it is then possible to solve for the lowland moisture balance. We explore this potential by reconstructing the isotopic composition of precipitation in the Venezuelan Andes from the oxygen isotope composition of diatom opal preserved in lake sediments. The water balance of northern South America is reconstructed for the past 10,000 yr through modeling the isotopic evolution of water vapor as it is transported from the Atlantic Ocean to the high Andes. The reconstruction is compared to ice core and marine isotope records from tropical South America.

2. Methods and data

2.1. Study site

Laguna Verdes Alta (LVA, 8° 51.17′ N, 70° 52.45′ W, 4215 m) and Baja (LVB, 8° 51.49′ N, 70° 52.42′ W, 4170 m) are small lateral-moraine dammed lakes in the Venezuelan Andes (Fig. 1). Both lakes are groundwater-fed with overland flow contributing water only during heavy precipitation events. LVA has a small outflow stream while LVB has no surface outflow suggesting LVA is hydrologically open while LVB is hydrologically closed. This inference is supported by isotopic analyses of modern surface water samples from the region. On a plot of δD_{lw} vs. $\delta^{18}O_{lw}$, both lakes fall along an evaporative trend below the meteoric water line, however LVB is significantly more enriched than LVA (Fig. 2). The proximity of the lakes means they are subjected to the same climate (humidity, temperature and wind speed) and thermal regime, only differing significantly in their hydrologic balance. There is no evidence for past changes in the strength of the LVA outflow.

Sediment cores were retrieved from the deepest location in LVA (3 m water depth) and LVB (5 m water depth) using a modified square-rod Livingstone corer [9]. Sequential drives were overlapped 10 cm to ensure

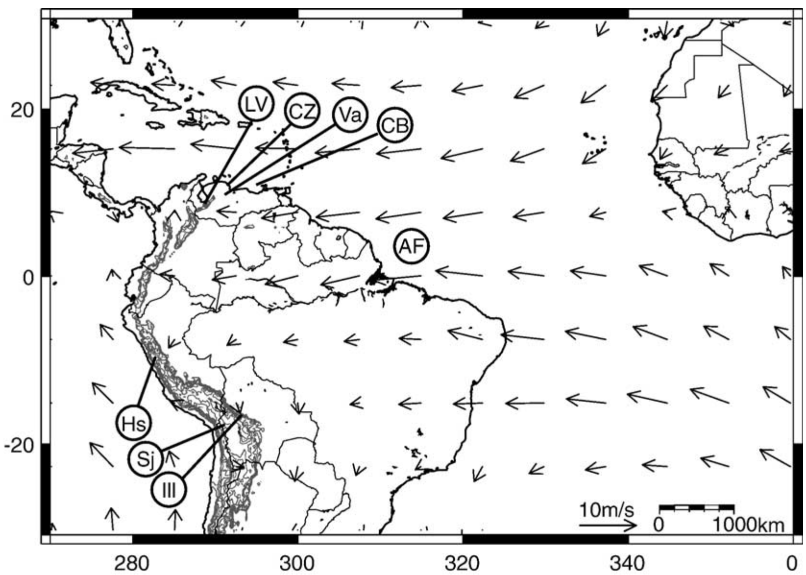

Fig. 1. Location of Laguna Verdes Alta and Baja (LV), Cuevo Zarraga (CZ), Lake Valencia (Va), the Cariaco Basin (CB), Nevados Huascarán (Hs), Sajama (Sj) and Illimani (Ill), and the Amazon Fan (AF). Arrows indicate the direction and magnitude of surface winds (annual average, 1000–850 mb, [28]).