South American Andes: A unique area for ice core-based tropical paleoclimate reconstruction

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Introduction

The Andean summits stretch out along about 7000 km of South America in a north-south transect from northern hemisphere low latitudes (Columbia, 5°N) to southern hemisphere high latitudes (south Chile, 55°S). Along this natural atmospheric circulation boundary, a large number of peaks reaching between 5000 m and 7000 m are covered with glaciers but only a few of them in Ecuador, Peru, Bolivia, Chile and Argentina are suitable for ice core paleoclimate investigation. The Andes are a specific area in the tropics where both Atlantic and Pacific influences on past climate variations can be explored. This is mainly because the atmospheric circulation can be roughly divided in two components (e.g. Montecinos et al., 2000): (i) north of 20°S, tropical NE-winds or Trade winds transport Atlantic Ocean moisture over the Amazonian basin to the Andes, (ii) south of 20°S, Pacific Ocean moisture is directly transported by SW westerly winds. Polar front inputs may also influence the southern Andes. Between these two areas, the South American Arid Diagonal is one of the driest regions in the world, where no glaciers exist. Thus, tropical ice cores are likely to contain information on both the Intertropical Convergence Zone and Hadley cells, and ENSO in the Pacific Ocean. Important modifications of this system started a few decades ago and will intensify in connection with industrial and agricultural development (IPCC, 2001). A detailed knowledge of the background state of the area (before anthropogenic influence) is essential to understand the anthropogenic effect on climate changes. In this context, a comprehensive study of Andean ice cores is essential to provide a comprehensive spectrum of climatic and environmental proxies.

Over the last few decades, several institutions have developed ice-coring programs in the Andes. Lonnie Thompson (Byrd Polar Research Center - OSU) pioneered these activities in 1983 on the Quelccaya glacier (Peru), followed by Huascarán (Peru) and Sajama (Bolivia). Since 1997, other institutions (Institut de Recherche pour le Développement - Great Ice – France, Paul Scherrer Institut – Switzerland, and their South American partners: Instituto Hydraulica y Hidrologia - Bolivia, Instituto Nacional de Meteorologia y Hidrologia – Ecuador, Servicio Nacional de Meteorologia e Hidrologia – Peru, Centro de Estudios Cientificos – Chile, etc.) have joined this effort to extend the ice core investigation on Cerro Tapado (Chile), Illimani (Bolivia), Chimborazo (Ecuador), Mercedario (Argentina) and Coropuna (Peru), in order to reconstruct a latitudinal transect of paleoclimate records (Fig. 1). A new deep ice core program is being

Fig. 1: Location of deep drilling sites where ice cores were extracted along the South American Andes. Arrows indicate the main atmospheric circulation paths, map colors illustrate the mean annual precipitation

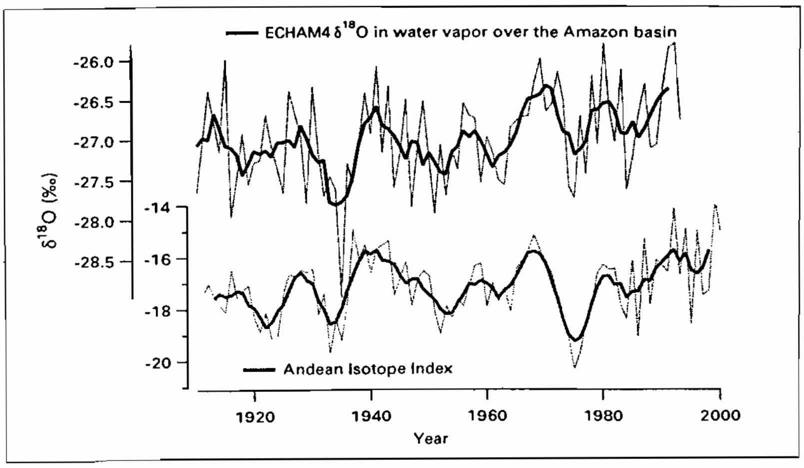

Fig. 2: Andean Isotope Index calculated from $\delta^{18}O$ records from Illimani, Sajama, Huascaran, Quelccaya and $\delta^{18}O$ of water vapor over the Amazonian region as simulated by the atmospheric general circulation model ECHAM 4. For both curves, the dotted line is raw data, the solid line is the 5-year running average (adapted from Hoffmann et al., 2003).

developed at mid-latitudes to fill the gap between the Andes and Antarctica (summits of San Valentin, Chile and San Lorenzo, Argentina). Thus, ice from the South American Andes is a climate archive that can offer a continuous record of our past climate, with identical proxies, from the equator to high latitudes.

Results from Andean ice cores

The different programs have demonstrated well that tropical ice cores can be dated, analyzed and interpreted in terms of climate changes. For dating, a combination of different methods is typically applied: annual layer counting, identification of reference horizons, such as past thermo-nuclear tests and volcanic eruptions (De Angelis et al., 2003), and radionuclide decay (Knüsel et al., 2003). Chemical and isotopic analyses on these ice cores strongly suggest that the tropics have participated in the well-known climate transitions over the last 20,000 years. The Sajama record goes back to around 25,000 years (Thompson et al., 1998) and is the oldest reconstruction along the Andes but other records from Huascarán (Thompson et al., 1995), Illimani (Ramirez et al., 2003) and Coropuna (P. Ginot, pers. comm.) also cover the last glacial transition and interestingly show similar isotopic variations compared with polar ice cores (a glacial maximum, a deglaciation interrupted by a "reversal" event, a Holocene optimum). The open question is which teleconnections could explain such similar climate changes.

Tropical ice cores also offer a high temporal resolution (seasonal resolution over the last centuries), allowing a detailed study of specific events or periods, such as the Little Ice Age or the last few centuries. For example, the isotopic composition of the ice (δD and $\delta^{18}O$), insoluble dust mass and ice core stratigraphy were the first proxies investigated in the Quelccaya ice core and allowed a 1000-year accumulation history reconstruction in the Andes (Thompson et al., 1985). Another interesting result is the water stable isotope decadal signal over the 20th century common to all the ice cores (Quelccaya, Huascarán, Sajama and Illimani) (Hoffmann et al., 2003). This Andean Isotopic Index (Fig. 2) is fairly well reproduced by atmospheric general circulation models (AGCM) and, according to recent studies dealing with both direct observations (Vimeux et al., 2005) and AGCM (Vuille and Werner, 2005), it should be related to past humidity changes in tropical South America and over the tropical Atlantic Ocean. However, when the reconstruction reaches a high temporal resolution, such as seasonal variations, some important post-depositional effects like those resulting from high sublimation affecting chemical proxies have to be considered (Ginot et al., In press; Ginot et al., 2001). The impact of such effects on isotope records is highly dependent on the drilling sites (Stichler et al., 2001; F. Vimeux, pers. comm.). Accordingly, further systematic studies on tropical ice cores sites are needed to fully exploit this unique high-resolution natural climate archive.

Project facts

Project: Andean ice core investigations
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Funding: IRD, The Award for Enterprise Rolex for Chimborazo operation, NSF, Paul Scherrer Institut, University Bern (Switzerland).
Where: Andes
When: Since 1974
What: Ice cores back to LGM, Multiproxy studies.
Web page: www.mpl.ird.fr/hydrologie/greatice/ www-bprc.mps.ohio-state.edu/Icecore/, http://lch.web.psi.ch/index.html
Database: www-bprc.mps.ohio-state.edu/Icecore/dataandimages.html

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Vimeux Françoise, Ginot Patrick (2006)

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Pages News, 14 (1), 19-20