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Glacial to Holocene changes in sea surface temperature and coastal vegetation in north central Chile: high *versus* low latitude forcing

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A B S T R A C T

North central Chile is located at an important climatic transition zone between humid conditions under the influence of the Southern Hemisphere Westerly Winds in the south and the extremely dry climate of the Atacama Desert in the north. Offshore, equatorward flowing cold waters of the Peru–Chile Current converge with relatively warmer waters coming from the low latitudes. Based on terrestrial and marine proxies from the same archive (GeoB 7139-2) (30°12′S; 71°59′W), we show that during the Glacial (between ∼33 and 19 kyr) cold sea surface temperatures paralleled enhanced humidity with high terrestrial input and abundant vegetation on the adjacent land, suggesting a stronger influence of cold waters from the Antarctic Circumpolar Current and the Westerly Winds. While the deglacial sea surface temperature warming started at ∼19 kyr, the humidity decrease occurred around 17–16 kyr BP. The early to mid-Holocene is characterized by extremely warm and dry conditions. We suggest that climate changes were driven by fluctuations in Antarctic sea-ice extent and the circulation of the Hadley cell, both ultimately linked to insolation changes. Our records further imply warm and dry conditions in north central Chile during the Northern Hemisphere Heinrich events.

1. Introduction

The relative influence and importance of high and low latitudes as drivers of Glacial/interglacial climate changes remain an intriguing question for understanding past climate mechanisms. Ice-core and marine records suggest that the deglacial warming started a few thousand years earlier in the Southern Hemisphere (SH) (Charles et al., 1996; Petit et al., 1999) and may have been triggered by increasing austral spring insolation combined with Antarctic sea-ice feedbacks (Stott et al., 2007). On the other hand, it has been shown that climate oscillations may originate from the tropical Pacific, potentially involving a long-term modulation of interannual-to-decadal climate changes of El Niño–Southern Oscillation (ENSO) (Cane, 1998). Stalagmite records from the low latitudes suggest a strong influence of summer insolation changes on the atmospheric system, i.e. the East Asian Monsoon (Wang et al., 2004) and the South American Summer Monsoon (Cruz et al., 2005). Based on a re-analysis of existing ice-core data sets, Alley et al. (2002) suggested that the data were fully consistent with northern-insolation control of ice-age cycles, where changes would have started in the Northern Hemisphere (NH) high latitudes and then spread to tropical and southern regions. Lamy et al. (2007) recently showed that the pattern of SST changes off southern Chile over the last deglaciation can be interpreted in terms of an ultimate NH forcing and subsequent transfer of the signal to the SH involving the bipolar seesaw mechanism.

During the last Glacial time, abrupt coolings of Artic air temperature and sea surface temperatures (SST) in the North Atlantic Ocean, linked to the so-called Heinrich Events (HEs; Hemming, 2004), were balanced by warming over Antarctica (Blunier and Brook, 2001) and in the Southern Ocean mid-latitudes (Lamy et al., 2004). These data provided strong evidences for the so-called thermal bipolar seesaw mechanism (Crowley, 1992; Broecker, 1998) involving changes in the Atlantic meridional overturning circulation and the atmosphere. A number of studies highlighted that HEs were linked with abrupt shifts in the location of the Intertropical Convergence Zone (ITCZ) (Peterson et al., 2000; Wang et al., 2006; Leduc et al., 2007).

The southeast Pacific mid- to low latitudes are best located to trace the timing in major oceanographic and atmospheric changes. Off north central Chile, cold Antarctic waters converge with warm equatorial waters (Strub et al., 1995, 1998). Studying SST changes in this region enables to trace influences of both high and low latitudes on driving climate changes. North central Chile is also

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located at the northernmost limit of the SH Westerly Winds (SWW) (Cerveny, 1998). The associated strong precipitation gradient provides the opportunity to register variations originating in the high and low latitudes, as the SWW are controlled by both the Antarctic low pressure and the subtropical high-pressure belts.

2. Regional settings

2.1. Oceanography

The study area is under the influence of both the southward flowing Peru–Chile Countercurrent (PCCC) and the northward flowing Peru–Chile Current (PCC) (Strub et al., 1998) (Fig. 1). The PCC supplies cold, Subantarctic surface waters originating from the region north of the Subantarctic Front. At the core site, the influence of the PCC is greater during austral winter, whereas the influence of the PCCC, bringing relatively warm waters from the low latitudes, is strong in austral summer. The dynamics of the PCCC is so far not well studied, but observations show a possible connection to wind strength changes in the EEP (Eastern Equatorial Pacific). An easterly (westerly) wind anomaly forces negative (positive) SST anomalies in the EEP and off the western coast of South America (Montecinos and Pizarro, 2005). A direct link with the PCCC is, however, not clear. Upwelling is a quasi-perennial feature at 30°S due to the southeasterly winds.

2.2. Continental climate

The Eastern South Pacific (ESP) is characterized by three main atmospheric features: the SWW, the subtropical high-pressure cell (STH) and the ITCZ (Fig. 1). In austral summer, the ITCZ reaches its southernmost position, the very stable STH cell located around 30°S blocks the frontal system of the SWW, which are concentrated in a tight band centered around 49–50°S (Trenberth, 1991; Cerveny, 1998). In austral winter, the ITCZ is located further north, the STH is shifted northward around 30°S and the SWW are reaching north central Chile. In the northeastern part of the Atacama Desert, an austral summer rainfall regime is dominant, linked to the South American Summer Monsoon (Zhou and Lau, 1998). In the southern part, the driest portion of the Atacama Desert, austral winter-rainfall is dominating due to rare incursions of the SWW, but vast areas receive virtually no rain. The vicinity of the STH and the upwelling of cold waters offshore cause this extreme aridity (Veit, 1996; Cerveny, 1998). The study area corresponds to a climatic transition

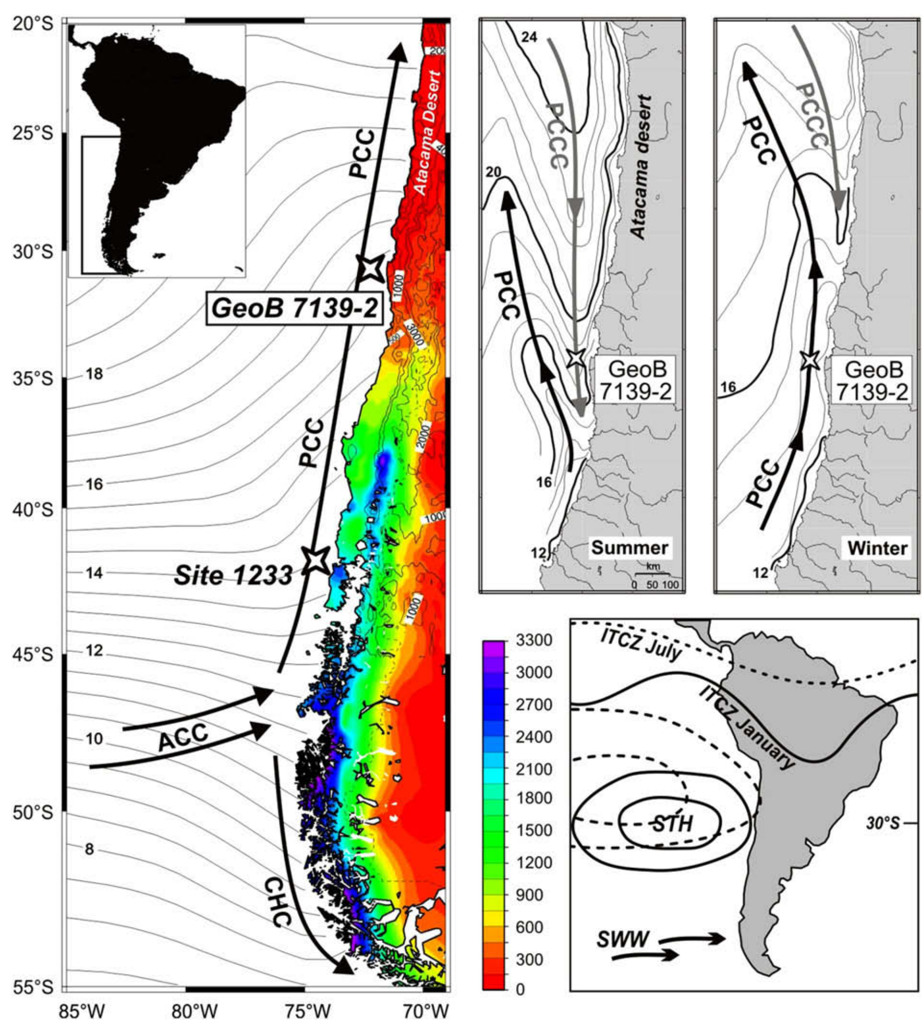

Fig. 1. Main oceanographic and atmospheric settings in the Eastern South Pacific region. Left: annual mean precipitation (mm/yr) (New et al., 2001), sea surface temperature (Reynolds et al., 2002) and oceanic surface currents (Strub et al., 1998) – PCC: Peru–Chile Current, PCCC: Peru–Chile Countercurrent; ACC: Antarctic Circumpolar Current, CHC: Cape Horn Current. The locations of core GeoB 7139-2 (30°12′S, 71°59′W) (this study) and ODP Site 1233 (41°00′S, 74°27′W) (Lamy et al., 2004) are indicated. Right top: austral summer and winter SST distribution in the core area (Strub et al., 1998). Right bottom: January and July position of the Intertropical Convergence Zone (ITCZ), the subtropical high-pressure cell (STH) and the mean location of the Southern Westerly Winds (SWW).