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# ONSET OF MODERN ENSO TELECONNECTIONS AND CLIMATE MECHANISMS FOR HOLOCENE DEBRIS FLOWS ALONG THE HYPERARID COAST OF NORTHERN CHILE-SOUTHERN PERU

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## 1. INTRODUCTION

The relationship between modern debris flows in the Antofagasta region of northern Chile (23ºS) and El Niño events was studied through the revision of local newspapers, rainfall data and the characterization of geologic sections [Vargas et al., 2000]. During the twentieth century, all the debris flow episodes were associated to heavy rainfall (20-40 mm/3 hr) in austral winter during the development phase of strong to moderate El Niño events: August 1930, June 1940, May 1982, July 1987 and June 1991 (Figure 1). Meteorological conditions for the development of heavy rains in June18, 1991 have been described in Garreaud and Rutllant [1996], but further verification and search for additional meteorological mechanisms in different phases of the ENSO cycle should lead to improved ENSO reconstructions from Holocene alluvial sequences in this region.

A similar historical revision was performed for the Tacna-Ilo coastal area in southern Peru [Ortlieb and Vargas, 2003]. Eight flooding events since 1960 were associated to heavy rainfall episodes during El Niño events: January 1983, December 1997 and January 1998; July 1963 and 1972, September 1963, 1965 and 1997. Major debris flows occurred in January 1983 and September 1997, and minor events in July 1972 and January 1998 (Figure 1). However, the floods reported in September 1960, 1961 and 1962 are not related to El Niño [Ortlieb and Vargas, 2003], suggesting that other mechanisms not previously reported may be also involved in the generation of sudden and strong rainfalls in this region during early austral spring.

Here we investigate meteorological mechanisms producing heavy rains in coastal northern Chile and southern Peru and their relationship with present ENSO-related atmospheric circulation anomalies, to interpret the climate significance of debris flow deposits, as well as the Holocene evolution of ENSO manifestations along the western coast of South America.

## 2. DATA AND METHODS

The analysis of meteorological mechanisms was based on daily weather charts obtained from the NCEP/NCAR reanalysis [Kalnay et al.,1996]. Selected anomaly (A) charts, based on 1968-1996 long-tern means, are:

a) Mid-troposphere circulation from geopotential heights at 500 hPa (AH500),
b) Upper-troposphere vector wind charts at 250 hPa (AVW250),
c) Vertical p-velocity (omega) in the lower-troposphere over the study area at 850 hPa (AOM850).

Composites for each storm have been constructed from these daily weather anomaly charts. The chronostratigraphy of debris flow sequences in the Antofagasta (23ºS) region was determined considering their morphostratigraphic relationship with the marine terrace associated to the Last Interglacial Maximum (LIM) $^{14}$C determinations and the recognition of twentieth century anthropic remains.

## 3. RESULTS AND CONCLUSIONS

Our analysis reveals that in austral winter-spring meteorological mechanisms explaining the occurrence of heavy rains in coastal southern Peru and northern Chile in the last 50 years are associated to El Niño-related atmospheric circulation anomalies derived from tropical-extratropical teleconnections, generically referred to as Pacific South America (PSA) teleconnection wave patterns [Mo and Higgins, 1998]. The subtropical atmospheric circulation anomaly pole associated to these teleconnection patterns becomes manifested as subtropical troughing off western South America [e.g. Rutllant and Fuenzalida, 1991]. These circulation anomalies affect northern Chile or southern Peru when the PSA subtropical teleconnection pole off South America is anomalously strong or located equatorward of its usual position, respectively.

In austral summer during the mature stage of El Niño, heavy rains tend to occur only in southern Peru, in connection the build-up of potential instability due to positive SST anomalies in the climatologically warmer Arica's (18ºS) coastal bend, concomitant with weak subsidence. The trigger mechanisms for the release of this potential instability are mid-troposphere, mid-latitude weather disturbances that become enhanced as the South

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Pacific Convergence Zone (SPCZ) drifts eastward during the mature stage of strong El Niño events.

During La Niña or neutral (non-El Niño) conditions, short-lived heavy rainfall events tend also to occur exclusively along the southern Peru coast, where the effects of comparatively higher SSTs at the Ilo-Arica–Iquique triangle [e.g. Schweigger, 1964] and the blocking of the stronger southerly flow by the steep topography as the coastline bends from a meridional to an almost zonal orientation [e.g. Garreaud and Muñoz, 2004], critically reinforce the lifting of the lower troposphere ahead of weak mid-troposphere troughs in the westerlies associated with transient PSA atmospheric circulation anomalies.

Our comparison of the geological records from the southern Peru and northern Chile coastal zones supports the idea of an onset of the modern ENSO tropical-extratropical climate teleconnection during the mid Holocene, ca. 5,300-5,500 cal. BP, consistent with a series of other ENSO variability proxies from the western slope of the Andes. Before that, different manifestations during the latest Pleistocene and early Holocene suggest that this climate teleconnection pattern did not fully operate. In that period, we suggest that an alternative climate mechanism similar to the La Niña-like enhancement of the southerly flow off northern Chile, could explain the occurrence of debris flows in southern Peru concomitantly with the absence of heavy rainfall in a cooler and cloudier northern Chile. In fact, low-level southerlies diverge when accelerating over the warmer waters north of Iquique (20ºS), enhancing upwelling and coastal low cloudiness. This condition is favourable for human settlement. These results contradict previous linear interpretations of paleoproxies of ENSO variability from the southernmost Peru area, and more generally encourage careful analyses of possible climate mechanisms prior to extrapolating present-day conditions.

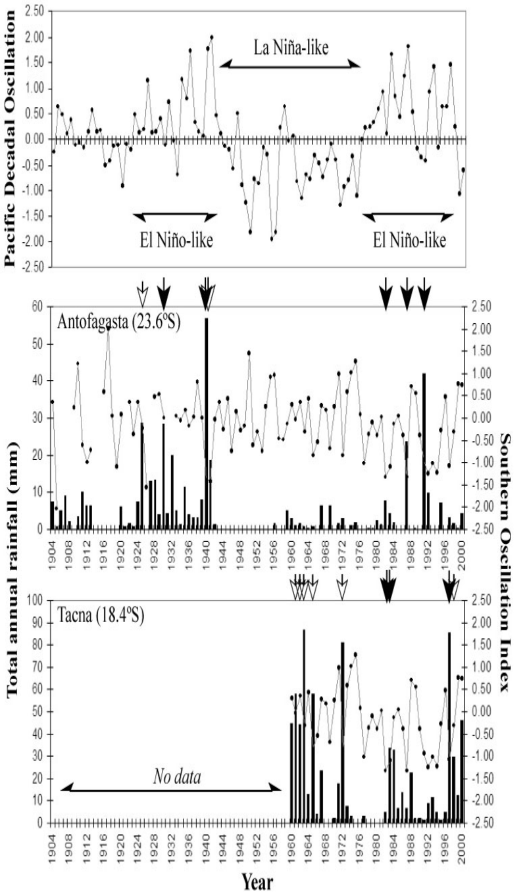

Figure 1. Comparison of total annual rainfall at Antofagasta (northern Chile) and Tacna (southern Peru) with the Southern Oscillation Index (SOI) and the Pacific Decadal Oscillation (PDO) Index [e.g. Mantua et al., 1997]. Black and white arrows represent debris flow and flooding events, respectively [Ortlieb and Vargas, 2003].

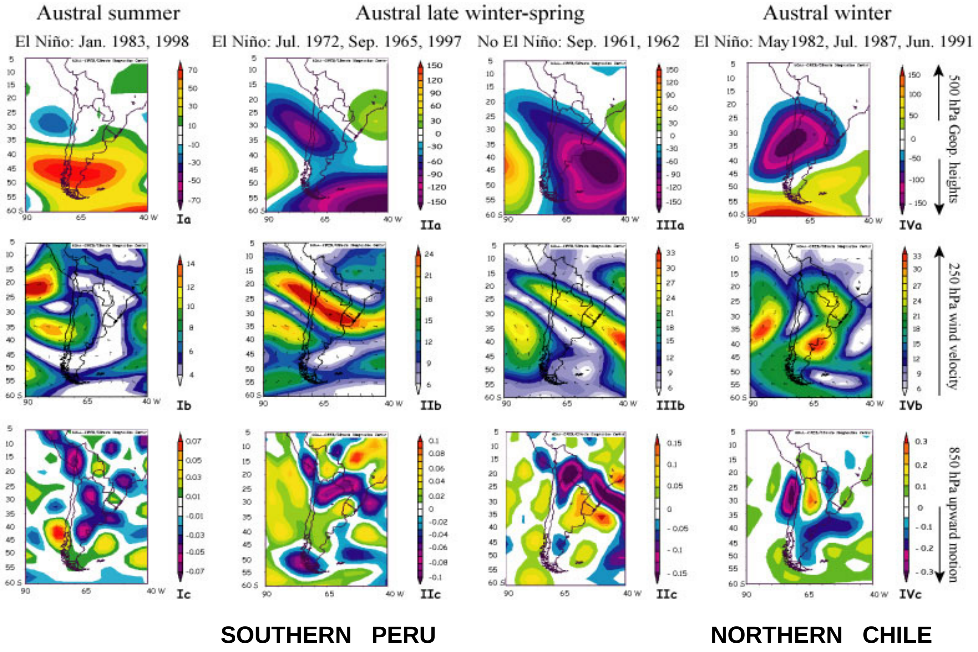

Figure 2. Composites of atmospheric circulation anomalies from NCEP/NCAR Reanalysis data [Kalnay et al., 1996]: (a) 500 hPa geopotential heights (b) 250 hPa vector winds, and (c) 850 hPa p-velocities. From left to right, composites correspond to the first storms of (I) January 1983 and 1998 (El Niño/austral summer); (II) August-September 1965 (El Niño/austral late winter); (III) September 1961 and September 1962 (non El Niño/austral late winter); (IV) July 1987 and June 1991 (El Niño/austral winter). Events represented in (I), (II) and (III) affected southern Peru, while those in (IV) affected northern Chile. In a) positive/negative anomalies represent anticyclonic/cyclonic anomalies or decreasing/enhancing rainfall anomalies eastward of the corresponding anomaly centers. In a Standard Atmosphere, constant pressure surfaces of 500, 250 and 850 hPa approximately correspond to 5500, 10500, and 1500 m above mean sea level, respectively.

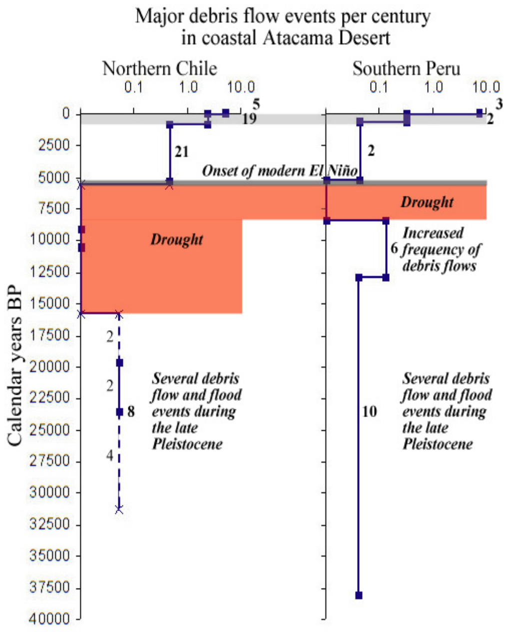

Figure 3. Comparison of the number of major debris flow and flood events per century inferred from alluvial deposits in southernmost Peru and northern Chile, based on previous [Keefer et al 2003; Ortlieb and Vargas, 2003; Fontugne et al., 1999] and new data. Numbers at the rights side of each curve indicate the total debris flow events inferred for the corresponding periods. Lower and upper limits of periods characterized by different periodicities were determined according direct available radiocarbon data (squares) or from extrapolated age estimates (crosses).

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