A Multi-Century Tree-Ring Based Precipitation Reconstruction in the Altiplano: Integrating Instrumental Records, Tree-Rings and Historical Archives

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Abstract

We present a multicentury perspective of past precipitation variations in the Altiplano estimated from historical documents and a precipitation reconstruction based on *Polylepis tarapacana* tree-rings. The tree-ring reconstruction covers the past 700 years, and captures 54% of the instrumental precipitation variance. Spectral analysis of the tree-ring reconstruction reveals significant peaks at interannual, decadal and interdecadal periods which are in agreement with the main oscillatory modes of the instrumental records, and the Niño3.4 and PDO indices. During the 1585-1807 period the Spaniards consistently recorded the occurrence of wet/dry years because of water runoff was used to power the silver mills of Potosi, Bolivia. This past hidroclimate archive shows a remarkable similarity with the tree-ring reconstruction. The relationship between these records adds confidence on both proxies as reliable sources of precipitation variations across the Altiplano and represent a unique opportunity to better understand climate variability in this region during the past centuries. The development of climate-sensitive and well-replicated tree-ring records from this tropical-montane region provide information not only to reconstruct past environmental conditions at various temporal scales, but also to understand particular events in the past human history in the Andes.

Key words: Polylepis tarapacana, tree-ring precipitation reconstruction, Altiplano

Extended Abstract

Water availability is the main limitation for future socio-economic development in many regions of the world. Water shortages affect human activities directly and also indirectly through natural ecosystems and their vital services to society. This is particularly true for the high altitude regions in the tropics such as the South American Altiplano. In the second half of the 20th century the Altiplano has experienced a persistent warming trend, an increase in the elevation of the 0ºC isotherm, and the consequent rapid and unprecedented melting of ice caps and sustained shrinkage of glaciers. These climatic and environmental changes occur in conjunction with a growing demand for hydrological resources due to population increase. However, instrumental records of climate in the tropics are scarce. In addition, most tropical records are short, fragmentary and heterogeneous. Longer records are needed to understand the nature of climate variations, and how the interannual modes of climate variability have evolved under changes in long-term background conditions. There is a need to develop climatic proxy records from natural archives such as corals, tree rings, ice cores, and others to complement the current limited nature of the instrumental record in the tropics. In consequence, the development of climate-sensitive and well-replicated tree-ring records from tropical regions represents a major challenge in our efforts to reconstruct past environmental changes at regional and global scales.

Figure 1 *Polylepis tarapacana* growing on the slope of Tata Sabaya volcano, Bolivia, at 4600 m.

Polylepis tarapacana is a small tree growing at elevations of 4500-5000m on volcanoes of the high Altiplano of Bolivia, Chile and Argentina (Fig. 1). Previous studies have shown the radial growth of this tree is highly sensitive to climate variations in the Bolivian Altiplano and demonstrated the significant skill of this species as a proxy for precipitation variation (Morales et al 2004, Soliz et al 2009). Ongoing sampling of *Polylepis tarapacana* has led to the development of a 700-year long regional chronology for the southern Bolivian Altiplano. This significant contribution to tropical dendrochronology (sites are between 17-23˚S) has allowed estimation of rainfall variability in the high Andes and the identification of severe droughts during past centuries (Fig. 2). This tree-ring reconstruction captures 54% of the instrumental precipitation variance. Spectral analysis of the tree-ring reconstruction reveals significant peaks at interannual, decadal and interdecadal periods which are in agreement with the main oscillatory modes of the instrumental records and the Niño3.4 and PDO indices.

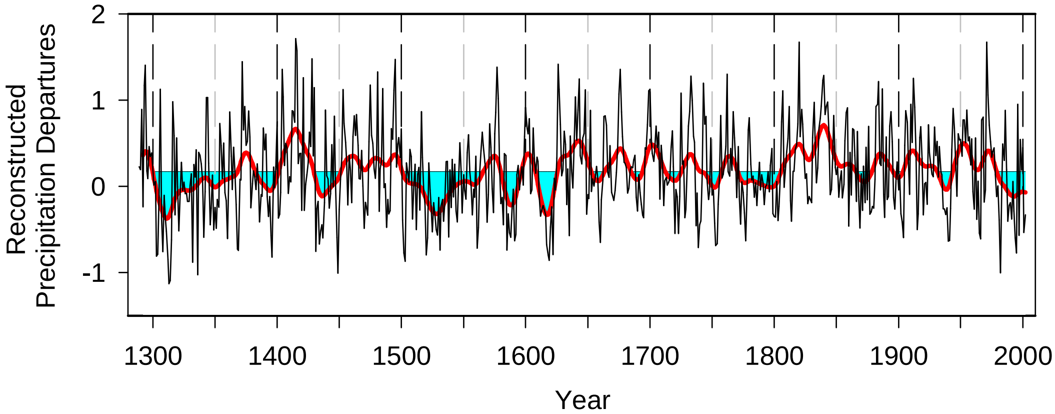

Figure 2 Tree-ring reconstruction of the annual (April-March) precipitation for the southern Bolivian Altiplano region based on the Standard Regional Curve

During the 1585-1807 period the Spaniards consistently recorded the occurrence of wet/dry years they needed to have information on water runoff that was used to power the silver mines of Potosi, Bolivia. This past hydroclimate archive shows a remarkable similarity with the tree-ring reconstruction. The relationship between these records adds confidence that both proxies are reliable sources of information about precipitation variations across the Altiplano and represent a unique opportunity to improve our understanding of climate variability in this region during the past centuries.
The tree-ring precipitation reconstruction also provides an important contribution to the interpretation of documented changes in the Pre-Inca settlement of this region. Recently, archeological research led by Nielsen has shown that lower elevation, open villages close to water sources and irrigable farmlands, were abandoned in the 14th century in favour of fortified sites with evidence of local warfare (Nielsen 2002).

Precise dating of this transition was hampered by the low resolution (+/- 50 years) of radiocarbon dating of wood associated with these structures (Fig. 3). The tree-ring precipitation reconstruction shows a significant persistent drought between 1301 and 1361 that coincides with the onset of the social changes in these Pre-Inca communities. Moreover, the tree-ring record shows two subsequent long-lasting droughts in the 14th and 15th century that followed these initial drought years. This tree-ring evidence of 14th drought century supports Nielsen's previous archeological hypothesis which suggested that droughts destabilized the earlier economy based on dry farming and herding, triggering warfare for access to natural resources including water for irrigation and therefore the need for defendable settlements. The peaceful "vulnerable villages" in the Altiplano flat lands were replaced by hilltop, fortified settlements (Pukaras) in response to these changes. Initial dendrochronological dating of individual timbers from some structures supports this dating but ongoing studies are needed to provide more detail. These studies may also provide archeological wood that can be used to extend the tree-ring chronology further back in time.

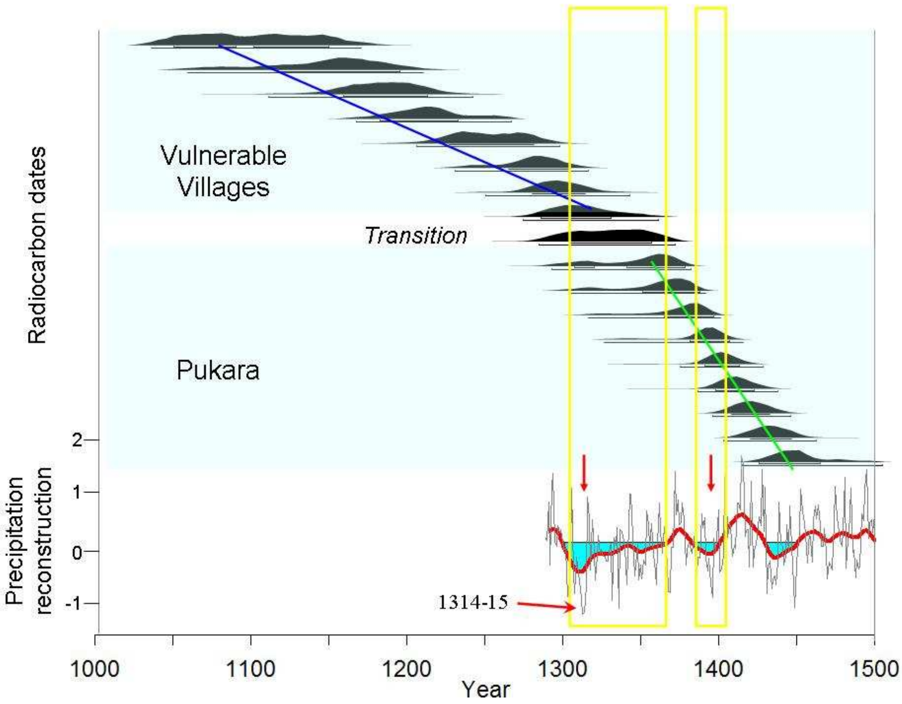

Figure 3 Comparison of ^{14}C dates (with error terms) from timbers in "Vulnerable Villages" and Pukaras with the tree-ring precipitation reconstruction from *Polylepis tarapacana* for the 14th and 15th centuries. The precipitation reconstruction record shows that the years 1314 and 1315 were the severest drought in the last seven centuries and that a long lasting droughts (ca. 1300-1360) occurred in this region during the 14th century. This supports the hypothesis that the changes in village type and social conditions were probably triggered by competition for water resources.

This newly developed record provides, for the first time, a long decade-century perspective on hydrological variability in the Altiplano-an area where precipitation records are very short (20 to 50 years) and streamflow records even shorter (5-15 years).

The tree-ring precipitation reconstruction identifies severe persistent drought at decadal scales during the last 700 yrs that had significant consequences for the economy and socio-cultural activities of the Altiplano communities. Dry conditions prevailed throughout most of the 14th century, including droughts from about 1300 to 1360 during most of the phase of pukara occupation, suggesting a more direct link between pukara use and resource stress. The concept of natural range of precipitation variability and its historical effects on local human socioeconomic and sociocultural activities is essential to future conservation planning in the context of global environmental changes. This long reconstruction helps us to understand the role of climate in shaping local societies.

Although 20th century droughts were not as severe as earlier ones, warming trends at these high elevation sites will reduce snowpack and glaciers (Jomelli et al. 2009) resulting in decreasing water yields that will be superimposed on this natural range of variability that has been characterized for first time. Together with recent climate changes, mining activities, agriculture and local populations are all increasing rapidly, leading to growing demand and pressures on water supply, thereby increasing the risk of future water shortages and droughts that must be addressed in water resource management for the Altiplano.

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