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Supplement of

Centennial-scale precipitation anomalies in the southern Altiplano (18° S) suggest an extratropical driver for the South American summer monsoon during the late Holocene

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1. Radiocarbon chronology of Lago Chungará

Figure S1. Age-depth model for Core 7 from Lago Chungará. The model is constrained by 3 AMS radiocarbon dates obtained from Subunit 2b in cores 11 and 14. Those dates were translated into Core 7 after correlation based on seismic profiles and tephra keybeds identified as peaks in magnetic susceptibility (Sáez et al., 2007). The age-depth line corresponds to a linear interpolation of the median distribution of the calibrated date, while the dotted lines denotes an additional linear interpolation of the 2σ calendar range for all ages.

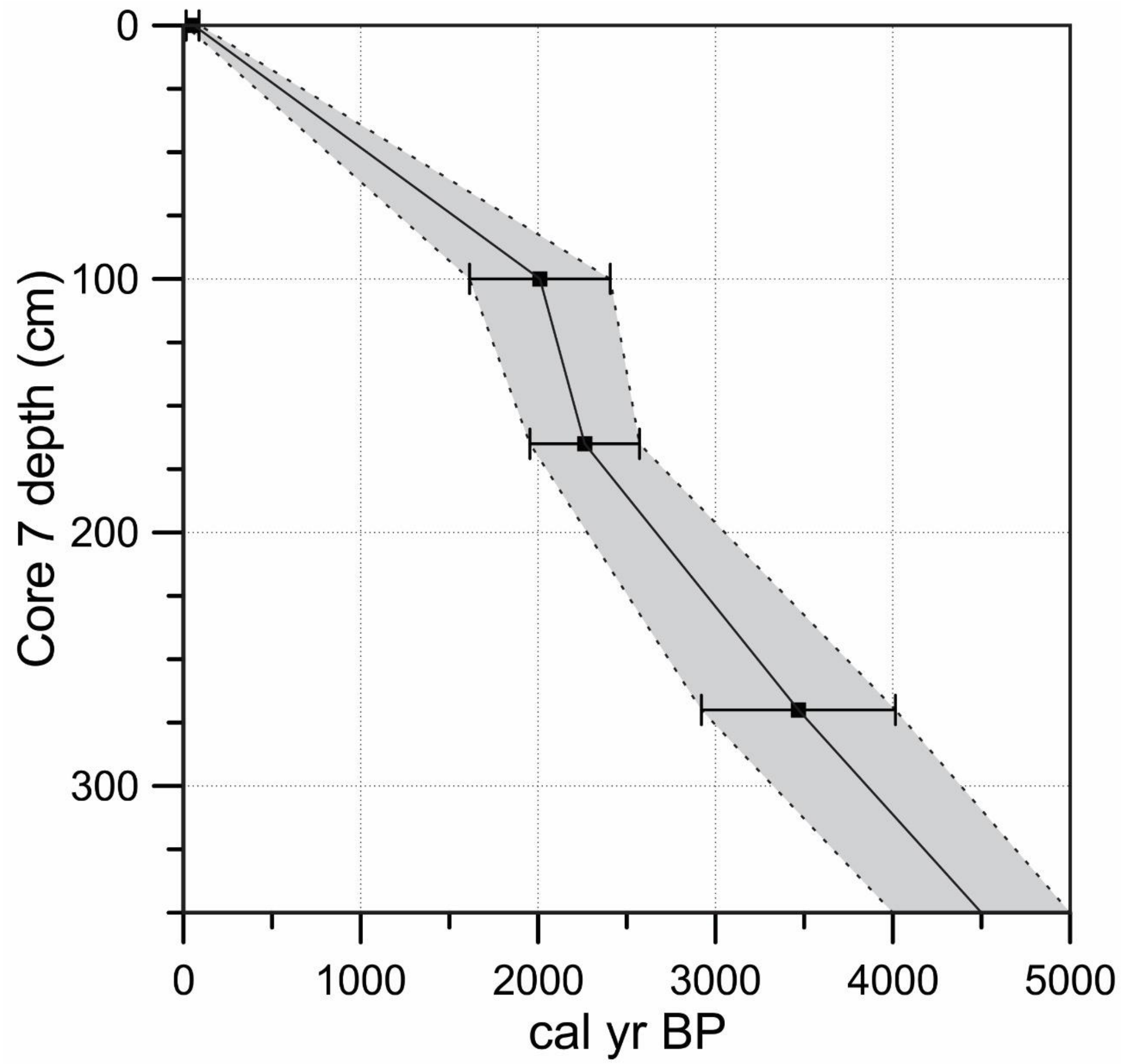


Table S1. Details of the radiocarbon dates from Lago Chungará used in this study. The calendar age was calculated considering a constant reservoir effect of 3,260 ^{14}C years. Calibration was performed using the Southern Hemisphere terrestrial curve (SHCal13) (Hogg et al., 2013) in the R software platform (R Core Team, 2014). More details of the radiocarbon chronology can be obtained in Giralt et al. (2008).

Laboratory code	core	depth (cm)	^{14}C age	1σ	Median probability (cal yr BP)	youngest 2σ intercept (cal yr BP)	oldest 2σ intercept (cal yr BP)	Calibration curve
Poz-8726	14 A-1	100	4620	40	2010	1791	2188	SHCal13
Poz-8720	11 A-2	165	4850	40	2263	2073	2382	SHCal13
Poz-8721	11 A-2	270	7290	50	3468	2658	4263	SHCal13

2. Multivariate analyses

2.1 Canonical Correspondence Analysis (Fig. S2)

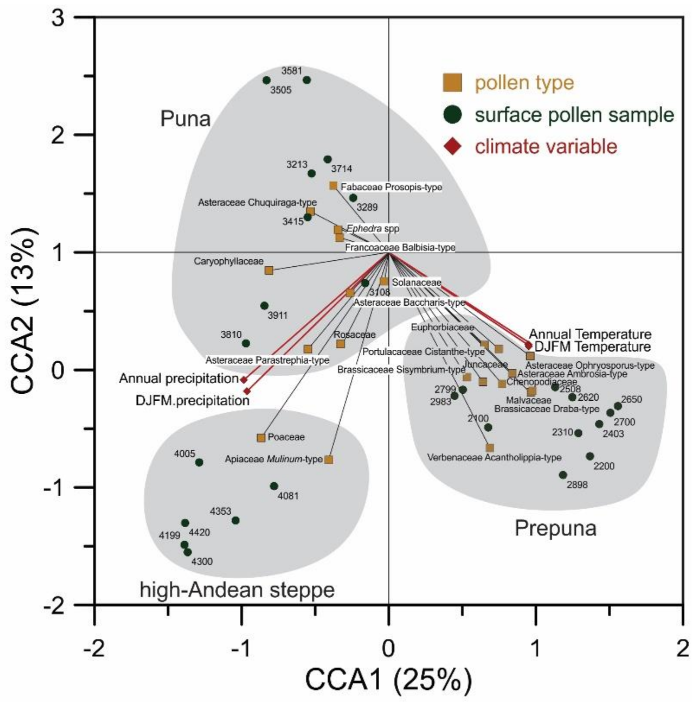
Methods

In order to explore the relationships between the modern surface pollen dataset and climate variables in more detail, we performed a Canonical Correspondence Analysis (CCA) defined by the surface pollen transect assemblages (n = 26) and constrained to annual and summer (DJFM) temperature and precipitation data from the WorldClim2 dataset (Fick and Hijmans, 2017). CCA was run after obtaining a gradient length >1 in Detrended Correspondence Analysis of the surface samples. Prior to running the CCA, a square-root transformation was performed to the data. All multivariate analyses were performed in the software R using the package "Vegan" (R Team, 2014).

Results

The CCA axes (CCA 1 and CCA 2) explains 25 and 13% of the total variance. Temperature variables (annual and DJFM means) were positively correlated with Prepuna taxa and negatively correlated with Puna and high-Andean steppe taxa. Precipitation variables (annual and DJFM totals) were positively correlated with high-Andean steppe. Samples at elevations between 2300-2900 masl were associated with Prepuna taxa, samples between 3100-3900 masl with Puna taxa, and samples above 4000 masl were plotted along with high-Andean pollen types.

Figure S2. Canonical Correspondence Analysis of the surface pollen transect and constrained by climate variables of the WordClim2 dataset.



2.2 Principal Component Analysis on modern and fossil samples (Fig. S3)

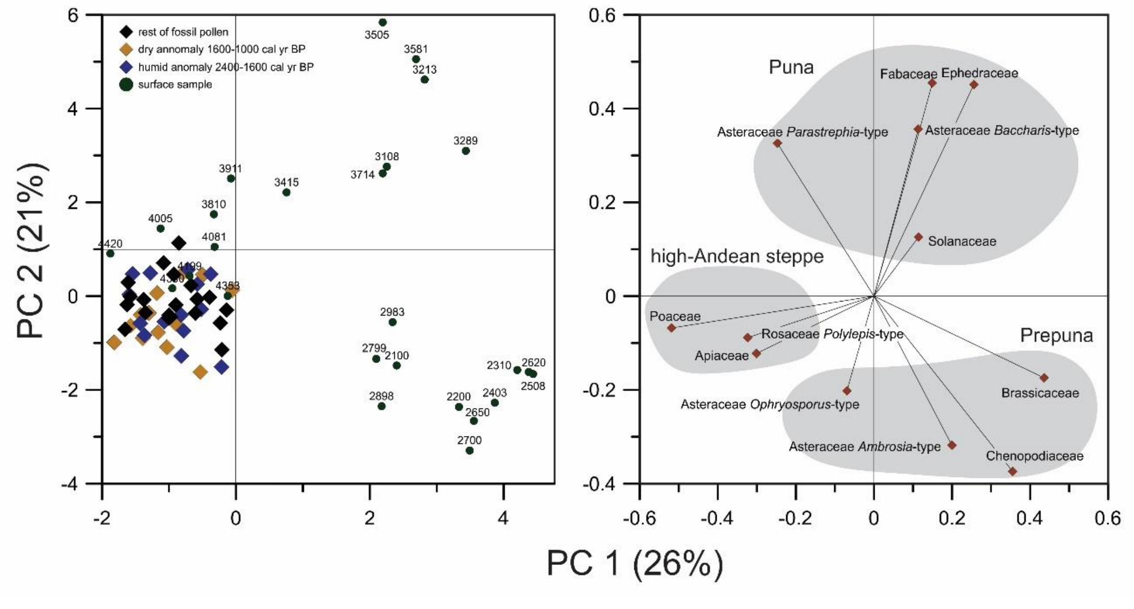
Methods

To explore how well the fossil pollen assemblages are represented by the surface vegetation types we performed a Principal Component Analysis (PCA) projecting the fossil samples from Chungará (n = 49) into the ordination defined by modern pollen assemblages of our surface pollen transect (n = 26; see section 4.2). PCA was performed after square-root transformation using the software R with the package “Stats” (R Team, 2014). Only the taxa common to both modern and fossil datasets were included in the analysis (n = 12).

Results

The two main components of the PCA (PC 1 and PC 2) explained 26 and 21% of the total variance, respectively. In terms of taxon loadings (right panel), PC 1 distinguishes between positive correlations with Brassicaceae, Chenopodiaceae, Asteraceae *Baccharis*-type and *Ephedra* spp, and negative relationships with Poaceae, Rosaceae *Polylepis*-type and Apiaceae. PC 2 contrasts positive values of *Ephedra* spp and Fabaceae with negative values of Chenopodiaceae, Asteraceae *Ambrosia*-type and Asteraceae *Ophryosporus*-type. In terms of sample scores (left panel), fossil samples are clustered around negative values of PC 2, whereas surface samples are evenly distributed across both axes. There is no spatial difference in the position between samples that correspond stratigraphically to the humid (2400-1600 cal yr BP) and dry (1600-1000 cal yr BP) Chungará anomalies (left panel).

Figure S3. Principal Component Analysis with modern surface samples and fossil samples from the Chungará record. Taxa loadings are depicted on the left panel and sample scores on the right panel.



2.3 Principal Component Analysis on the fossil sample from Lago Chungará (Fig. S4)

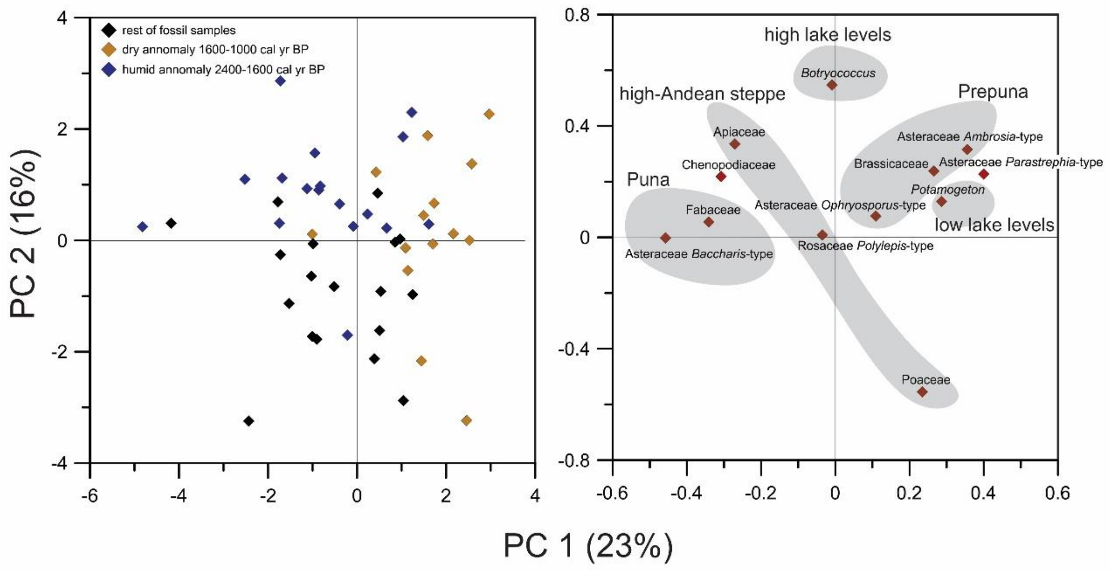
Methods

To explore the relationship between samples that compose the Chungará record, the fossil pollen ensembles (n = 49) were analysed independently using Principal Component Analysis (PCA) prior to square-root transformation. The analysis was conducted with the aid of the software R with the package “Stats” (R Team, 2014).

Results

The two main components of the analysis explain 23 and 16% of the total variance of the fossil assemblages. The taxa score plot (right) shows that PC 1 is positively correlated with Prepuna taxa and low lake levels indicators, and negative correlations with Puna and high-Andean steppe taxa. PC 2, on the other hand, contrast positive relationship with high lake level indicators and negative values of Poaceae. The sample score panel (left) shows that samples corresponding to the dry climate anomaly (1600-1000 cal yr BP) occur closer to the Prepuna and low lake level indicators; whilst samples corresponding to the wet climate anomaly (2400-1600 cal yr BP) are closely associated with high-Andean steppe and high lake level indicators.

Figure S4. Principal component Analysis of the Chungará pollen record. The left Panel depicts the taxa loadings and the right panel shows the sample scores with samples associated with the humid (dry) anomaly in blue (yellow).



3. References

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