Article

Geodetic Mass Balances and Area Changes of Echaurren Norte Glacier (Central Andes, Chile) between 1955 and 2015

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Abstract: The Echaurren Norte Glacier is a reference glacier for the World Glacier Monitoring Service (WGMS) network and has the longest time series of glacier mass balance data in the Southern Hemisphere. The data has been obtained by the direct glaciological method since 1975. In this study, we calculated glacier area changes using satellite images and historical aerial photographs, as well as geodetic mass balances for different periods between 1955 and 2015 for the Echaurren Norte Glacier in the Central Andes of Chile. Over this period, this glacier lost 65% of its original area and disaggregated into two ice bodies in the late 1990s. The geodetic mass balances were calculated by differencing digital elevation models derived from several sources. The results indicated a mean cumulative glacier wide mass loss of -40.64 ± 5.19 m w.e. (-0.68 ± 0.09 m w.e. a^{-1}). Within this overall downwasting trend, a positive mass balance of 0.54 ± 0.40 m w. e. a^{-1} was detected for the period 2000–2009. These estimates agree with the results obtained with the glaciological method during the same time span. Highly negative mass change rates were found from 2010 onwards, with -1.20 ± 0.09 m w.e. a^{-1} during an unprecedented drought in Central Andes of Chile. The observed area and the elevation changes indicate that the Echaurren Norte Glacier may disappear in the coming years if negative mass balance rates prevail.

Figure S1. (**a**) Photographs from the new small lake in center of the Echaurren Norte Glacier, March 2015 (photo by David Farías). (a) Bedrock visible, (b and d) debris cover over the glacier surface, (c) water.

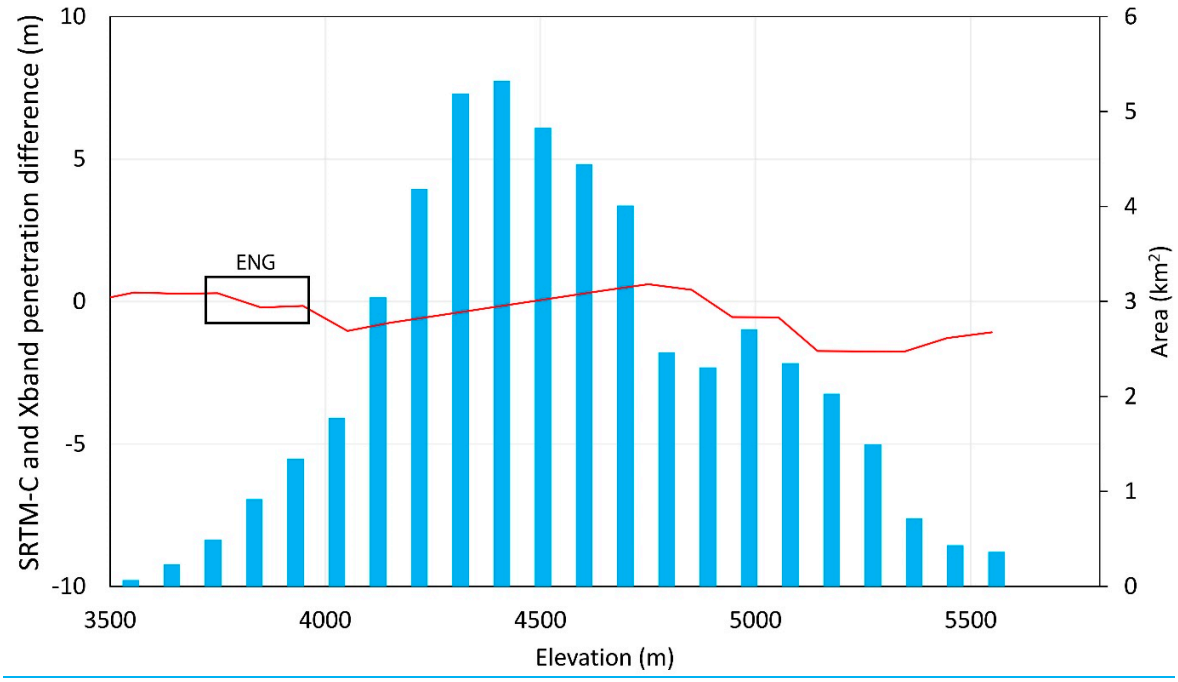

Figure S2. Hypsometric plot of the observed SRTM-C and X band penetration difference, average in 100m glacier elevation bins. Black box indicates the elevation range of the Echaurren Norte Glacier. Since Echaurren Norte Glacier was not covered by X band we analyzed 20 glaciers located in the same Maipo basin.

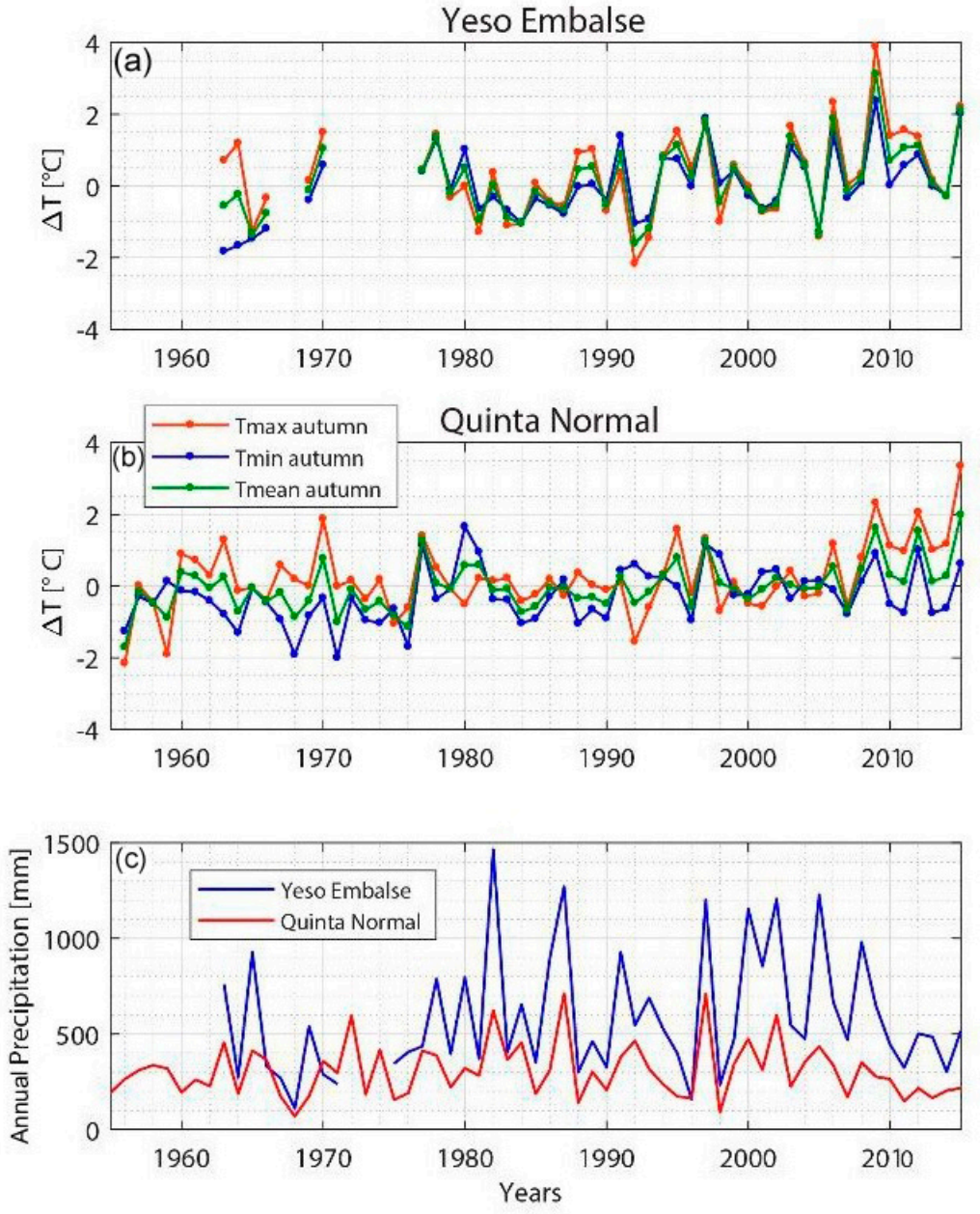

Figure S3. (**a**) Annual temperature anomalies at El Yeso weather station and (**b**) and Quinta Normal station between 1955 and 2015. Significant warming trends were observed in autumn (maximum, minimum and mean values). (**c**) Annual precipitation at the El Yeso weather station between 1962 and 2015. Since 2010 an uninterrupted drought in Central Andes can be observed. Quality control and procedures of climatic dataset in Burger et al. [66].

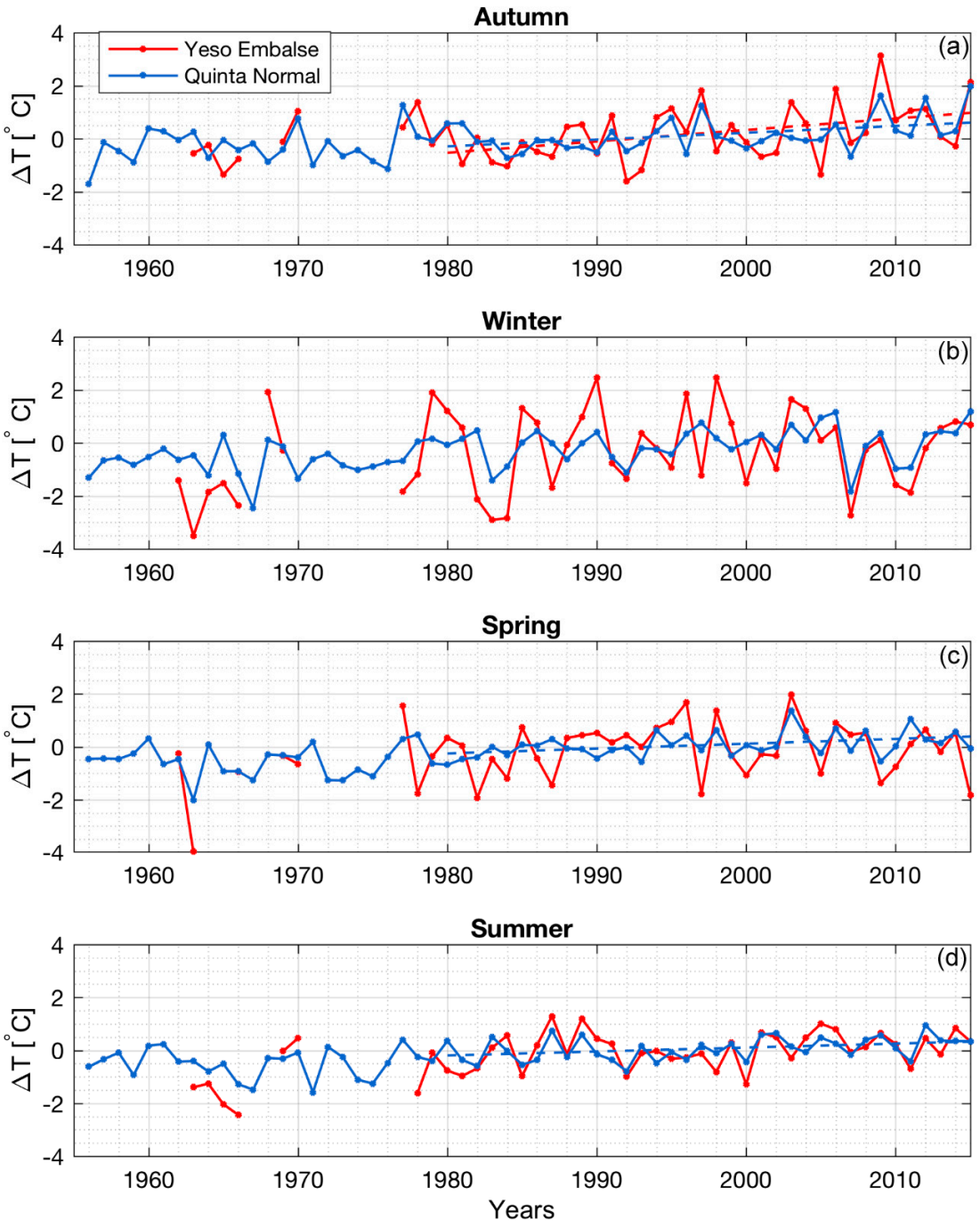

Figure S4. (**a–d**) Mean temperature anomalies per season between 1962 and 2015 in the El Yeso weather station and Quinta Normal (valley) station. Quality control and procedures of climatic dataset in Burger et al. [66].

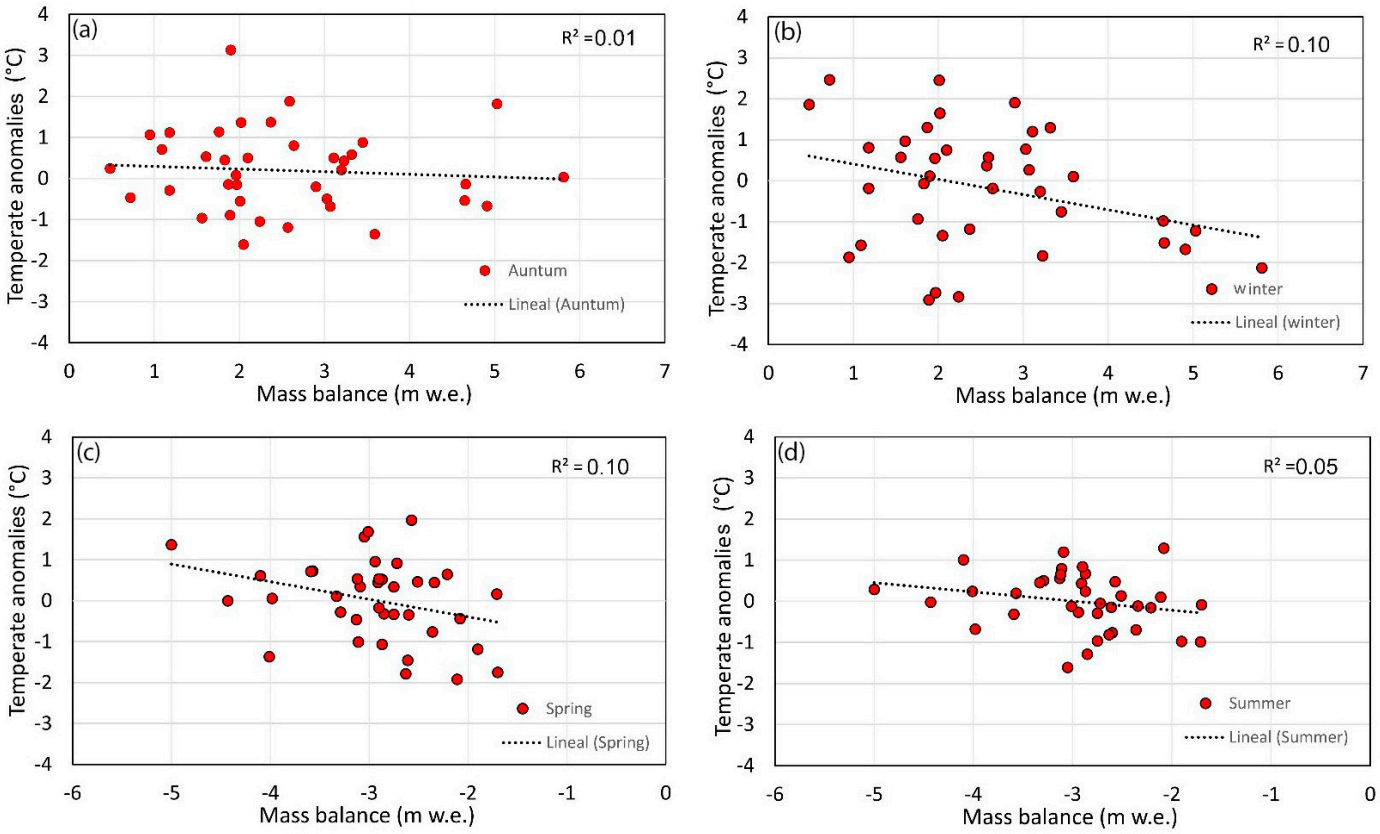

Figure S5. Correlation analysis between accumulation of Echaurren Norte Glacier and temperature anomalies in (**a**) winter and (**b**) autumn. Correlation between ablation of Echaurren Norte Glacier and temperature anomalies in (**c**) spring, and (**d**) summer.

	Quinta Normal		El Yeso	
	Trend (ºC/decade)	**pvalue**	**Trend (ºC/decade)**	**pvalue**
Autumn	0.26	0.01	0.43	0.008
Winter	0.13	0.21	0.09	0.67
Spring	0.18	0.009	0.04	0.79
Summer	0.15	0.03	0.16	0.11

Table S1: Seasonal temperature trends between 1980 and 2015, calculated using a linear least square fit. Quality control and procedures of climatic dataset in Burger et al. [66].