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Paleoclimatic reconstruction during the Little Ice Age in the Llanganuco basin, Cordillera Blanca (Peru)

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The Equilibrium Line Altitude (ELA, m) is a good indicator for the impact of climate change on tropical glaciers , because it varies in time and space depending on changes in temperature and/or precipitation.The estimation of the ELA and paleoELA using the Area x Altitude Balance Ratio method (AABR; Osmaston, 2005) requires knowing the surface and hypsometry of glaciers or paleoglaciers (Benn et al. 2005) and the Balance Ratio (BR) correct (Rea, 2009).

In the Llanganuco basin (~ 9°3´S; 77°37´W) there are very well preserved moraines near the current glaciers front. These deposits provide information to reconstruct the extent of paleoglaciers since the Little Ice Age (LIA) and deduce some paleo-climatic variables.

The goal of this work has been to reconstruct the paleotemperature (°C) during LIA, deduced from the difference between ELA $AABR_{2016}$ and paleoELA $AABR_{LIA}$.

The paleoclimatic reconstruction was carried out in 6 phases: Phase 1) Development of a detailed geomorphological map (scale 1/10,000), in order to identify glacial landforms (advance moraines and polished rocks) which, due to their geomorphological context, can be considered of LIA, so palaeoglaciers can be delimited. Current glacial extension was done using dry season, high resolution satellite images. Phase 2) Glacial bedrock Reconstruction from glacier surface following the GLABTOP methodology (Linsbauer et al 2009). Phase 3) 3D reconstruction of paleoglacial surface using GLARE tool, based on bed topography and flow lines for each defined paleoglacial (Pellitero et al., 2016). As perfect plasticity model does not reflect the tension generated by the side walls of the valley, form factors were calculated based on the glacier thickness, lateral moraines and the geometry of the valley following the equation proposed by Nye (1952), adjusting the thicknesses generated in the paleoglacial front. Phase 4) Calculation of BR in a reference glacier (Artesonraju; 8° 56'S; 77°38'W), near to the study area, using the product BR = b • z • s, where BR= Balance Ratio; b= mass balance measured in fieldwork 2004-2014 (m); z= average altitude (meters) and s= surface (m^2) of each altitude band of the glacier (with intervals of 100 m

altitude). A value BR = 2.3 was estimated. Phase 5) Automatic reconstruction of the ELA $AABR_{2016}$ and paleoELA $AABR_{LIA}$ using ELA Calculation tool (Pellitero et al. 2015) after 3D reconstruction of the glacial and paleoglacial surface in phases 2 and 3. Phase 6) Estimation of paleotemperature during LIA by solving the equation of Porter et al. (1995): ΔT (°C)= $\Delta ELA \cdot ATLR$, where ΔT= air temperature depression (ºC); ΔELA = variation of ELA AABR 2016-LIA and ATLR = Air Temperature Lapse Rate, using the average global value of the Earth (0.0065 °C/m), considered valid for tropics.

The results obtained were: ELA $AABR_{2016}$= 5260m, paleoELA $AABR_{LIA}$= 5084m, and ΔT = 1.1 °C. The reconstruction of air paleotemperature is consistent with different studies that have estimated values between 1–2 °C colder than the present, with intense rainfall (Matthews & Briffa, 2005; Malone et al., 2015).