Glacier changes since the Local Last Glacial Maximum in the South-West slope of Nevado Hualcán, Cordillera Blanca, Peru, deduced from moraine mapping and GIS-based analysis

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INTRODUCTION

Assessing hazards and risks associated with the shrinking of ice in mountain areas is facilitated by quantitative data on present and past rates of change and by a general understanding of landforms and landscape evolution. The present study focuses on the Río Chucchún and Auquishcocha catchments above the city of Carhuaz (Fig.1). The aim was to reconstruct earlier glacial phases in the SW slope of Nevado Hualcán, in order to compile quantitative information on surface areas and Equilibrium Line Altitudes (ELAs).

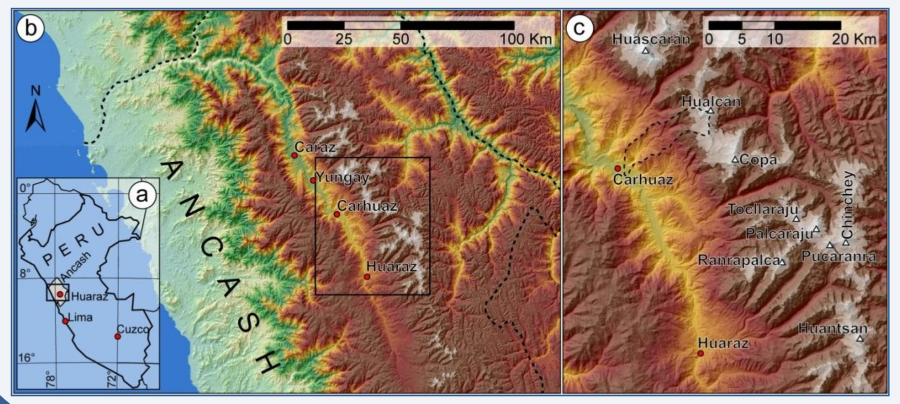

Fig.1 (a) Location of the province of Ancash; (b) Overview of the Cordillera Blanca within Ancash; (c) Detail of the Cordillera Blanca with the cities of Huaraz and Carhuaz and the Chucchún river catchment as the main study site (dashed line) (ASTER GDEM2, color shaded relief).

ELA CALCULATIONS

The Equilibrium Line Altitude (ELA) is the theoretical contour line dividing the accumulation and the ablation zones, where net mass balance is zero. We used four methods to calculate the ELAs (Table2): 1) the mid-range elevation, 2) the Accumulation Area Ratio (AAR), 3) the Area x Altitude (AA) and 4) the Area x Altitude Balance Ratio (AABR). The results differ by up to 550m from one method to another, with the characteristic tropical AAR=0,82 and mid-range elevation with the bergschrund as the highest point providing lowest/most realistic values and AABR providing highest and less realistic values (Table2).

AAR method
- under steady-state conditions
- accumulation area of the glacier occupies a fixed proportion of the entire glacier area
- AAR values ranging from 0,75 to 0.82 as suggested for tropical glaciers.

mid-range glacier elevation
- close correlation with ELA for a zero mass balance *(5)*.
- maximum elevation of the glacier both from the summit and from the Bergschrund

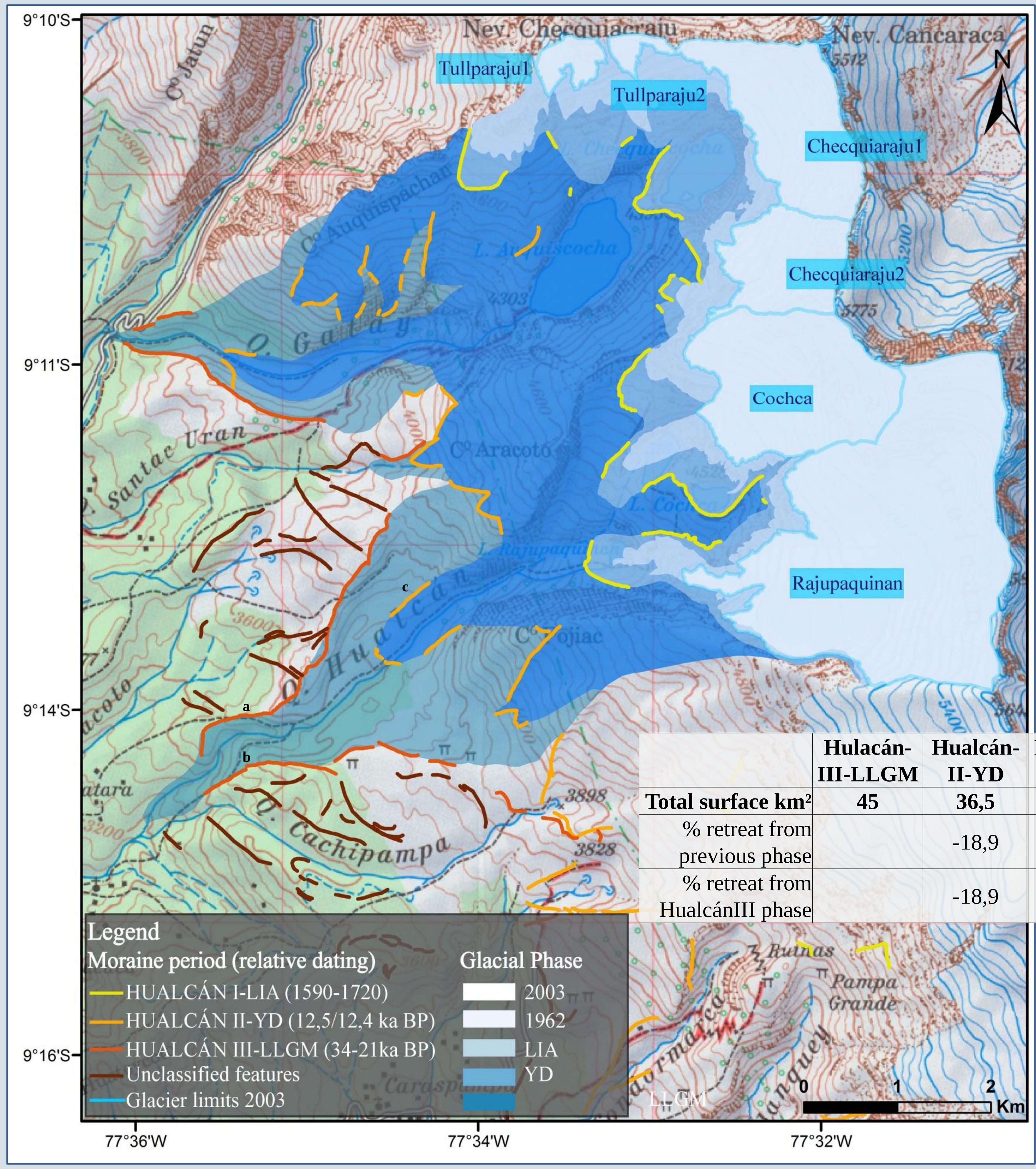

Fig.2 Moraine mapping for Hualcán I, II and III advances, and reconstruction of glaciers in five glacial phases (base map: Alpenvereinskarte 1:100.000). The relative dating of moraines is indicated based on previous studies from different authors in the Peruvian Andes (see references). The total surface area of the group of glaciers decreases along the period studied. Letters in black correspond to the moraines shown in Fig.3.

	Hualcán-III-LLGM	Hualcán-II-YD	Hualcán-I-LIA	1962	2003
Total surface km²	**45**	**36,5**	**21**	**16,8**	**13,7**
% retreat from previous phase		-18,9	-42,5	-20	-18,5
% retreat from HualcánIII phase		-18,9	-53,3	-62,7	-69,6

Table 1 Surface area of the five glacial phases mapped in Fig.2, and percentages of retreat from previous phase and with respect to Hualcán-III.

ELAs SW Slope Nevado Hualcán 2003

GLACIER	ELA AAR[1]	ELA AAR[2]	ELA Mid-range elevation		ELA AA (UGRH glacier inventory)	ELA AABR
	AAR[1] = 0,75	AAR[2] = 0,82	Summit	Bergschrund		
Rajupaquinan	4940	4890	5298	5011	5269	5443±31,5
Cochca	4845	4800	5336	4889	5182	5334±25,5
Checquiaraju2	4960	4920	5274	5084	5172	5255±20
Checquiaraju1	4820	4780	5052	4916	4988	5017±17
Tullparaju2	4945	4930	5094	4976	5017	5010±5,5
Tullparaju1	5010	4990	4991	5068	5104	5135±7
Mean for group	4904	4870	5174	4991	5122	5207

AAR[1]: Kaser & Georges (1997) AAR[2]: Kaser & Osmaston (2002)

Table 2 Results from ELA calculation through 4 different methods. The altitude of the ELA varies from 80m (glacier Tullparaju2) to 550m (glacier Rajupaquinan) between the different methods. The ELA-AABR results show the median ELA using BR values from 5 to 25.

AA method
- used by UGRH in the 2010 Peruvian glacier inventory.
- $ELA = \sum z*a / A_t$ (z=mean altitude of each contour belt; a=area of each contour belt; A_t=total area of the glacier

AABR method
- Principle: parts of a glacier which are far above or below the ELA have greater spot net balances
- Mass balance of distant areas is weighted by more than areas that are close to the ELA.

MORAINE MAPPING AND GLACIER RECONSTRUCTION

Moraine mapping was used for paleo-glacier reconstruction. Relative dating of moraines was carried out using previous work on the Peruvian Andes. Paleoglaciers were reconstructed by following the position of the moraines (Fig.2): Hualcán-I-LIA (Little Ice Age), XV-XVIIIth cent. *(7)*; Hualcán-II-YD (Younger Dryas), ~12,5 ka BP *(2)*; and Hualcán-III-LLGM (Local Last Glacial Maximum), 34-21ka BP *(1,6)*. Glaciers in 1962 and 2003 were delimited through photointerpretation. The results show a decrease in the surface area of 19% for Hualcán-II-YD, 53% for Hualcán-I-LIA, 63% for 1962, and 70% for 2003, when compared to Hualcán-III-LLGM (Table1).

Fig.3 View of the Pampa de Shonquil (3600m asl) and the moraines from Hualcán-II-YD (light orange) and Hualcán-III-LLGM (dark orange) glacial phases. Letters in black correspond to the moraines in the central map.

CONCLUSIONS

The present work shows a strong glacier shrinkage in the SW slope of Nevado Hualcán throughout the period under study. Assuming that those changes are due only to changes in temperature warming can be estimated to be around 3ºC since LLGM and 0.8ºC since the maximum glacier extent of LIA. These values are close to the mean global temperature change during the corresponding intervals.

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