Supplementary File to 'Multi-decadal glacier area and mass balance change in the Southern Peruvian Andes'

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S1 – Landsat-2 scenes used

Scene ID	Date acquired	Region
LM02_LT1TP_002070_19750729_20200908_02_T2	29th July 1975	Vilcanota
LM02_LT1TP_003070_19750730_20200908_02_T2	30th July 1975	Vilcanota
LM02_LT1TP_004069_19750731_20200908_02_T2	31st July 1975	Vilcanota
LM02_LT1TP_004069_19750625_20180425_01_T2	25th June 1975	Urubamba
LM02_LT1TP_003069_19750730_20180426_01_T2	30th July 1975	Vilcabamba & Urubamba
LM02_LT1TP_004069_19750731_20180426_01_T2	31st July 1975	Vilcabamba & Urubamba

All orthorectified Landsat-2 Tier 1 Level-1 Precision Terrain (L1TP) scenes at 60 m spatial resolution were downloaded from Earth Explorer.

S2 – Volume change extended methods

All ASTER Level 1A (L1A) data over each of the studied regions were downloaded from NASA Earthdata. L1A data ware raw unprocessed data without applied geometric and radiometric correction and are acquired at 15 m spatial resolution. These L1A images were then converted into DEMs using the AMES Stereo Pipeline. We used the following parameters:

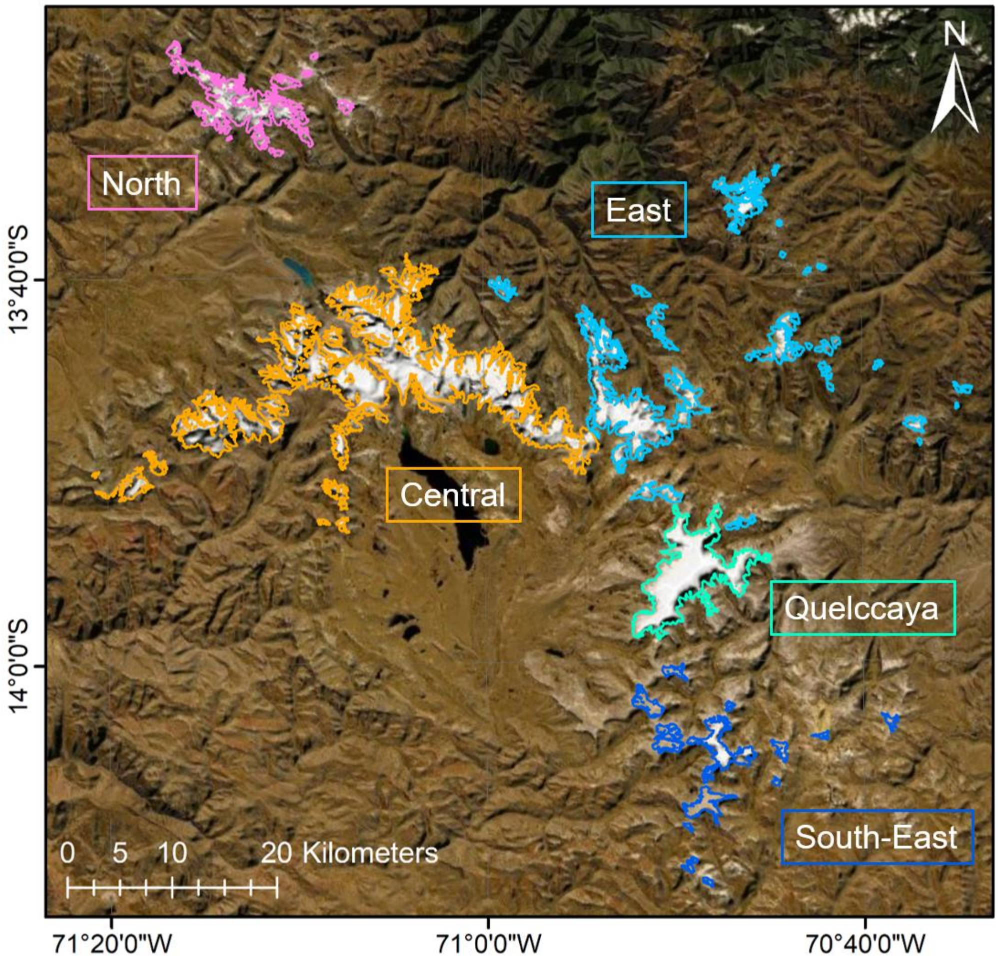
- --corr-seed-mode = 2
- --disparity-estimation-dem = TanDEM-X tile
- --disparity-estimation-error = 6
- --corr-kernel = 7 7
- --tr = 0.00027 (spatial resolution = 30 m)

DEMs that were successfully generated were subsequently aligned using *demcoreg* (Nuth and Kääb, 2011) to a TanDEM with a third-order polynomial to correct for planimetric and altimetric shifts. This alignment procedure was only conducted over stable areas, and so excluded glacierised areas using the RGI outlines within *demcoreg*. DEMs and associated metadata were then uploaded to Google Earth Engine using *geeup*.

In Google Earth Engine, calculations are performed on a pixel-by-pixel basis. All DEMs were clipped to mask elevations outside of the range of the Cordilleras (2000 m to 6500 m) to remove all highly erroneous values (e.g. from low-lying clouds). Each pixel was then clipped to only include DEMs containing values within the median ± 100 m. We trialled using the standard deviation as a filter in this step (i.e. median ± standard deviation), but in some areas the range was too high and this included too many erroneous data points. Following these filters, we extracted a single value (the median of remaining points if more than 3 data points per year, or mean of 2) per pixel per year. The date associated to this value was changed to 1st January of each year to take account of the differing use of mean / median to extract this single value.

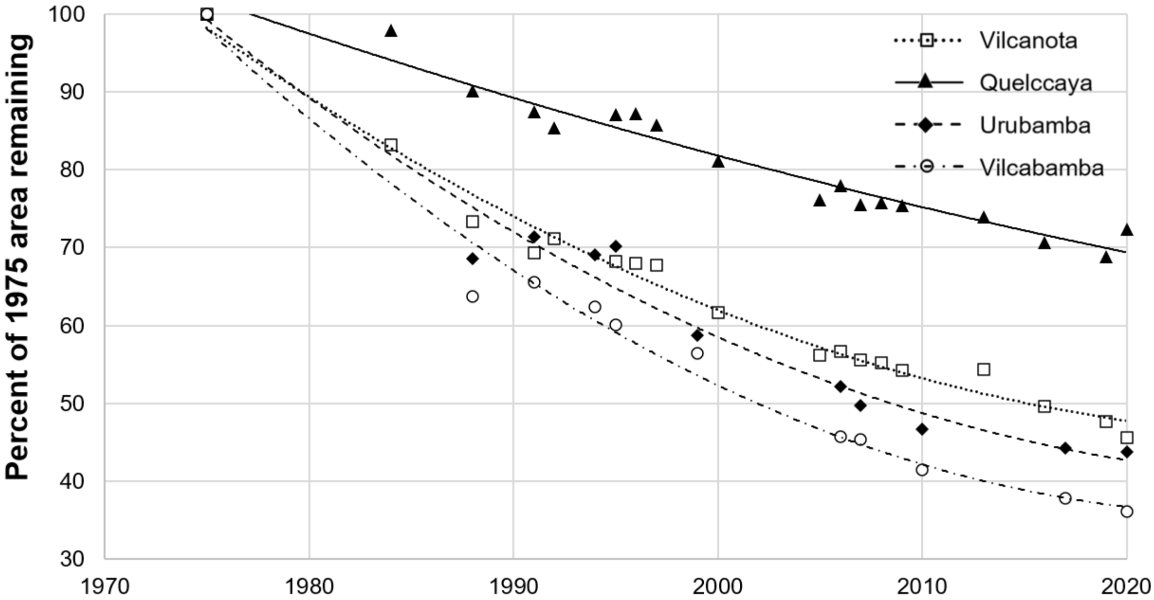
We then fit a linear regression through these values to extract rate of elevation change per year per pixel. For the Cordillera Vilcanota, this linear regression was fit to three time periods: 2000 – 2010, 2010 – 2020, and 2000 – 2020. For the Cordilleras Vilcabamba and Urubamba, we only fit a linear regression to the full time period (2000 – 2020) owing to high uncertainty. Cloud in the L1A ASTER images meant fewer DEMs were able to be produced in these regions, and so there was less data for a robust linear regression.

S3 – Sub-regions of the Cordillera Vilcanota



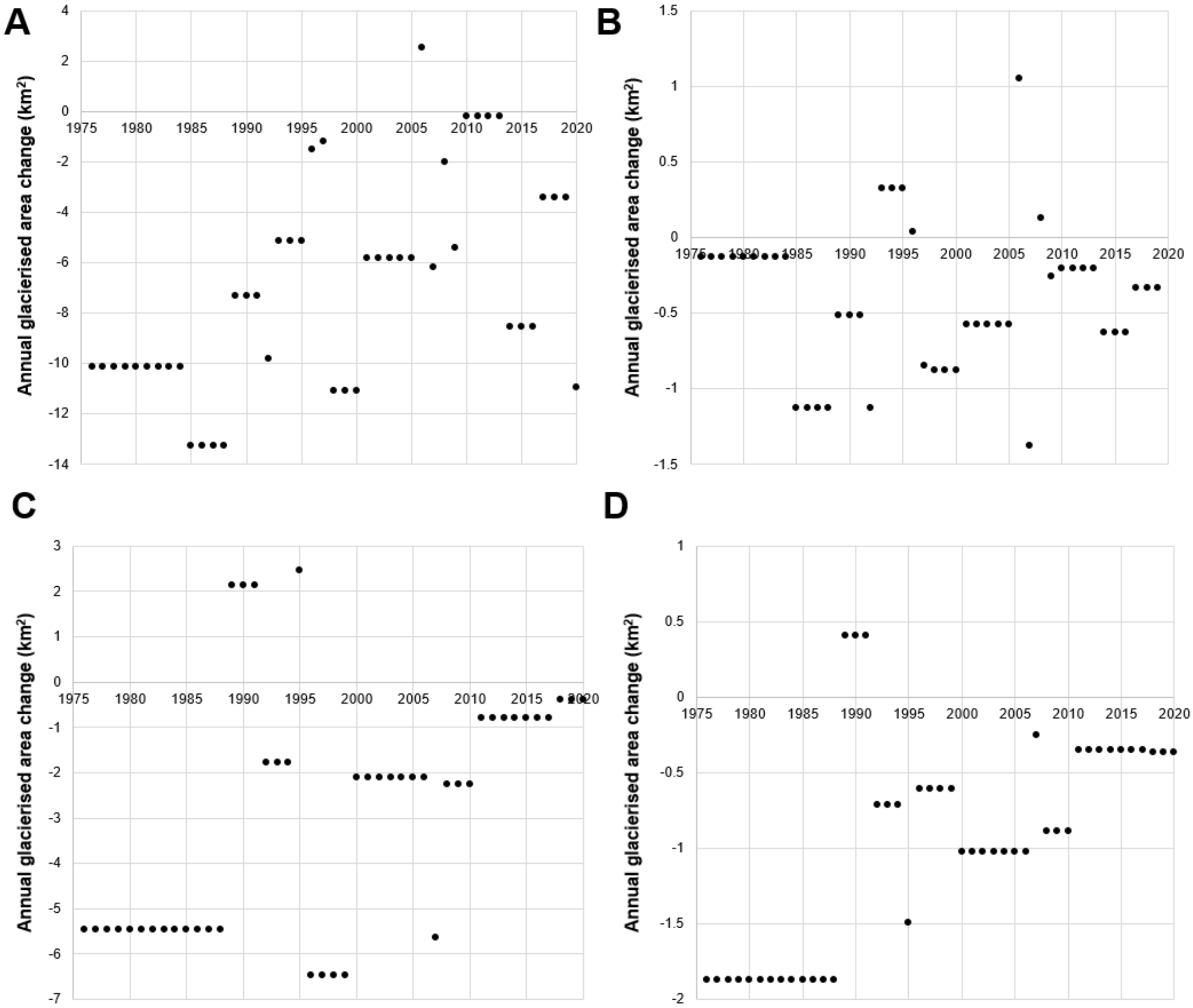
Sub-regions of the Cordillera Vilcanota used in the calculation of median glacier elevation. Glacier outlines shown here from 1984. Basemap from DigitalGlobe.

S4 - Glacier area reduction as proportion of 1975 area



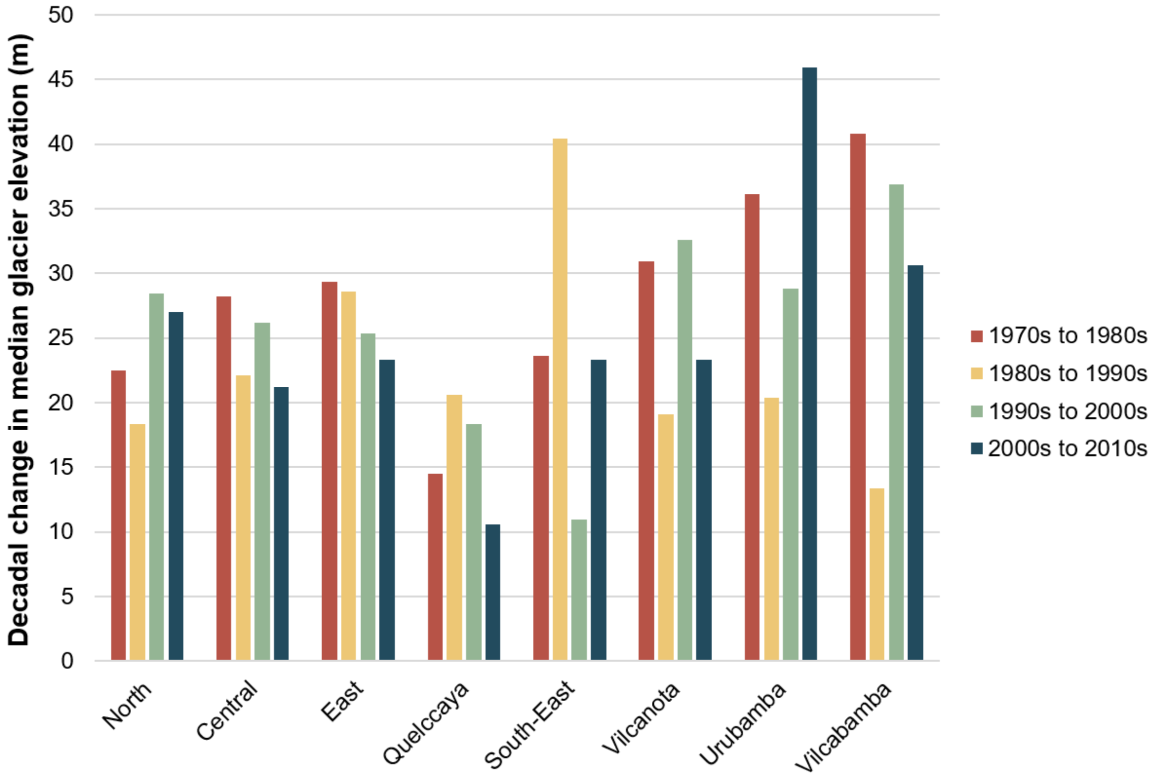
Area change of the Southern Peruvian Cordilleras as a percentage of their original (1975) glacierised area.

S5 – Mean annualised rate of glacier area change



Mean annual rate of ice area change over the A) Cordillera Vilcanota, B) Quelccaya ice cap, C) Cordillera Vilcabamba, and D) Cordillera Urubamba.

S6 – Decadal rates of change in area-weighted average of regional ELA



Decadal change in median glacier elevation through time for each region. North, Central, East, Quelccaya, and South-East are sub-regions of the Cordillera Vilcanota (S3).

S7 – Full statistical tests for drivers of ice area change

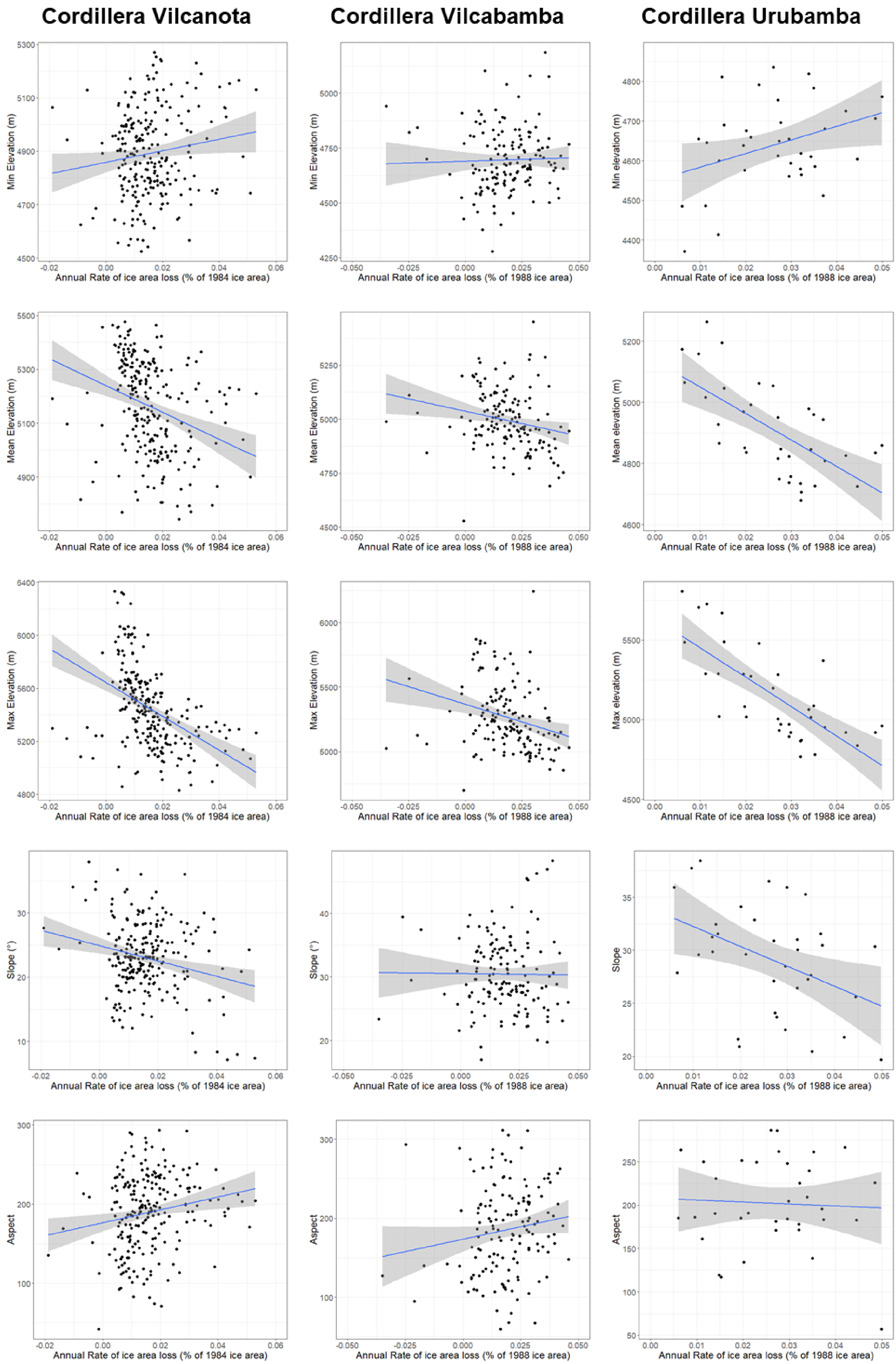
Region	Max. annual air temperature		Mean annual air temperature		Annual precipitation		Number of frost days		Mean elevation	
	R	*p*	*R*	*p*	*R*	*p*	*R*	*p*	*R*	*p*
Vilcanota	-0.576	9.14×10^{-5}	-0.514	0.000962	0.193	0.0331	0.361	0.00891	-0.233	0.000311
Vilcabamba	-0.338	0.00414	-0.277	0.0287	-0.163	0.179	0.305	0.0102	-0.161	0.0449
Urubamba	-0.576	0.000171	-0.446	0.00388	-0.156	0.0816	0.370	0.00285	-0.578	0.000177

Region	Max elevation		Min elevation		Aspect		Slope	
	R	*p*	*R*	*p*	*R*	*p*	*R*	*p*
Vilcanota	-0.394	3.88×10^{-10}	-0.169	0.00937	0.174	0.00762	-0.269	2.83×10^{-5}
Vilcabamba	-0.241	0.00240	0.0803	0.319	-0.0482	0.550	-0.107	0.183
Urubamba	-0.677	4.27×10^{-6}	0.368	0.0252	0.0125	0.942	-0.301	0.0703

Analysis of correlations exclude the 1975 data point for ice area as this does not overlap with the climate dataset which begins in 1980. Climate data correlated directly against ice area measurements. Topographic data correlated against rate of ice area change as a proportion of 1984 (Vilcanota) or 1988 (Vilcabamba / Urubamba) area.

S8 – Full statistical tests for drivers of ice area change

Grey areas represent 95% confidence interval for regression.


Cordillera Vilcanota
Cordillera Vilcabamba
Cordillera Urubamba
Min Elevation (m)
Min elevation (m)
Mean Elevation (m)
Mean elevation (m)
Max Elevation (m)
Max elevation (m)
Slope (°)
Slope
Aspect
Annual Rate of ice area loss (% of 1984 ice area)
Annual Rate of ice area loss (% of 1988 ice area)