Andean Permafrost in Taluses and Blockslopes in the Agua Negra Catchment, Argentina - Distribution and Hydrological Significance

Melanie Stammler, Diana A. Ortiz, Tamara Koehler, and Lothar Schrott

in acknowledgement of the cooperation with
Dario Trombotto (IANIGLA-CONICET, Mendoza) and
Cristian Villarroel (CIGEOBIO-CONICET, San Juan).

Introduction

- The Dry Andes in central and northern Argentina are characterized by the development of an extensive periglacial environment[1].
- Periglacial landforms in the dry Andes store essential water resources. This is of hydrological significance for the high-mountain system and being subject to climate change impact.[2]
- Since permafrost bodies show a delayed reaction to changing climatic conditions compared to glaciers, the hydrological significance of permafrost landforms will become even more relevant in the future, and with that issues like water scarcity and water quality.[3]

[1] Schrott & Götz (2013)
[2] Halla et al. (2021)
[3] Masiokas et al. (2020); Trombotto and Borzotta (2009); Schrott (1998)

Study area

- Typical distribution of (peri)glacial features[1] in the upper Agua Negra catchment in the semi-arid Andes of Argentina
- Catchment hosts major water storages for irrigation, industry and domestic use in the Andean foreland.

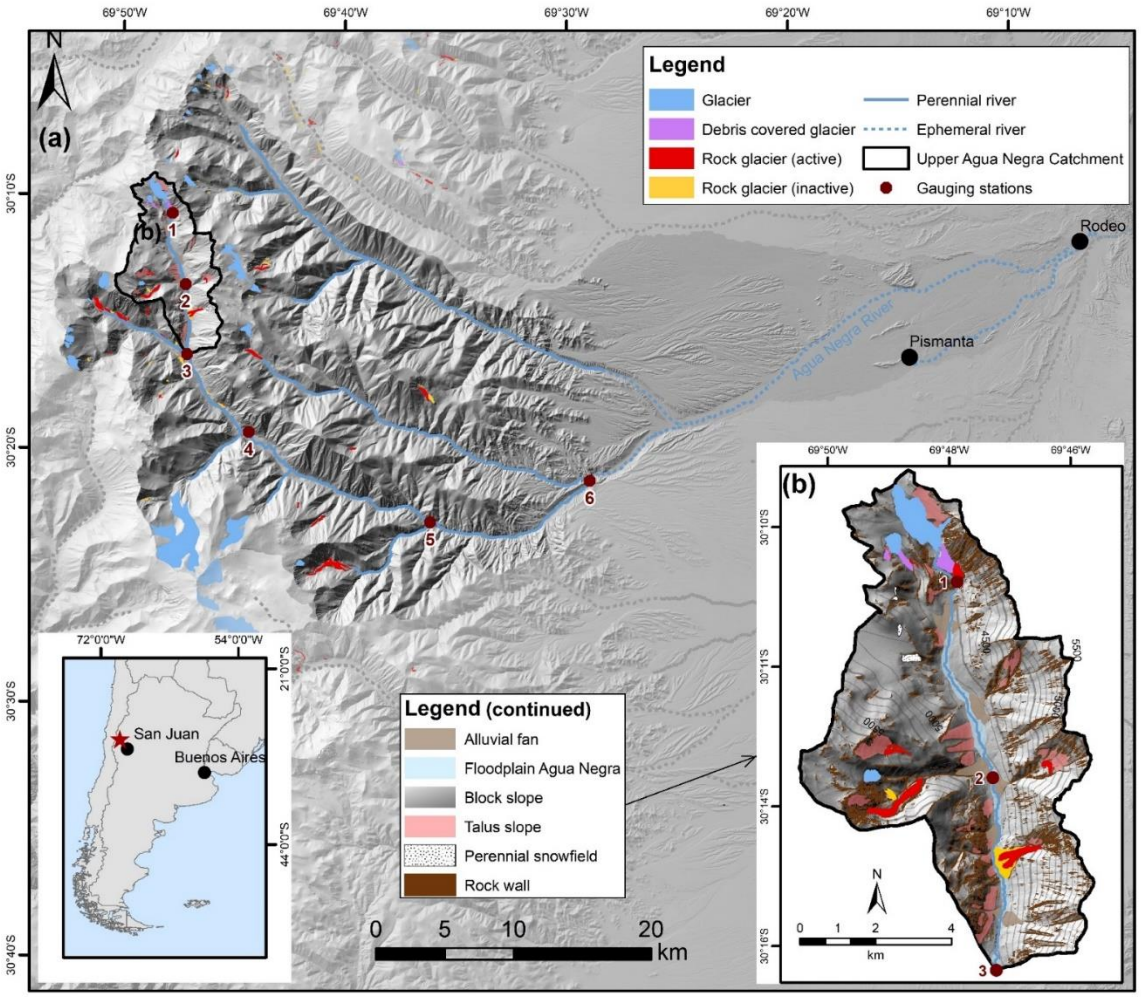


Figure 1: Map of the study area showing the Agua Negra catchment, San Juan Province / Argentina[2]

[1] IANIGLA-CONICET (2018)
[2] Hillshade based on TanDEM-X data; Mapping of glaciers, rock glaciers and debris covered glaciers by IANIGLA-CONICET (2018)

Block- and talus slopes

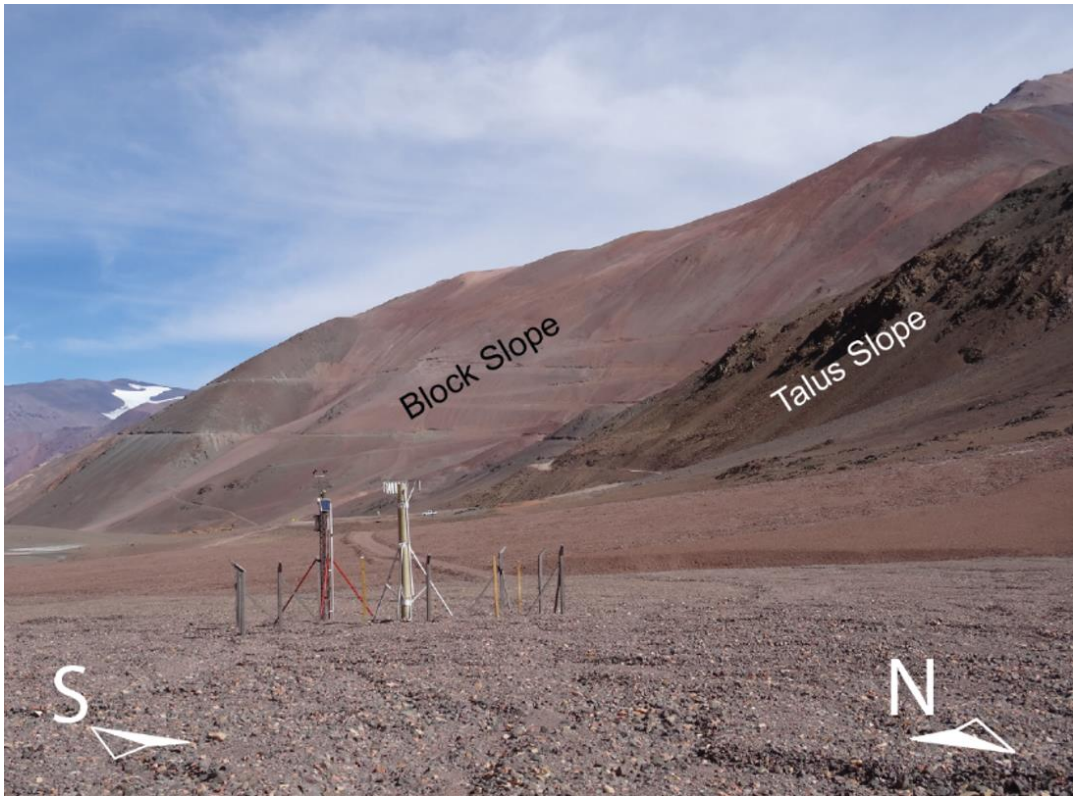


Figure 2: Block- and talus slope in the Upper Agua Negra catchment, San Juan Province / Argentina[2]

- Rock glaciers are the most visible expression of permafrost in the vegetation-free landscape[1],
- Blockslopes, talus slopes, and protalus ramparts are the most dominant landforms above 4000 m altitude (approx. surface coverage 73%).

[1] cf. Blöthe et al. (2021); Halla et al. (2021)
[2] Own figure, photo: Lothar Schrott 2019

Research objective

Permafrost bodies act as water storages in an area scarce in precipitation. It is essential to detect and quantify this resource. While research on rock glaciers has gained in prominence, research on talus- and block slopes is lacking. **We hypothesize that above 3900m, these landforms contain a so far neglected amount of ice.**

The research will enrich our knowledge on the hydrological importance of Andean permafrost by the following approach:

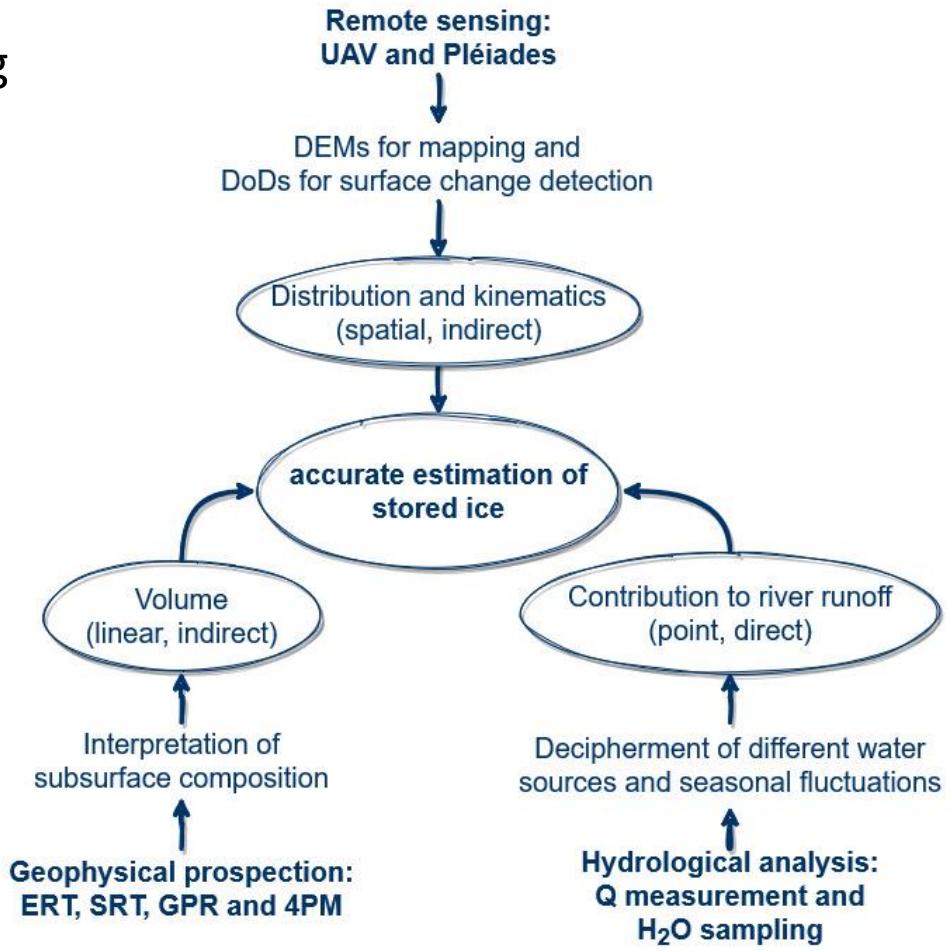


Figure 3: Multi-method approach used in this study[1]

[1] own figure

Aims and Methods: Remote sensing

Repeated drone surveys to gain high-resolution optical data of key sites

Aim: insight and monitoring opportunities for changes in permafrost conditions in a challenging terrain; detection of e.g. permafrost degradation and landform kinematics.

Methodology and products: calculate digital elevation models (DEMs) of difference to analyse surface changes.

Improvement: increase of spatial resolution by DEM creation based high resolution optical tristereo data, namely Pléiades.

Figure 4: Phantom 4 RTK drone and controller used in the Agua Negra catchment.

Figure 5: Example for ground control points used to georeference UAV-based DEMs

Aims and Methods: Geophysical Prospection

Repeated 2D profiles of Electrical Resistivity Tomography (ERT), Seismic Refraction Tomography (SRT), and Ground Penetration Radar (GPR) along cross and longitudinal profiles.

Aim: estimation of active layer thickness and permafrost distribution; detection of taliks and water flows.

Methodology and products: calculation of ice contents and water storage capacities through 4 Phase Modelling approach;
detailed information about the internal structure.

Improvement: Temperature and humidity loggers in different depth along the geophysical provide cross-checking direct values.

Figure 6: Longitudinal ERT profile measured on a blockslope in the upper Agua Negra catchment

Figure 7: Setting and Installation of an iButton to record temperature at the midpoint of an ERT profile measured on a Talus slope

Aims and Methods: Hydrological Analysis

Continuous and discontinuous discharge measurements in combination with hydrogeochemical analyses along the Agua Negra river

Aim: estimation of the hydrological significance of different cryogenic landforms and their runoff contribution

Methodology and products: Detection of runoff contributions by continuous water level- and repeated salt tracer measurements using stage-discharge rating curves; hydrograph separation is supported by hydrogeochemical analyses of various water sources in the catchment

Improvement: bucket measurements; meteorological, hydrological and hydrogeochemical data from cooperation partners and local institutions

Figure 8: One of the six gauging stations continuously measuring discharge along the Agua Negra river

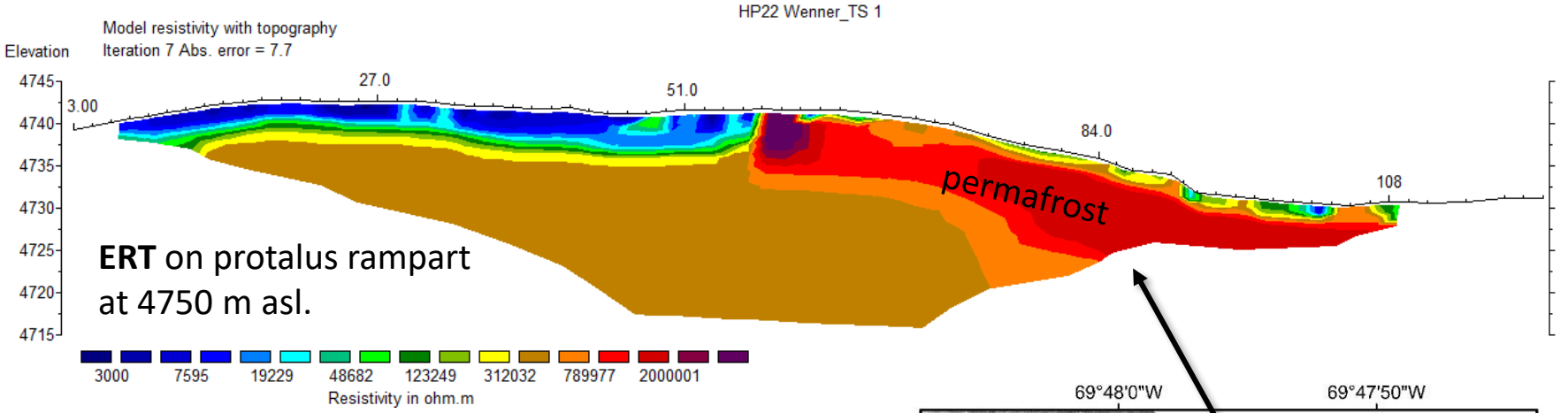
Figure 9: Repeated bucket measurements at Dos Lenguas rock glacier spring

Work in progress and preliminary results

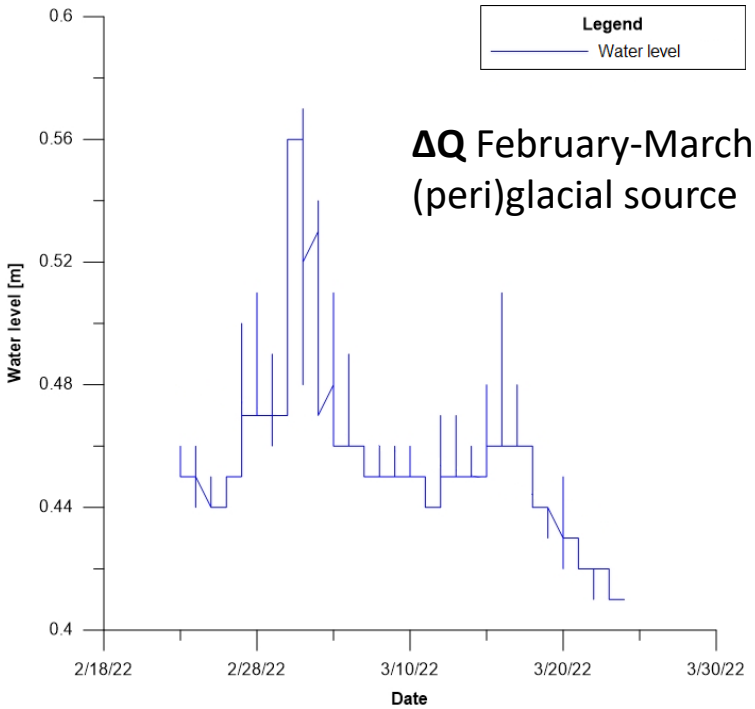
- We create UAV-based DEMs at three key sites and process the Pléiades data to obtain a catchment-wide DEM with high resolution.
- We process ERT and SRT data to get the first overview regarding the internal structure of block- and talus slopes in the area.
- We analyse and classify the preliminary results obtained with the aim of finding first indications of the presence of ice.
- We will identify the chemical footprint of 38 water samples from 38 key sites along the AN river based on isotope signatures and tracer tests in cooperation with Karlsruhe Institute of Technology (KIT).
- Continuous discharge measurements at the six gauging stations will play a central role in future evaluations once a sufficient database is available.

Based on all preliminary results we plan additional measurement sites as well as repetition of profiles for the upcoming data acquisition field trip in fall 2022.

Preliminary results



ERT on protalus rampart at 4750 m asl.



ΔQ February-March 2022, (peri)glacial source

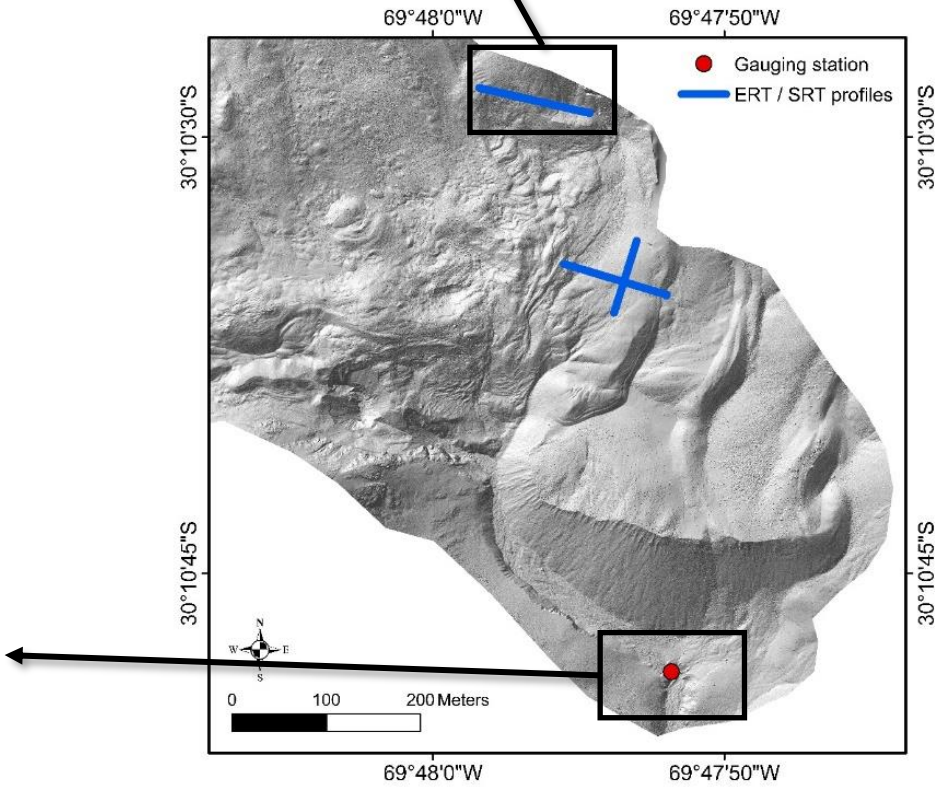


Figure 10: Compilation of some preliminary findings from the first field campaign in spring 2022

Preliminary ERT profile findings

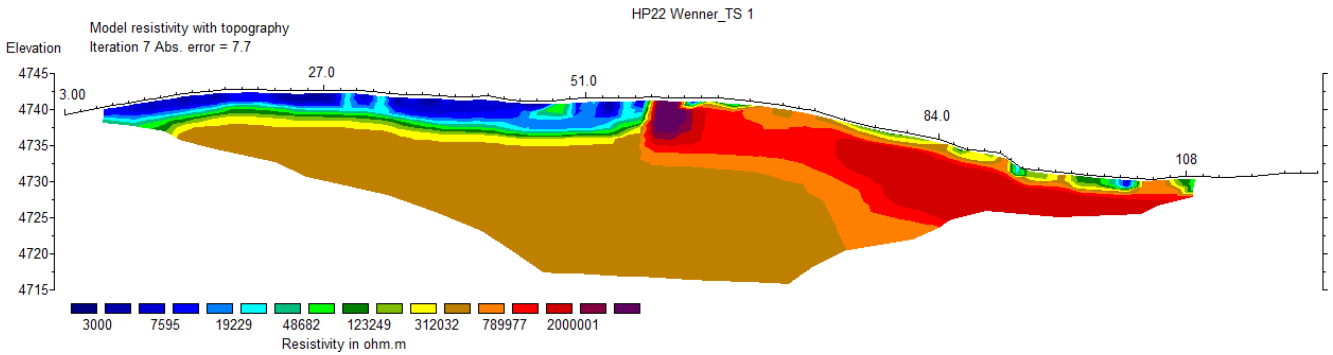


Figure 11: Shown on the right is the result of a longitudinal ERT profile at 4800 m altitude: Half of the profile extended over a talus slope (0 m - 54 m). From 54 m onwards, the profile covers a protalus rampart. Electrical resistivities in the subsurface are > 300 kohm.m, which can be interpreted as ice-rich permafrost in both landforms. An SRT profile was measured on the same location as ERT and a temperature sensor (iButton) was installed at profile meter 57. The SRT results are being processed. Seismic velocity as well as recorded temperature values are expected to confirm the presence of permafrost.
On the right, an image with the profile made on the landform in red, and the temperature recorder in green.

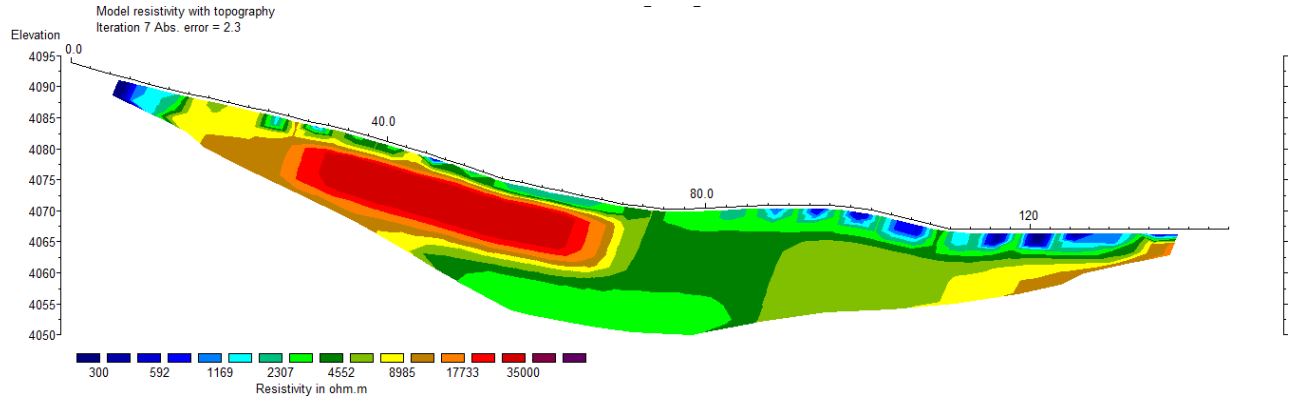


Figure 12: Vertical ERT profile measured in the lower part of a talus slope located at the lower limit of the upper Agua Negra catchment (around 4100 m asl). The electrical resistivity values (>35 kohm.m) are compatible with permafrost and its distribution is related to the base of the talus (the steepest part of the profile), as described by Lambiel and Pieracci, 2008. SRT was carried out at the same ERT location, and the data is currently processed.

Preliminary findings from hydrological analysis

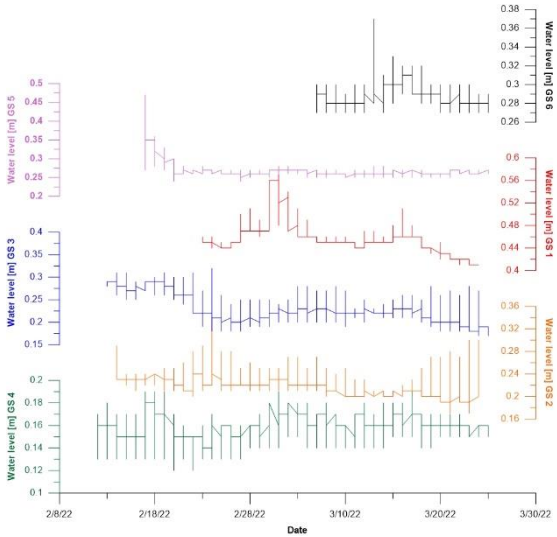


Figure 13: Continuous water level measurements at the six gauging station in February to March 2022

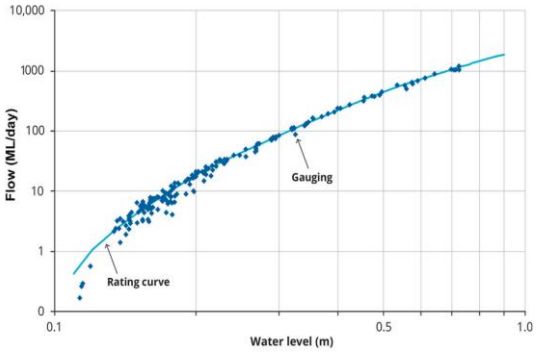


Figure 14: Exemplary stage-discharge rating curve derived from continuous water level measurements and repeated discharge measurements (e.g. with Salt tracing) (Lowe et al. 2017)

Figure 15: Additional bucket measurements on natural springs

Figure 16: Water sampling at Agua Negra glacier

Accurate estimation of the hydrological significance of regional cryogenic landforms (esp. blockslopes and taluses) in a representative semi-arid high Andean watershed

Outlook

Remote sensing

- Combined analysis of UAV-derived and Pléiades-based DEMs

Geophysical prospection

- Quantification of ice/water storages within block and taluses through the application of a petrophysical joint inversion or Four Phase Modelling approach.

Hydrological analysis

- Decipher origin and respective quantity of different water sources contributing to AN runoff

Possibility of determining with greater precision the distribution of permafrost in the arid Andes will lead to a more accurate estimation of solid-state water reserves stored in periglacial landforms in arid Andean catchments.

Contact and abstract details

Thank you for your attention!
Please be encouraged to contact

Melanie Stammler (*on behalf of all co-authors*)
Stammler@uni-bonn.de

… and follow the QR-Code for finding our abstract.

References

- Blöthe, J. H., Halla, C., Schwalbe, E., Bottegal, E., Trombotto Liaudat, D., & Schrott, L. (2021): Surface velocity fields of active rock glaciers and ice-debris complexes in the Central Andes of Argentina. *Earth Surface Processes and Landforms*, 46(2), 504-522.
- Halla, C., Blöthe, J. H., Tapia Baldis, C., Trombotto Liaudat, D., Hilbich, C., Hauck, C., & Schrott, L. (2021). Ice content and interannual water storage changes of an active rock glacier in the dry Andes of Argentina. In: *The Cryosphere*, 15(2), 1187-1213.
- IANIGLA-CONICET, Ministerio de Ambiente y Desarrollo Sustentable de la Nación (2018). IANIGLA-Inventario Nacional de Glaciares. Informe de la subcuenca del río Blanco. Cuenca del río San Juan, Pp. 62.
- Lowe, L., Szemis, J., & Webb, J. A. (2017): Uncertainty and environmental water. In: *Water for the Environment, Academic Press*, 317-344.
- Masiokas, M.H., Rabatel, A., Rivera, A., Ruiz, L., Pitte, P., Ceballos, J.L., Barcaza, G., Soruco, A., Bown, F., Berthier, E., Dussaillant, I., & MacDonell, S., (2020): A Review of the Current State and Recent Changes of the Andean Cryosphere. In: *Frontiers in Earth Science,* 8 (99), 1-27.
- Schrott, L., & Götz, J. (2013): The periglacial environment in the semiarid and arid Andes of Argentina - hydrological significance and research frontiers. In: Borsdorf, A. (Ed.): *Forschen im Gebirge. IGF Forschungsberichte*, 5, 53-62.
- Schrott, L. (1998): The hydrological significance of high mountain permafrost and its relation to solar radiation. A case study in the high Andes of San Juan, Argentina. *Bamberger Geographische Schriften*, 15, 71-84.
- Trombotto, D., & Borzotta, E. (2009): Indicators of present global warming through changes in active layer-thickness, estimation of thermal diffusivity and geomorphological observations in the Morenas Coloradas rockglacier, Central Andes of Mendoza, Argentina. In: *Cold Regions Science and Technology*, 55, 321-330.