



## **Interannual and decadal variability in glacier contribution to runoff from high-elevation Andean catchments: understanding the role of debris cover in glacier hydrology**

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Central Chile's economy relies on melt water from glaciers and snow to sustain a robust growth and agricultural and mining activities, as well as to provide drinking water to major cities. Water from glaciers is particularly relevant during dry periods, increasingly frequent and modulated by the occurrence of El Niño and La Niña episodes. These recurrent climatic events play an important role on glacier storage, runoff production and long term changes in glacier mass balance and streamflow, but their long-term effect is still little understood.

Here we present a combined data and modelling study that aims at reconstructing the climatic forcing, glacier response and runoff generation from high elevation catchments of central Chile over the four past decades. Recent modelling studies have considerably advanced our understanding of water storages and of the spatial distribution of energy, mass and water fluxes in glacierised Andean catchments. However, they all have focused on simulations of a few years or melt seasons for which extensive field datasets were available to constrain model parameters. Very little is known about long term fluctuations in glacier mass balance and the resulting changes in runoff from glacierised catchments. Debris-covered glaciers are an important element of the Andean cryosphere, are increasingly recognized as responding in a distinctive manner to climate compared to clean ice glaciers, and have the potential to affect the hydrological regimes of catchments substantially.

Here we exploit a large amount of field data collected on the Bello, Piramide and Yeso glaciers and their catchments to set up a physically-based glacio-hydrological model that can reproduce the major water and energy fluxes, storages and interactions between glaciers, snow and hydrology. The model includes modules to simulate melt under debris, avalanching and other major cryospheric processes, and we validate it with independent datasets of runoff, glacier mass balance and spatial fields of snow depth from LiDAR surveys. We then use the model to study the long term fluctuations of glacier mass balance and runoff over the past four decades, and the role of ENSO in modulating decadal trends and oscillations. Second, we use the model simulations to understand the role that debris plays on the long-term mass balance of glaciers in the region, and compare runoff regimes, seasonality and amounts from debris-covered and debris-free glaciers.

High elevation precipitation is a very large cause of uncertainty in our hydrological and mass balance simulations. Despite this uncertainty, our results show that the debris-covered Piramide glacier has a remarkably more negative mass balance compared to Bello and Yeso, due to a combination of its lower elevation and the enhancing effect of thin debris. The debris-free glaciers show consistently little losses or a slightly positive mass balance, suggesting that they might have reached a minimum size at high elevations where ablation no longer dominates.