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Dynamics of rock glaciers and debris-covered glaciers in the Central Chilean Andes over the last 50 years

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In the semiarid Central Andes of Chile at 33.5°S., mountain permafrost is widely present above 3500-4000 m asl, especially in the form of rock glaciers, which often coexist with glaciers and debris-covered glaciers. This peculiar configuration of the cryosphere involves complex and poorly known responses of its components to climate change. Our study area in the Laguna Negra catchment is part of a watershed that provides up to two-thirds of the drinking water supplies to Chile's capital Santiago (5.5 million inhabitants) during the dry summer months. The 35 km^2 watershed contains 2.3 km^2 of uncovered glaciers, 0.9 km^2 of debris-covered glacier area and 4.3 km^2 of rock glaciers, and hosts the longest series of glacier mass balance measurement in Chile (Echaurren Norte glacier). Using orthorectified aerial photographs of 1956 and 1996 and a high resolution satellite image of 2008, we mapped the geometric changes that affected the glacier and the debris-covered glacier of the Punta Negra sub-catchment during the last 50 years. Surface displacements and volume changes were estimated based on 1956 and 1996 digital elevation models (DEMs), and the total loss of water equivalent in the catchment was quantified. At a shorter time scale, rock glaciers and a debris-covered glacier are being monitored since 2004, providing insights into their kinematics and near-surface thermal regime.

The orthophotos reveal a 44.7% reduction of the uncovered glacier area between 1955 and 1996, and only small surface changes between 1996 and 2008. The volume reduction of both uncovered and debris-covered glaciers is estimated at at least 3.9 million m3 water equivalent between 1955 and 1996. The second noticeable change is the growth of the thermokarst areas on the debris-covered glacier, with the formation of new and the widening and deepening of existing melt-out depressions between 1955 and 2008. The thermal monitoring revealed that, in 2003/04, the mean annual ground surface temperature ranged from 7.9°C at 2987 m asl to 0.8°C at 4020 m asl, displaying a linear relationship with altitude similar to the air temperature lapse rate and that the snow cover lasted between 3 and 8 months. A negative winter thermal equilibrium was observed only at the highest (4020 m asl) site, suggesting the presence of perennial frozen ground underneath.

GPS monitoring of the surface displacement between 2004 and 2009 revealed horizontal velocities ranging from 0.25 to 0.5 m/yr on the rock glaciers and the debris-covered glacier. The latter is affected by stronger vertical lowering (12-22 cm/yr), which is attributed to the intense downwasting and thermokarst development.

As depicted by our study, the evolution of the cryosphere in the Central Chilean Andes during the last 50 years highlights the very different responses of glacier and permafrost to climate change. It also suggests an increasing relative importance of debris-covered glaciers and especially rock glaciers as stores of water compared to uncovered glaciers and thus ongoing changes in geomorphic and hydrological processes that still need to be investigated.