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Glaciers and their declining role in buffering current and future megadroughts in the Southern Andes

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Megadroughts are multi-year precipitation deficits that cause severe hydrological, ecological, agricultural or socioeconomic droughts, and they are increasing world-wide in duration, severity and extension. The Chilean Megadrought is among the most severe, persistent and extensive droughts on record in South America (from 2010 to present), and offers an ideal study case to understand the importance of glaciers during periods of water stress. Here, we simulate the response of glaciers in the Central Andes of Chile and Argentina to both the ongoing Chilean Megadrought and to megadroughts projected to occur by the end of the century under climate change scenarios.

We use the TOPKAPI-ETH glacio-hydrological model to simulate the evolution, mass balance and runoff of the 100 largest glaciers in the Southern Andes between 30°S and 40°S, representing a total of 78 km^3 of ice volume (63% of the total glacier volume in the region). TOPKAPI-ETH is a spatially distributed physically-based model with parameterisations of mass redistribution due to ice flow, avalanching and ice melt under debris, as well as snow albedo decay and distributed ice albedo, which are key elements to represent the impact of snowfall reduction on surface melt. We run the model at high horizontal (100 m) and temporal (3-hour) resolutions forced by gridded meteorological data. Parameters are calibrated and evaluated for each selected glacier using geodetic mass balance and surface albedo for the period 2000-2019. The model is then used to simulate the period 2000-2099 using outputs from four Global Climate Models (GCM) under a moderate (RCP2.6) and a high (RCP8.5) future greenhouse gas (GHG) emission scenario. End-of-century megadroughts are defined as the driest 10-year period during 2075-2100 for each GCM

and RCP. We use the decade 2000-2009 as a reference period, since it has been identified as a period of near-neutral glacier mass balance in the study area. The Chilean megadrought caused a precipitation deficit of −36±11% across glaciers, but total glacier runoff (sum of snowmelt, ice melt and rainfall) during 2010-2019 remained nearly unchanged (decrease of −2%) compared to the 2000-2009 reference period. These small changes were due to a 5% loss in total glacier volume that resulted in a 120% increase in total ice melt. In contrast to the relatively small changes in glacier runoff during 2010-2019, glacier runoff is projected to decrease significantly during end-of-century megadroughts compared to the reference period (2000-2009): by −10±4% under RCP2.6 and by −21±11% under RCP8.5 on an annual basis, and by −35±6% and −50±6% during summer.

Our results demonstrate that ongoing glacier retreat reduces glaciers' fundamental capacity to buffer precipitation deficits during extreme droughts, increasing water scarcity for ecosystems and livelihoods in the mountain regions of South America. Crucially, the future megadroughts will occur under substantially warmer conditions than the current megadrought, likely increasing water demand of downstream areas.