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Modelling the hydrological response of debris-free and debris-covered glaciers to present climatic conditions in the semiarid Andes of central Chile

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We investigate the main contributors to runoff of a 62 km2 glacierized catchment in the semiarid Andes of central Chile, where both debris-free and debris-covered glaciers are present, combining an extensive set of field measurements, remote sensing products and an advanced glacio-hydrological model (TOPKAPI-ETH). The catchment contains two debris-free glaciers reaching down to 3900 m asl (Bello and Yeso Glaciers) and one debris-covered avalanche-fed glacier reaching to 3200 m asl (Piramide Glacier). A unique dataset of field measurements collected in the ablation seasons 2013-14 and 2014-15 included four automatic weather stations, manual measurements of snow depth and debris cover thickness, discharge measurements at glaciers outlets, photographic monitoring of surface albedo as well as ablation stakes measurements and snow pits. TOPKAPI-ETH combines physically-oriented parameterizations of snow and ice ablation, gravitational distribution of snow, snow albedo evolution, glacier dynamics, runoff routing and the ablation of debris-covered ice.We obtained the first detailed estimation of mass balance and runoff contribution of debris-covered glaciers in this mountainous region. Results show that while the mass balance of Bello and Yeso Glaciers is mostly controlled by air temperature lapse rates, the mass balance of Piramide Glacier is governed by debris thickness and avalanches. In fact, gravitational distribution by avalanching on wet years plays a key role and modulates the mass balance gradient of all glaciers in the catchment and can turn local mass balance from negative to positive. This is especially the case for Piramide Glacier, which shows large amounts of snow accumulation below the steep walls surrounding its upper area. Despite the thermal insulation effect of the debris cover, the contribution to runoff from debris-free and debris-covered glaciers is similar, mainly due to elevation differences. At the catchment scale, snowmelt represents more than 60% of the annual contributions to runoff during both hydrological years, but ice melt can reach up to 35% during the dry year and up to 51% during summer. Both the glacier mass balance and the runoff contributors are subjected to a strong interannual variability. We suggest that such a data collection effort is essential for the correct calibration of process-based glacio-hydrological models and we encourage more in-depth studies in this direction to decrease uncertainties in present and future hydrological simulations in this region.