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The projected precipitation reduction over the Central Andes may severely affect Peruvian glaciers and hydropower production

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Abstract

Water from glaciers is crucial for the Peruvian hydropower production. Hence, we investigate the glacier-atmosphere and climate interactions in the Cordillera Vilcanota, considering scenarios of significant precipitation reductions until 2100. The glacier mass balance model ITGG-2.0 is used for analysing the energy balance components regarding the projections. The results indicate that a precipitation decrease not only affects the accumulation rate of glaciers but also influences the ablation energy availability. Therefore, glacier retreat in the Central Andes is expected to accelerate, making water availability unsustainable and likely leading to future shortages for the hydropower sector and for other water consuming systems.

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1. Introduction

Water resources are crucial for Peru's energy production, where more than 50% of the total energy is produced by hydropower plants [1]. During the dry season (austral winter), water availability of many hydropower plants is dependent on runoff from glacierized basins. The dry season contribution of glacier melt to the river Santa, Cordillera Blanca (Fig. 1b), for example, was estimated to be about 40% at catchment scale [2]. In this context, and with regard to increasing energy demands and to tensions between water users [3], studying atmosphere-glacier interactions, as well as possible influences of climate change on glacier mass balance and glacial runoff, is of great importance.

For the Tropical Andes, several studies at different spatial and temporal scales have already investigated these relations. By combining multiple data sources a massive ice loss for glaciers in the Cordillera Vilcanota, Southern Peru (Fig. 1c) was detected since 1985 [4]. However, the reaction of glaciers to climate change is complex and glaciers need a response time to find a new equilibrium. For example in the Cordillera Blanca, strong glacier retreats observed since the 1980s may in part be the response of the warming during earlier decades [5]. In some studies, glacier mass balance is modelled at catchment scale to estimate glacial runoff [e.g. 6–8] and for a limited number of glaciers in the Tropical Andes energy balance studies have been performed [e.g. 9–11]. At tropical latitudes, the seasonality of air temperature and solar radiation is low and the availability of melt energy throughout the year is dominated by other processes. Albedo determines the shortwave radiation budget [12] and sublimation was found to be an important process e.g. on Zongo glacier, Cordillera Real, Bolivia [13] and on Artesonraju glacier, Cordillera Blanca [14], during the dry season. On Zongo glacier, reduced melt rates are furthermore caused by reduced longwave emission for clear-sky conditions [15]. The seasonal variation of these processes can be related to the hygric seasonality of the tropics [16,17]. In the Cordillera Blanca, precipitation variability is the main driver of mass balance variability on interannual scale [18]. It was furthermore revealed that glacier melt calculations relying on temperature-index approaches are not suitable to model the relevant processes in tropical conditions [19].

As a consequence of the projected atmospheric warming, future severe glacier mass losses are expected in the Tropical Andes, leading to important water scarcity during the dry season once the glaciers have vanished [20]. For the 34% glacierized Llanganuco catchment, Cordillera Blanca, a strongly increased runoff seasonality for future conditions was found [6]. Results of a statistical runoff analysis by Baraer et al. [21] suggest that several watersheds in the Santa river catchment may have already passed the peak discharge.

A recent study [22] revealed that future precipitation over the Central Andes may decrease to levels never reached during the last millennium. In their study, they relate precipitation to upper level wind conditions and found that austral summer precipitation (DJF) over the Central Andes could decrease by 19-33% by the end of the 21st century. Such changes will severely affect water availability throughout the year, since hydropower, agriculture, and drinking water supply continuously rely on naturally stored water input from the austral summer period. In combination with the reduction of water input further changes in atmospheric conditions are expected.

Here, the aim is to investigate the consequences of a precipitation reduction on the melt water availability from Peruvian Glaciers. Therefore, we analyse the seasonal variation of energy sources for glacier melt for present and future conditions with the glacier mass balance model ITGG-2.0 [6]. We focus on the Cordillera Vilcanota, Southern Peru, where downstream water is used, among others, for hydropower generation.

2. Study site and data

The Cordillera Vilcanota is the second largest glacierized mountain range in Peru, located in the south of the country (about 14° S, 71° W, Fig. 1). The climate is characterised by wet austral summers and dry winters. The region comprises the Quelccaya Ice Cap, the largest tropical ice cap on earth and Laguna Sibinacocha, a 15 km long, dammed glacial lake used for dry season water provision for hydropower generation downstream. Glaciers in the Cordillera Vilcanota span an elevation range of 4700-6364 m a.s.l. and covered an area of 279 km^2 in 2009 [23]. The glaciers are subject to strong area and volume losses. While glacier area reduced 33% between 1970 and 2009 [23], estimated mass loss was about 40-45% between 1985 and 2006 [4]. At the same time new glacial lakes developed [24].

The National Meteorological and Hydrological Service of Peru (SENAMHI) maintains an automatic weather station (AWS) on Quisoquipina glacier (13.8° S, 70.9° W, 5192 m a.s.l., Fig. 1c). Here, we use records of air temperature, albedo, downwelling and upwelling longwave and shortwave radiation recorded between 2011 and 2013. Fur-