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Future changes of precipitation types in the Peruvian Andes

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In high-altitude regions, such as the Peruvian Andes, understanding the transformation of precipitation types under climate change is critical to the sustainability of water resources and the survival of glaciers. In this study, we investigate the distribution and types of precipitation on a tropical glacier in the Peruvian Central Andes. We utilized data from an optical-laser disdrometer and compact weather station installed at 4709 m ASL, combined with future climate scenarios from the CMIP6 project, to model potential future changes in precipitation types. Our findings highlight that increasing temperatures could lead to significant reductions in solid-phase precipitation, including snow, graupel and hail, with implications for the mass balance of Andean glaciers. For instance, a 2 °C rise might result in less than 10% of precipitation as solid, in regard to the present day, transforming the hydrological processes of the region. The two future climate scenarios from the CMIP6 project, SSP2-4.5 and SSP5-8.5, offer a broad perspective on potential climate outcomes that could impact precipitation patterns in the Andes. Our study underscores the need to revisit and expand our understanding of high-altitude precipitation in the face of climate change, paving the way for improved water resource management strategies and sustainable glacier preservation efforts in these fragile ecosystems.

Keywords Precipitation types, High-altitude precipitation, Climate change scenarios

Precipitation and its various types are crucial variables with significant impacts on society, climate, and hydrological processes[1]. Over the Andes regions, due to the current warming, glacier retreat is affecting water use in large-scale export-oriented agriculture, subsistence farming and pastoralism[2,3]. Socio-economic issues have an impact on mountain hydrology and, as result, on water availability[4]. This retreat is highly important since 99% of the tropical glaciers are situated in the Andes of South America and about 68.4% of them are located on Peru[5]. Additionally, across the Andes regions, Rabatel et al.[6] points out that the phase of precipitation is crucial to changes in the glacial melting process, since snowfall clearly reduces melting (albedo effect) and rainfall increases it.

About 5.8 million people are living in Peruvian Andes, and many of them are highly vulnerable to climate changes and glacier melting variability. For instance, Buytaert et al.[3] studied water supply dependence on glacier melting versus climate variability, for Quito (Ecuador), La Paz (Bolivia) and Huaraz (Peru), all Andean cities, and found that the contribution of glacier melt to the water supply is 5.3%, 61.1% and 67.3%, respectively. Hence, water sustainability is an important issue across those Andean regions in a climate change context.

In high mountain regions such as the Andes, solid precipitation (snow, graupel, and hail) can increase surface albedo and snow accumulation, while liquid precipitation (drizzle and rain) is more closely associated with runoff and infiltration[7,8]. It is well known that the effects of global warming will lead to changes in precipitation regimes, and that will include liquid/solid precipitation phases and their proportions[9]. Precipitation-type discrimination is, therefore, essential to accurately assess these impacts.

Since the information provided by rain gauges installed at weather stations is limited by giving only precipitation amounts (mm), past studies have developed methods and equations to define a threshold to separate solid and liquid precipitation using different meteorological variables such as air temperature[10], air pressure[11], dew point[12], wet-bulb temperature and relative humidity[13], while authors like Sun et al.[14] and Marks et al.[15] have

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