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Comparing model complexity for glacio-hydrological simulation in the data-scarce Peruvian Andes

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Glacierized catchments are of great importance for water supply sustaining diverse human livelihoods, economies, and cultures. Despite their importance, both glacierized headwaters and downstream areas remain poorly monitored. Nevertheless, a considerable amount of international and local research has dealt with hydrological models including different levels of complexity, data sources, and goals. In addition, the increasing availability of free software and powerful automatic model calibration tools facilitates the use of complex models even to non-expert users. As a result, models could show a good performance despite misconceptions. That is also true for the tropical Andes where low data availability and quality combined with large uncertainties on glacio-hydrological and meteorological processes prevail.

Accordingly, this study aims to identify if simple or more complex glacio-hydrological models can perform robust simulations for tropical glacier-fed basins combined with scarce data. The study case was carried out in the Sibinacocha (4,822 m a.s.l) and Phinaya (4,678 m a.s.l.) catchments, both located in the headwater of the Vilcanota-Urubamba river basin, in the Cusco region, Peru. These outer-tropical catchments are characterized by pronounced dry and wet seasons and hold a glacier extent of about 8 and 18%, respectively. Three conceptual models were implemented, in order of increasing complexity: 1) the lumped Shaman model (developed in this study), and the semi-distributed 2) HBV-light, and 3) RS Minerve. All simulations were implemented on a monthly time step from 1981 to 2010. Hydroclimatological data series were obtained from the gridded PISCO dataset at 10 km spatial resolution and two local weather stations. Furthermore, changes in glacier surface were delineated for three years (1986, 1994 and 2004) by using a semi-automatic NDSI approach based on satellite imagery. Finally, a comprehensive evaluation was performed using common measures of model performance, the associated flow signatures, and different runoff components.

Results show that all model complexities allow for an acceptable performance (R^2 > 0.65, Nash-Sutcliffe > 0.65, Nash-Sutcliffe-ln > 0.73) with small differences related to the model structure. However, more complex models require a more comprehensive calibration strategy and assessment to avoid simulations with apparently high model performance driven by inadequate assumptions. Moreover, more complex models require a better understanding of the underlying hydrological processes that is often hampered by data scarcity, limited knowledge and field accessibility in the Peruvian Andes. Results suggest that a careful calibration strategy, additional data collection, and the implementation of simple models can provide more robust simulations rather than opt for increasing model complexity. For robust hydrological modeling, a comprehensive assessment of the flow signatures and runoff components is pivotal. These findings have been incorporated into a framework that aims for expert and non-expert conducted robust glacio-hydrological simulation under data scarcity. Nevertheless, high uncertainty and limited knowledge hamper a more thorough process understanding and the improvement of related model results which illustrates the limitations of their predictive character. In such a context, additional data collection with local participatory approaches combined with policy-making for climate change adaptation and water management can benefit from approaches that support decision making under high uncertainty.