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Multi-scale temporal variability in the hydrology of a tropical glacierized watershed

G.-H. Crystal Ng (1,2), Leila Saberi (1), Rachel McLaughlin (1), Jeffrey La Frenierre (3), Andrew Wickert (1,2)
(1) University of Minnesota, Earth Sciences, United States, (2) University of Minnesota, Saint Anthony Falls Laboratory, Sciences, United States, (3) Gustavus Adolphus College, Geography, United States

Climate models predict the greatest increases in temperature at high elevations in low latitudes, making tropical glacierized regions some of the most vulnerable hydrological systems in the world. Observations already reveal decreasing discharge due to retreating glaciers in the Andes, which holds 99% of all tropical glaciers. However, the time scales over which meltwater contributes to streamflow remain highly uncertain in these settings, hindering our ability to predict how shrinking glaciers will impact future water resources. A major source of this uncertainty is the sparsity of tropical glacier monitoring: these areas typically lack resources for watershed monitoring, so our current understanding is largely limited to intensive field campaigns. How to extend these isolated snapshots to predict the overall future of tropical glacierized watersheds remains unexplored. We present a multi-method approach that includes repeat hydrochemical tracer sampling, stable isotope measurements, time series analysis of hydroclimatic variables, and integrated watershed modeling; we synthesize these to assess how contributions of glacial meltwater to stream discharge vary over time in a sub-humid watershed on Volcán Chimborazo, Ecuador. Glacier ablation occurs year-round, and even "dry" periods receive appreciable precipitation; this reduced seasonality complicates the task of identifying when and how much meltwater supplies streamflow. Mixing model analyses for five sets of synoptic water sample results spanning 2012 to 2017 show a sizable range of 28% to 62% meltwater contribution, but these samples still represent isolated times. Hydroclimatic correlations further reveal that temperature-driven melt causes hourly fluctuations in discharge, while precipitation leads to weekly variability in discharge. Watershed model simulations indicate that both discharge and melt contributions vary on a sub-monthly timescale, and that melt contributions at certain times may be even less than 28%, the lowest result from the mixing model analyses. Transport pathways explain this diversity of time scales. Tracer and model results indicate that groundwater constitutes over half of stream discharge, explaining the longer (weekly) time scale link between precipitation and discharge, while simulated surface runoff from meltwater accounts for the fast diurnal connections between discharge and melt. Meltwater may also be associated with slower transport; stable isotope results indicate that some meltwater infiltrates into groundwater systems, and the model simulates meltwater to constitute at least 10% of groundwater discharge to streamflow. Overall, our findings caution against extrapolations from isolated measurements: stream discharge and meltwater contributions in tropical glacierized systems can vary substantially at a diverse range of hourly to interannual time scales, due to both climatic and hydrogeologic factors.