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Physically-based distributed mass balance modeling of a tropical glacier: An application to backward modeling of past climate

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The use of spatially distributed (2-D) mass balance models has increased in recent years, but mostly focuses on extratropical glacier surfaces. Here we present the first application of a process-based 2-D model to an African glacier: Kersten Glacier on Kilimanjaro. Multi-year data from an automatic weather station (AWS) at 5873 m a.s.l. (500 hPa) serve to force the model. Validation variables comprise surface temperature, surface height change, snow depth, and incoming radiation - all of which indicate a good model performance. Analyses of the interannual variability in the most significant total mass budget terms (surface accumulation, melt, and sublimation), as well as in the related energy fluxes, exhibit a strong link to atmospheric moisture of a particular year. This is because net shortwave radiation (a result of both cloudiness and surface albedo) is the most variable energy flux on monthly to annual time scales. Internal accumulation (refreezing of melt water), however, shows a time lag and is strongest after a very wet year. Due to the limited validation data at lower elevations, we also perform a detailed sensitivity study by varying 17 model parameters - which yields a total mass loss estimate of 522 +/- 105 kg/m2/year under present climate conditions.

Moreover, the verified model allows us to perform backward modeling of the last maximum extent of Kersten Glacier in the 1880s, which is indicated by a well preserved terminal moraine. This step reveals decreases in precipitation (30-45%), water vapor pressure (0.1-0.3 hPa) and cloud cover (2-4 percentage units) as the most likely local climate change between late 19th century and present. Thus, the study also demonstrates how 2-D modeling can help reconstruct past climate for a remote place prior to the availability of measurements. In our case these findings have great relevance for the debate of surface versus mid-tropospheric climate change in the tropics.