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Unifying large-scale atmospheric dynamics and glacier scale mass balance without the need for scale bridging

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We present a novel combination of methods to quantify the local mass response of mountain glaciers to large-scale circulation. Previously, such multi-scale approaches bridged the mountain-induced mesoscale atmospheric circulation by statistical transfer functions or subgrid parameterizations and relied on simplified glacier mass balance (MB) models. Here we show, illustrated by climatologically contrasting seasons on Kilimanjaro (East Africa), that a process-resolving distributed MB model produces robust energy and MB patterns at the glacier surface – regardless of whether it is forced by in-situ meteorological measurements or direct (uncorrected) output from high-resolution limited-area atmospheric model (LAM) simulations, which cover an atmosphere-ocean-land domain. One great finding is that explicitly modeled clouds of the LAM can be incorporated as MB model forcing, which helps to better assess the commonly used "cloud factor" parameter in MB modeling. Diagnosing dynamical, thermodynamic and microphysical processes of the mountain-induced mesoscale circulation exemplifies how vertical gradients in local meteorological variables can be illuminated, which are in turn required for distributed MB modeling. All these results are encouraging for future research because they demonstrate that a dynamical system, which acts on very different space-time scales, can be quantified in a fully process-based way – if dynamic meteorology and glaciology are exploited in a complementary sense. This entails advantages for both forward problems (enhanced process-understanding of glacier response to climate forcing) and backward problems (extraction of more detailed climate signals from past extents of small mountain glaciers).