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Kilimanjaro ice cliff recession patterns derived from terrestrial photogrammetry

Michael Winkler (1), W. Tad Pfeffer (2), Klaus Hanke (3), Nicolas J. Cullen (4), and Georg Kaser (1)

(1) Center of Climate & Cryosphere, Department of Geography, University of Innsbruck, Austria (michael.winkler@uibk.ac.at), (2) University of Colorado at Boulder, INSTAAR, Boulder, CO, United States (tad.pfeffer@colorado.edu), (3) Surveying and Geoinformation Unit, Institute for Basic Sciences in Civil Engineering, University of Innsbruck, Austria (klaus.hanke@uibk.ac.at), (4) Department of Geography, University of Otago, Dunedin, New Zealand (njc@geography.otago.ac.nz)

Ice cliffs are intriguing features of glaciers around the world, but little is known about mechanisms of their formation and maintenance. Ice cliffs also characterize the plateau glaciers on Kilimanjaro, Tanzania (3˚S, 37˚E). Their heights range from 3 to more than 40 meters and they have at least persisted since the late 19th century when early explorers documented them. Snow accumulation is only possible on the flat parts of the plateau glaciers but not on the vertical or near-vertical cliffs. Dry calving due to ice dynamics is unlikely and ice ablation through sublimation and melt by far out weighs the negligible mass gain by deposition of water vapour. Consequently, as soon as the cliffs are established, they are forced to retreat and thus, the areal shrinkage of the glaciers on Africa's highest peak is closely linked to the existence of these cliffs. In order to extract climate change details from the glaciers on Kilimanjaro, the sensitivity of the ice cliffs to climate fluctuations must be understood.

Strikingly, the cliffs are mainly either north- or south-facing which entails at this near-equatorial site that direct sunlight either always hits the cliff faces from dawn till dusk, or not at all. The examination of the annual insolation patterns at a 25m high, south-facing sample cliff shows that it is not hit by direct shortwave radiation from March to October. During this time not enough energy is available for melting and only sublimation occurs. From November to February the cliff is sunlit 12 hours a day and its surface temperature can reach 0˚C. Melting sometimes occurs during some hours, although air temperature is almost always below freezing. Point measurements at the sample cliff reveal a 20-30 times faster retreat during the sunlit period because melting is a much more energy-efficient ablation process than sublimation.

Repeat terrestrial photogrammetric surveys have been carried out at the transition dates from the shaded to the sunlit period and vice versa. Using a calibrated DSLR camera and photogrammetric software for automatic stereo matching it was possible to derive digital surface models (DSMs) of the sample cliff with an accuracy of a few cm. The comparison of the DSMs provides a laminar picture of the changes at the cliff between the two retreat phases. Small scale variations in aspect and slope as well as alterations in the surface roughness can be quantified. Additionally, recession rates can be studied as a function of aspect, slope, height above ground, and insolation phase. These findings can be used to validate future process-based mass balance models for the ice cliff and will help to quantify the role of deformation.