LETTER

Response to Mölg et al.: Glacier loss on Kilimanjaro is consistent with widespread ice loss in low latitudes

Our paper (1) does not seek to review all potential controls on glacier mass balance (MB) but to (*i*) present ice volume-change calculations, revealing that glacier thinning now accounts for ∼50% of the ice-volume loss for the summit ice fields, (*ii*) update changes in the areal extent of the ice fields based on newer (2007) aerial photographs, and (*iii*) highlight that ice loss on Kilimanjaro is not exceptional. We disagree with Mölg et al. (2) that we inappropriately propose that Kilimanjaro's "shrinking ice fields are not unique" (1). The reduction in areal extent and ice volume (shrinking) of Kilimanjaro's ice fields is not unique; it is consistent with the well-documented widespread glacier retreat in lower latitudes. Mölg et al. (2) obfuscate the issue of Kilimanjaro's glacier recession by not differentiating between processes responsible for decreasing ice area (i.e., vertical wall retreat) and more typical MB processes acting on horizontal surfaces, where the balance is currently negative. In fact, since 2000, we have documented area-weighted plateau thinning of ∼4 m, a tremendous increase over the rate of 1 m per decade inferred from historic photographs (3) for the last century.

The use of relative versus absolute numbers does not affect our conclusions. By any measure, the glaciers on Kilimanjaro will be largely gone within decades (Fig. 1), and an earlier disappearance is likely given our result that thinning now plays an important role in total ice loss. Mölg et al.'s (2) statement regarding the differential long-term trend of glacier loss on the summit versus the slopes requires clarification. Fig. 1 (*Inset*) illustrates that, after ∼1960, their rates of area loss have been nearly identical. We acknowledge the potential of geothermal heat to influence MB, but the only evidence is extremely localized (meter-scale) impacts at or near the Northern Ice Field (NIF). We are unaware of any evidence suggesting that geothermal heat has contributed to ablation of the water-saturated Furtwängler Glacier (FG).

Aridity, through its impact on the albedo/radiation regime, is important but so is temperature and its threshold capacity to force melting. An incremental rise of surface temperature above melting (observations support multiple hours per day and year-round rises) has tremendous capacity to induce accelerated melt, which is commonly evident at the surface of all Kilimanjaro glaciers. We do not dispute the observations of "strong and widespread melting" in the 1880s (2); however, these do not invalidate the ice-core evidence that the summit of the NIF has not experienced significant melting in prior centuries (4). The evidence simply does not permit unsupportable declarations that Kilimanjaro MB processes "bear only indirect connections, if any, to recent trends in global climate" (3). One model cannot account for all of the observed behavior that reflects a complex interplay of many temporally and spatially variable environmental and glaciological controls. Finally, the only reference in the literature to Kilimanjaro as a flagship is by Mote and Kaser (3).

L. G. Thompson[a,b,1], H. H. Brecher[a], E. Mosley-Thompson[a,c], D. R. Hardy[d], and B. G. Mark[a,c]

[a]*Byrd Polar Research Center, The Ohio State University, Columbus, OH 43210;* [b]*School of Earth Science, The Ohio State University, Columbus, OH 43210;* [c]*Department of Geography, The Ohio State University, Columbus, OH 43210; and* [d]*Department of Geosciences, University of Massachusetts, Amherst, MA 01003*

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[1]To whom correspondence should be addressed. E-mail: thompson.3@osu.edu.

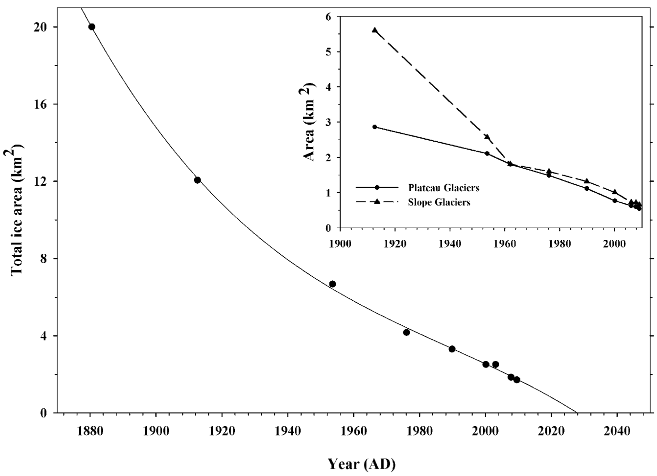

Fig. 1. All available ice area determinations for Kilimanjaro (1880 from ref. 5, 1912, 1953, 1976, and 1989 from ref. 6, 2000 from ref. 4, 2003 from ref. 7, 2007 from ref. 1, and 2009 from previously unpublished data). Smooth line is a third-order regression ($r^2 = 0.999$). *Inset* shows area determinations for glaciers on the summit and the slopes (1912, 1953, 1976, and 1989 from ref. 6).

LETTER

Glacier loss on Kilimanjaro is an exceptional case

Thompson et al. (1) present the glacier extent on Kilimanjaro for 2007 and the associated numbers of glacier shrinkage (area and thickness) along with a discussion of the roles of climatological drivers. Because the authors miss vital details of the physical processes acting on Kilimanjaro, they inappropriately propose that "these shrinking ice fields are not unique" (1). We think it is essential to acknowledge these details, because they provide an exceptional opportunity to unravel changes of multiscale linkages in the climate system (sections 6 and 7 in ref. 2).

Regarding glacier shrinkage, usage of relative numbers (1) conceals that absolute rates of area loss have decreased in recent decades (Table 1). Physically, absolute rates of area or volume loss are, however, the most meaningful manifestation of climate forcing (2). Even if outlined conversely by Thompson et al. (1), there is now agreement that slope glaciers are losing mass (522 ± 105 kg m^{-2} yr^{-1}) (2). Their long-term trend of area loss, nonetheless, differs from the plateau glaciers (3), so linear extrapolation of total glacier loss (1) leads unsurprisingly to an uncertain prediction (1). Finally, geothermal heat ablates ice in localized areas of the volcano (figure 6 in ref. 4), which requires at least consideration (e.g., ref. 2) when describing disintegration of small glaciers like Furtwängler (1).

For climatological drivers, the atmospheric physics have been established quantitatively to explain that a drier local atmosphere has much stronger effects on Kilimanjaro glaciers than a warmer local atmosphere (ref. 2 and references therein). Assuming that rising local air temperatures in Kilimanjaro's summit zone "are playing an important role" (1) lacks physical basis. Moreover, according to a study cited by Thompson et al. (1; figure 2 in ref. 5), the rise in tropical high-elevation air temperature since the 1970s approaches zero at Kilimanjaro's location. Considering mass fluxes, the undeniable fact that melting occurred in former centuries is based on the observation of "strong and widespread melting" in the 1880s by early scientists (6), and this is consistent with the physically based mass-flux reconstruction for that time (2). Therefore, concluding "the absence of surface melting" on Kilimanjaro before recent decades (1) is invalid.

In summary, there is consensus that glacier loss on Kilimanjaro continues (1–3) and that global warming has probably impacted this loss in recent decades (1, 2), most likely through regional shifts in precipitation zones that result from large-scale warming of air and oceans (ref. 2 and references therein). However, the details above show that Kilimanjaro should not be used as a flagship for contemporary glacier loss for three reasons. (*i*) A rise in local air temperature does not play an important role, because physics teaches us that atmospheric moisture is the principal driver on Kilimanjaro. (*ii*) Glacier shrinkage is not accelerating because absolute rates of total area loss have decreased recently. (*iii*) Melting at present is not unique, because melting was observed in former centuries as well. To lump Kilimanjaro into widespread glacial retreat (1) is, moreover, a waste of an exceptional proxy of climate change.

Thomas Mölg[a,1]***, Georg Kaser***[a]***, and Nicolas J. Cullen***[b]
[a]*Center of Climate and Cryosphere, University of Innsbruck, Innsbruck, 6020, Austria; and* [b]*Department of Geography, University of Otago, P.O. box 56, Dunedin, New Zealand*

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[1]To whom correspondence should be addressed. E-mail: thomas.moelg@uibk.ac.at.

Table 1. Annual rates of area change in different periods calculated from numbers in Thompson et al.'s (1) table 2 (first three columns)

Map year	Area (km^2)	No. of years	Annual rate of area change per observation period (km^2 yr^{-1})
2007.8	1.851	1.7	−0.0465
2006.1	1.930	6.0	−0.0977
2000.1	2.516	10.2	−0.0774
1989.9	3.305	13.8	−0.0628
1976.1	4.171	22.5	−0.1113
1953.6	6.675	41.0	−0.1313
1912.6	12.058		

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