Clim. Past Discuss.,
https://doi.org/10.5194/cp-2020-61-AC3, 2020

Climate of the Past Discussions

Interactive comment on "Holocene glaciation in the Rwenzori Mountains, Uganda" *by* Margaret S. Jackson et al.

Margaret S. Jackson et al.

margaret.jackson@nuigalway.ie

Received and published: 1 August 2020

We have addressed each element of Referee 3's comments below. Where comments from Referee 3 overlap with comments from Referee 1 or 2 we make note. We highlight the original referee comments in «brackets» and outline our response below each relevant passage.

«This short manuscript is clearly written and well-organized, and reports a small but interesting new set of twelve Be-10 ages from glacial moraines, boulders, and bedrock surfaces in the Rwenzori Mountains. The authors present some reasonable interpretations of the Holocene glacial history at their field sites based on their data and field observations. These results are then compared with regional climate proxies and other glacial records in East Africa, and also to tropical glacier records in South America. Overall, I think these newly reported findings from the Rwenzori are valuable and add important knowledge to the glacial and climate history of tropical East Africa. However, the number of new exposure ages is quite modest, and as such, it is difficult to extrapolate from these to make strong arguments about commonalities with Holocene glacier records in South America and pan-tropical climate forcings. I support the publication of these results after appropriate revisions, but I urge the authors to be more cautious and realistic about the limitations of inferring global-scale correlations and climate forcing mechanisms from a small data set.

More specific comments and critiques are listed below. I hope the authors find these constructive, and I encourage them to address and resolve these in order to improve their manuscript. »

We thank Referee 3 for their thoughtful comments and agree that, while our assessment of the Rwenzori data in the context of regional climate records is robust, some inferences were overly speculative in terms of the broader, pan-tropical synchrony of Holocene glacial fluctuations. With this in mind (and with similar comments from Referees 1 and 2, see replies posted), we propose to refocus the final portion of our discussion to emphasise tropical East African glacial fluctuations during the Holocene and comparisons of tropical East African glacial chronologies with local climate (i.e., terrestrial temperature and precipitation) records. We will illustrate the utility of these glacial records in studying tropical East African paleoclimate conditions.

Below we outline our responses to each of Referee 3's comments, and our proposed alterations/improvements to the manuscript in each case where applicable.

« Lines 27-28: That's probably not a fair statement these days, at least outside Africa, as there have been a number of studies and reviews of tropical glaciation in recent years. »

(Here we provide the same response as given to a similar comment by Referees 1 and

2): We agree that our statement here is blunt and needs nuance. With this statement we are referring only to the relative paucity of data on Holocene tropical glacial fluctuations relative to what is known for higher-latitude glacial fluctuations. Figure 2 in Solomina et al. (2015) provides an illustration of this point. The 'low-latitudes' in this case are 22 data entries on Holocene glacial fluctuations, including one from Papua New Guinea, three from East Africa (one at Kilimanjaro and two from Mt. Kenya), and 18 from South America. Although this is by no means "little" data for the tropics, it is much less than higher-latitude regions. For example, the same data compilation includes eight studies from Spitsbergen and 15 entries from the monsoon-influenced Himalaya (Solomina et al., 2015). Figure 2 in Solomina et al. (2015) also highlights a fundamental element of many tropical glacial chronologies, namely that many of these entries for tropical glacial fluctuations do not provide information about glacial fluctuations throughout the Holocene, but rather more limited time slices. We think tropical glacial histories are of particular interest due to the relative lack of data from the tropics (and tropical Africa in particular), a point we will clarify in the revised version of the manuscript.

« Line 68: List in chronological order. It's also curious that the Late Holocene is not regarded here as a time period of interest - especially in light of statements about this work's relevance to modern/future climate change. »

We will change this sentence to introduce the Early and Middle Holocene periods in descending chronologic order. By stating here that the warm Early and Middle Holocene are periods of particular interest, we do not mean to suggest that the Late Holocene and modern period is not of interest. However, we think that investigating the past response of glaciers to warmer conditions is especially important within the larger context of modern warming and glacial sensitivity to climate change. We will clarify this in the text.

« Line 82 / Figure 1: The satellite image in panel b is not an acceptable substitute for a proper glacial-geomorphic map. The moraines and overall topography are very hard to see. I suggest replacing with a DEM or contour map if available, overlain by a more detailed map indicating glacial features and other relevant landforms in these valleys. Without a well-labeled glacial-geomorphic map, the text descriptions of these field areas are very hard to follow. »

We will replace Panel B in Figure 2 with a hill-shaded contour map with geomorphic features highlighted. We will also add similar map-view, hill-shaded contour maps to Figures 3 and 4 to highlight valley sample locations.

« Line 93: That is very inclusive. What kind of crystalline rock, exactly? »

The rocks of the Rwenzori include Precambrian metamorphic rocks, predominantly gneisses and schists, as well as amphibolites (McConnell, 1959; Ring, 2008; Bauer, 2010). The Nyamugasani valley is composed of quartz-rich gneiss, whereas the Bujuku valley is composed on its south side by amphibolite and on its north side (including Mt. Speke) by quartz-bearing schist and gneiss. We will add this information to the updated manuscript.

« Line 111: This is the first of many citations to an in-review manuscript that is not currently accessible to reviewers. Because many interpretations here are reliant on context and support from the results in the unavailable in-review manuscript, it is not really possible to properly assess this new manuscript. In fact, the frequent references to the in-press manuscript and the importance of those findings to the interpretation of the new ages reported here raises the question of why these data were not all reported together in a single paper. »

(Here we provide the same response as given to a similar comment by Referees 1 and 2): We agree that citing a paper not yet available to the public (Jackson et al, in review) at the time of submission was not ideal. This paper is now accepted for publication in Quaternary Science Reviews (QSR) and will be cited as Jackson et al. (2020). We provide a web link to the published journal article here [https://www.sciencedirect.com/science/article/pii/S0277379120304170].

The paper referred to (i.e., Jackson et al., 2020) reports and interprets a Rwenzori glacial chronology for late-glacial time (∼16-11 ka). We intentionally split off the data in the CP manuscript because it deals with a Rwenzori glacial chronology for the Holocene. We felt that the late-glacial and Holocene data required quite different backgrounds and understanding of regional and global climate conditions and dynamics, and the implications of these datasets were different in geographic and climatic scopes. As mentioned above, the number of new 10Be ages presented in the CP manuscript, while small, still greatly increases what is known about Rwenzori glaciation during the Holocene and is an important contribution to existing East African records.

« Line 123: I assume these calendar ages are recalibrated from the original radiocarbon data using updated calibration curves, but the details of the calendar age estimation need to be explained here. »

We recalculated the original published 14C ages using the IntCal13 radiocarbon curve (Reimer et al., 2013) and the Calib 7.1 calculator (Stuiver et al., 2020). Ages are reported as the midpoint age, with 2-sigma uncertainty. We will make note of the radiocarbon age calibration and presentation and expand upon this in the Methods section.

« Line 190: How is the landslide dated? How reliable is that age? »

The landslide is dated using10Be dating of boulder surfaces on the landslide. Three 10Be ages from boulders near the toe of the landslide yielded ages between ∼11 and 12 ka, with two samples returning near-identical ages of ∼11 ka. These data were first reported in the Dartmouth College Senior Honors Thesis of Cavagnaro (2017). The data are also in the Jackson et al. (2020) available here: [https://www.sciencedirect.com/science/article/pii/S0277379120304170].

« Line 229 / Table 1: Density and erosion columns can be eliminated since the values are uniform for all samples. Instead, just note these values in a footnote. Also, how close are the three boulders (RZ-12-22, 24, 25) with indistinguishable latitude-longitude coordinates? A field photo would help show the field relations. »

We include density and erosion here so that readers can easily ‘copy and paste’ these data into the online calculator used to calculate these reported exposure ages (v2 and v3 of the online calculator as described by Balco et al. (2008) and subsequently updated). We will eliminate the columns here as suggested and include them in the ‘copy-paste’ version of the table in an online supplement. We will include additional field photos of this moraine in Figure 3 to help aid in reader understanding and interpretation of the landform and the samples collected/discussed.

« Lines 241-244: It’s an odd choice to show Be-10 concentrations instead of apparent ages for the bedrock surfaces on Figure 4, even if there’s a suspicion of complex exposure scenarios. This forces readers to find the ages in Table 3 (where they are reported) to gain some sense of the exposure durations and how they fit in with the other ages on the map. Also, if isotope inheritance is the concern, then that same issue could also potentially apply to the boulder surfaces - as acknowledged in the discussion. »

(Here we provide the same response as given to a similar comment by Referee 2): We initially reported these data as ratios rather than as ‘exposure ages’ in order to prevent readers from perhaps misinterpreting the data when reviewing the figures. We note in the text that it is inadvisable to treat these bedrock ages as ‘simple’ exposure ages of single duration. However, we understand the need for clarity in the figure, and will change these show the ‘exposure age’ of these bedrock samples. We will mark these samples in the legend as ‘exposure-age equivalent’ rather than ‘yr BP’.

« Line 246 / Table 2: Why are the isotope ratios in a different table than the concentrations (and the ages, for that matter)? I suggest some consolidation of the three tables, ideally into one table if possible. The first three columns are identical in all of them, other columns can be eliminated (as noted earlier), and it’s inconvenient to have to retrieve data from individual samples spread across three different tables. Also, given that the sample ratios are just over one order of magnitude above the blanks, it is important to consider how well these blank values are known. If they are all prepared from the same spike, it appears they vary quite a bit - and are therefore known with far less certainty than implied by the analytical uncertainties on individual blanks. This is a potentially important source of uncertainty for the youngest samples that's not being properly represented. »

We included data in tables as would be required for simple 'copy-paste' use and comparison when calculating or recalculating the 10Be ages. We can consolidate the data within these tables for ease of reference within the text, and will provide data in a 'copy-paste' format in a supplement online. The ratios of the process blanks vary. The 12 samples reported here were processed in four separate batches over time, and thus reflect four separate process blanks (as listed in Table 2). We will reformat the tables for ease of use and interpretation.

« Lines 256-257: This looks to be a vague way of saying the boulder surfaces show few signs of erosion, and does not provide any useful information about the condition of the surfaces. Is it true erosion is not evident? I'm skeptical, as the sentence after this implies there may in fact be considerable erosion. Please provide more detailed descriptions of the quality and appearance of the sampled surfaces in the first paragraph of this section Also, please add some photos of the sampled boulders and surfaces - I would say at least a couple boulder/bedrock photos are required in order to show readers the sample sites. »

We will add additional field and sample photos to the manuscript in order to give a better indication of the conditions and contexts of sample surfaces. We will also expand on our description of sample surfaces and apparent erosion (or lack thereof).

« Line 276 / Figure 3: What is the vertical exaggeration in this figure? Assuming there's none, the Speke moraine would appear to be on a very steep and unstable location right beneath big cliffs that are prone to rockfall. In other words, it looks to be a risky place for exposure dating. This might not be as bad as it looks if the VE (if there is any) was turned down. »

We will add additional field and satellite photos of this site to Figure 3 in order to provide greater geomorphic context for the reader. We note that we were careful to select clasts for surface-exposure dating that occurred on the crest of the Speke moraine, were stable/rooted in till, and showed no evidence of post-depositions alteration/movement or potential deposition by direct rockfall.

« Line 301 / Figure 4: See earlier comment. It's very odd to show isotope concentrations rather than apparent ages for the bedrock in this figure. Please show the ages instead. »

(Here we provide the same response as given to a similar comment by Referee 3 above): We initially reported these data as ratios rather than as 'exposure ages' in order to prevent readers from perhaps misinterpreting the data when reviewing the figures. We note in the text that it is inadvisable to treat these bedrock ages as 'simple' exposure ages of single duration. However, we understand the need for clarity in the figure, and will change these show the 'exposure age' of these bedrock samples. We will mark these samples in the legend as 'exposure-age equivalent' rather than 'yr BP'.

« Lines 324-327: Not sure I agree with this interpretation. Steep ice-contact proximal slopes and more gentle ice-distal slopes are very typical of young / recently abandoned moraines, including those found in locations only minimally or not affected by rockfall. There's no evidence presented here ruling out the possibility of large volumes of debris transported sub- and englacially to the glacier margin as the moraine was being constructed. »

We will clarify that our suggestion of (some) rockfall contribution to the moraine is based on the presence of highly angular, apparently unweathered clasts that likely did not undergo any subglacial abraision/erosion. However, as there were some clasts that showed glacial abrasion, we infer that rockfall was not the sole source of material for the moraine.

Printer-friendly version

Discussion paper

« Lines 328-329: See earlier comment. How is it known that the sampled boulders were deposited by the glacier, rather than coming from rockfall from the upslope cliffs that came to rest in post-glacial times? »

(See prior comment/response above regarding Lines 324-327).

« Line 426: Rather than "dominate" consider replacing with "result in negative" »

We will alter the language here as suggested.

« Lines 434-436: You had said earlier that you would not use these two ages in any subsequent interpretations. If that's the intention, this speculation should be omitted here. »

We note in the text that we do not use these two boulder ages for subsequent interpretations. However, in light of the apparent similarity between the calculated exposure ages for these samples and the exposure-age equivalents for the bedrock samples upslope, we think it is necessary to remark on the similarity and the potential for these ages to reflect 'inherited' 10Be while acknowledging that a counter-argument may be made that these sample reflect a Middle Holocene readvance of ice on Mt. Weisman (absent inherited 10Be). We do not make any attempt to correlate these samples with broader paleoclimate records, or with other glacial fluctuations elsewhere in the tropics. We will make our (lack of) reliance on the ages clearer in the discussion and in this passage.

« Line 445: Replace "fact" with "interpretation" »

We will alter the language in this sentence to make clear that it is based on our interpretation/inference rather than a known 'fact'.

« Lines 511-513: This is a very far-reaching statement to support based on the modest number of new ages presented in this manuscript. The data are especially sparse for the Late Holocene; only 4 ages on one moraine segment are leaned on as being representative of the timing of Late Holocene glaciation in the East African tropics, which is a big extrapolation. And while tempting, it's an even bigger jump to then suggest these ages support a common pan-tropical climate forcing. Apart from the sparse chronology issue, there's also the uncertainty of what specific climate controls are dominating glacier mass balances in various tropical regions on separate continents and over a range of scales from regional to single-valley. The authors favor temperature as the main driver but acknowledge some major untested assumptions, hence a lingering enigma. I encourage the authors to dial it back here, and not go much further than to say their ages hint at similarities in Holocene glacial fluctuations in tropical South America and East Africa, but that a lot more age control (and more modeling, as they suggest) is needed to explore this further. »

We agree that there is certainly much more work to be done assessing the possible centennial-scale synchrony of Holocene glacial fluctuations across the tropics. We will change the tone and text to address the existing uncertainties in the comparison.

To address Referee 3's comment regarding the Late Holocene, we will make the remaining uncertainties in the timing and magnitude of regional glacial fluctuations clearer, although we note that the Late Holocene age of the Lewis Glacier moraine (∼ 210 yrs BP) dated by Shanahan and Zreda (2000) is similar to the age of the Speke moraine we report from the Rwenzori.

References:

Balco, G., Stone, J.O., Lifton, N.A. and Dunai, T.J.: A complete and easily accessible means of calculating surface exposure ages or erosion rates from 10Be and 26Al measurements. Quaternary Geochronology 3, 174-195. 2008.

Bauer, F.U., Glasmacher, U.A., Ring, U., Schumann, A. and Nagudi, B. Thermal and exhumation history of the central Rwenzori Mountains, Western rift of the east African rift system, Uganda. International Journal of Earth Sciences, 99(7), 1575-1597. 2010.

Jackson, M.S., Kelly, M.A., Russell, J.M., Doughty, A.M., Howley, J.A., Cavagnaro, D.B., Zimmerman, S.R.H., and Nakileza, B.: Glacial fluctuations in tropical Africa during the last glacial termination and implications for tropical climate following the Last Glacial Maximum. Quaternary Science Reviews 243, 106455. 2020.

McConnell, R.B.: Outline of the geology of the Ruwenzori Mountains, a preliminary account of the results of the British Ruwenzori expedition, 1951-1952. Overseas Geology and Mineral Resources 7, 245-268. 1959.

Putnam, A.E., Schaefer, J.M., Denton, G.H., Barrell, D.J., Finkel, R.C., Andersen, B.G., Schwartz, R., Chinn, T.J. and Doughty, A.M., 2012. Regional climate control of glaciers in New Zealand and Europe during the pre-industrial Holocene. Nature Geoscience, 5(9), 627-630. 2012.

Ring, U. Extreme uplift of the Rwenzori Mountains in the East African Rift, Uganda: Structural framework and possible role of glaciations. Tectonics, 27(4). 2008.

Solomina, O.N., Bradley, R.S., Hodgson, D.A., Ivy-Ochs, S., Jomelli, V., Mackinstosh, A.N., Nesje, A., Owen, L.A., Wanner, H., Wiles, G.C., and Young, N.E.: Holocene glacier fluctuations. Quaternary Science Reviews 111, 9-34. 2015.

Interactive comment on Clim. Past Discuss., https://doi.org/10.5194/cp-2020-61, 2020.