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Comment on 'Attribution of modern Andean glacier mass loss requires successful hindcast of pre-industrial glacier changes' by Sebastian Lüning et al.

R.F. Stuart-Smith [a,b,*], G.H. Roe [c], S. Li [d], M.R. Allen [a,e]

[a] Environmental Change Institute, University of Oxford, Oxford, OX1 3QY, UK
[b] Oxford Sustainable Law Programme, University of Oxford, Oxford, OX1 3QY, UK
[c] Department of Earth and Space Sciences, University of Washington, Seattle, WA, 98195, USA
[d] Department of Geography, Sheffield University, Sheffield, S10 2TN, UK
[e] Department of Physics, University of Oxford, Oxford, OX1 3PU, UK

In our previous study, 'Increased outburst flood hazard from Lake Palcacocha due to human-induced glacier retreat' (Stuart-Smith et al., 2021; henceforth S21), we found that it is virtually certain (>99% probability) that the observed retreat of the Palcaraju glacier in Peru's Cordillera Blanca cannot be explained by natural climate variability. Lüning et al. (2022; henceforth L22) claim that the numerical models used in Stuart-Smith et al. (2021) do not replicate the Andean temperature and glacier history of the Common Era, such that we provide an unsuccessful 'hindcast' of historical climatological and glacier-length changes that indicates limited glacier-length fluctuations in pre-industrial times, thus underestimating the potential contribution of natural variability to observed changes. It is our view that the claims made in L22 are based on altered data in one case, and, in others, on a selective and misleading characterisation of the existing literature of the glacial history of the region. The available glacial history of the region is, in fact, firmly in line with the findings of S21.

1. Response to main arguments in L22

L22 suggest that S21 underestimates the magnitude of pre-industrial climate and glacier-length variability, and that the contribution of anthropogenic influence to the observed retreat of the Palcaraju glacier (Peru) could therefore be smaller than indicated by S21. To do so, L22 present a series of data that appear to show large glacier-length and climate fluctuations over the last millennium in South America. However, we believe it can be shown clearly that some of the data have been altered relative to the underlying sources (for Strelin et al., 2008). Other sources of data have been selectively and misleadingly interpreted by L22 (e.g., Stroup et al., 2014; Neukom et al., 2011). The assessment of L22 is therefore disputed, and the data cited are in fact firmly in line with the findings of S21.

1.1. *Data from Ema glacier, Tierra del Fuego, Chile has been manipulated*

The panel labelled "Site 60" in Fig. 1 of L22 is stated by L22 to be data published in Fig. 9 of Strelin et al. (2008) (a copy of which is included in Fig. 1 of this comment). It is a length reconstruction for Ema glacier, located near the southern tip of South America and more than 45° of latitude away from the subtropical Palcaraju glacier in Peru (9°S) that our study concerns. In their purported reproduction of this figure, L22 makes two main changes that misrepresent key elements of this figure.

Firstly, the L22 version indicates that the ~1 km retreat in the most recent portion of the timeseries occurred prior to 1940, although Strelin et al. clearly state that the retreat took place after 1944. Indeed, Fig, 3B in Strelin et al. (2008) shows the 1944 moraine nestled close to the late-LIA moraines, and note that this is also supported photographically. L22 provide no basis for this difference to the data they claim to reproduce.

Secondly, from a side-by-side comparison of L22's figure and the original figure in Strelin et al. (our Fig, 1. below), we contend that it is clear that L22 have inserted substantial retreats of Ema glacier into their figure, centred around 500CE and 1050CE. The magnitudes of these

* Corresponding author. Oxford Sustainable Law Programme, University of Oxford, Oxford, OX1 3QY, UK.
E-mail address: rupert.stuart-smith@ouce.ox.ac.uk (R.F. Stuart-Smith).

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inserted retreats are approximately the same size as the 20th century retreat. The inserted retreat around 1050 CE is also inconsistent with the reconstruction provided in Strelin et al. (2008) Fig, 7D which shows only a minimal retreat of the glacier in the period that L22 claim saw a retreat comparable to that observed over the 20th Century.

Our view that the Strelin et al. data has been altered in L22 can be demonstrated by a digitization of the Strelin and L22 curves (Fig. 2, see also table of digitized points provided in the Supplementary). We think it is clear from Fig. 2c that the curve from Strelin et al. (see their Fig, 9B, reproduced here as Fig. 1a) has been altered, and that the inserted retreats in L22 are completely unsupported by the Strelin et al. data.

The purported existence of large preindustrial length fluctuations is L22's central claim. However, the Ema glacier record is the only quantification of glacier length they offer, and L22 communicate no reason to the reader for the alterations to the Strelin et al. data, or provide any other citation to support the inserted retreats.

In previous work, Lüning et al. (2019) presents the same figure for Ema glacier, and states that the curves were plotted by a correlation tool 'developed for geological well correlations in the areas of water, minerals and petroleum exploration'. The authors provide no technical details or explanation for the physical basis for applying these methods to a glacier. We believe that we have demonstrated clear errors in L22 and Lüning et al. (2019) that misrepresent the actual data. We hope that the authors will also issue a correction to their previous paper.

It is our view that the insertions and alterations in L22 obscure the fact that the actual data in Strelin et al. (2008) contradict L22's central claim. In fact, the length history in the original data from Strelin et al. (our Fig. 1a) is fully consistent with our results: industrial-era retreat greatly exceeds the largest fluctuations of the earlier part of the past millennium. This is also consistent with an industrial-era warming trend that exceeds the magnitude of natural temperature fluctuations of the prior millennium. We refer Lüning et al. to our other work that has evaluated the signal-to-noise ratio as a metric of the anthropogenic influence on glacier change (e.g., Roe et al., 2017; Roe et al., 2021). Around the world, industrial-era retreat is several-fold larger than late-Holocene length fluctuations (Zemp et al., 2015; Roe et al., 2017). As we noted in our manuscript, our assessment of the signal-to-noise ratio for Palcaraju (SNR = ~8) is consistent with that established elsewhere.

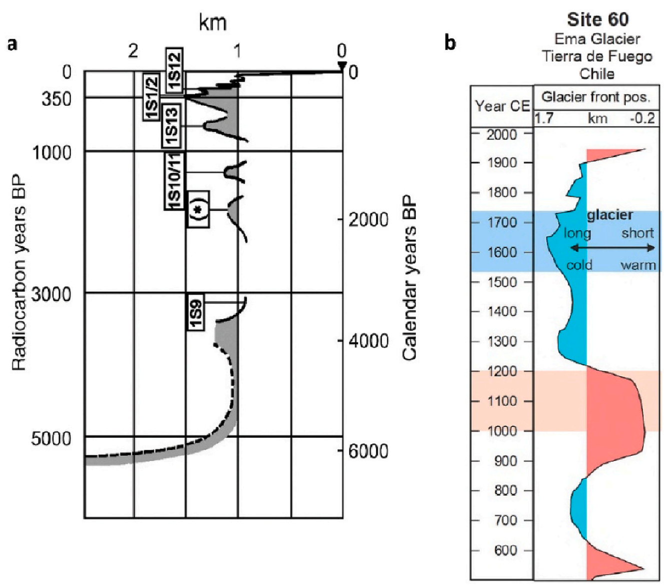

Fig. 1. (a) A reproduction of Fig. 9 (panel B) of Strelin et al. (2008) for the length history of Ema glacier in southern Patagonia; (b) The altered version of these data presented in L22. As clearly described in Strelin et al. (2008), the most recent point plotted in Fig. 1a (indicated by the triangle) shows the modern (2001 CE) position of the glacier, and most of the industrial-era retreat occurred after 1940. L22 alters the relative amplitude of advances and retreats in a way that creates the impression that retreats around 550 CE and 950 to 1150 CE, were as large as the industrial-era retreat. These inserted retreats would extend all the way to the right-hand edge of Fig. 1a if plotted on the same axis, and are absent from Strelin et al.'s data (L22's cited source). Note that the length change over the industrial era greatly exceeds the fluctuations of prior centuries in the original figure from Strelin et al. (2008), in line with results of S21, and contradicting the central claim of L22.

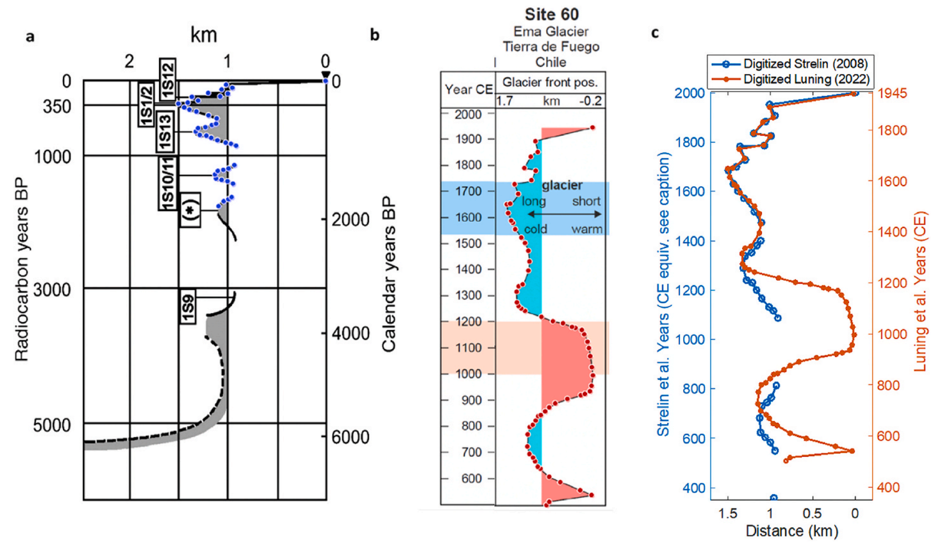

Fig. 2. Digitization analysis comparing the original Strelin et al. (2008) source data and the L22 version of it, for the length history of Ema glacier. The digitization of the Strelin and L22 curves was performed by manual extraction using WebPlotDigitizer (https://apps.automeris.io/wpd/), and tables of these digitized points are provided as Supplementary Data files. (a) Blue dots show digitized points taken from panel B of Fig. 9 of Strelin et al. (2008); b) red dots show digitized points taken from Site 60 panel of Fig. 1 of L22; (c) comparison of the two sets of digitized points. Note the different left- and right-hand-side time axes for Strelin et al. and L22. Strelin et al.'s last point indicates the terminus location for 2001 CE (see text for detail), whereas L22's last point is plotted at ~1945 CE. The Strelin et al. data plotted in our panel (c) spans the timeframe of 1600 to −51 radiocarbon years BP (digitized based on the horizontal gridlines in their figure). To facilitate comparison, in panel (c), the Strelin et al. timeframe is linearly mapped onto the interval 350 to 2001 CE-equivalent years, but note that there has been no conversion from radiocarbon to calendar years because the conversion assumptions differ and cannot be exactly reproduced. Irrespective of small differences in timing, the key point is that L22 alters the Strelin et al. length data prior to about 1200 CE, and inserts large retreats at ~550 CE and ~1000 CE that are not present in Strelin et al. L22 offer no other cited source for their revisions of the Strelin et al. data. The inserted retreats create the impression that prior retreats were as large as the most recent retreat, which is the critical claim in L22. However, it is clear from panel (c) that this claim is inconsistent with, and unsupported by, the cited source.

Finally, while geometric details differ between glaciers, the peak-to-peak pre-industrial fluctuations of ~500 m that Strelin et al. demonstrates for Ema glacier are fully consistent with our assessment of the magnitude of centennial-scale glacier fluctuations driven by interannual variability. In S21, we modelled this for Palcaraju (1 standard deviation = 230 m, see Fig. 4 of S21). Comparable globally distributed estimates of natural glacier fluctuations are also available (Roe et al., 2017).

1.2. *Data from Qori Kalis, Quelcaya ice cap firmly in line with S21*

L22 cites Stroup et al. (2014), a study that characterised the length fluctuations of Qori Kalis, an outlet glacier of the Quelcaya ice cap, that is much closer to Palcaraju than Ema glacier (~5° vs. ~45° of latitude away). However, L22 do not mention Stroup et al.'s primary conclusions (summarised in Stroup et al., Figs. 1 and 2), that for the past five centuries, Stroup et al. (2014) finds no earlier moraines extending further than 700 m down-valley from the known 1963 position, but they show a ~1.2 km retreat since 1963. Thus, again, it is indicated that industrial-era retreat has greatly exceeded the fluctuations of prior centuries.

In our view, it is misleading for L22 not to mention Stroup's findings on glacier-length history because they contradict the central claim in L22 that preindustrial length fluctuations are comparable to the modern retreat. This central finding from Stroup et al. is in fact entirely consistent with the findings of S21, contradicts L22, and is of obvious relevance here. We emphasise that the length history of Qori Kalis is fully consistent with our findings for Palcaraju, and indicates no climate fluctuations in prior centuries that are comparable to the industrial-era trends.

We also note that Fig. 2 of Stroup et al. indicates that Qori Kalis actually underwent a small retreat between ~300 to ~425 ybp, a period indicated and described in L22 as "the exceptionally cold natural climate anomaly of the LIA [Little Ice Age]". Moreover, Stroup et al. found no subsequent moraines down-valley of Hu I-g, one of the Huancané I moraines assessed in Stroup et al. and dated to ~230 years ago. This indicates an absence of any substantial 19th-century (i.e., a "late LIA") advances. Thus, Stroup et al. does not support L22's contention that "… part of the modern glacier melt must represent the natural rebound after the strong glacier advance during the exceptionally cold natural climate anomaly of the LIA." We refer Lüning et al., to the recent study of Roe et al. (2021), which demonstrates the lack of impact of antecedent cold events on glacier mass loss during the industrial era.

1.3. *Data on historical glacier change in the Cordillera Blanca is inconsistent with L22's assessment*

For the Cordillera Blanca itself, Rabatel et al. (2013; cited in both S21 and L22) summarises the literature on historical climate change and glacier-length change: industrial-era retreat exceeds the fluctuations over previous few centuries (in these settings, data on past fluctuations are typically available since ~1600). As noted in our paper, this holds true for Palcaraju glacier itself where the down-valley moraine has been dated to the late 17th Century (Emmer, 2017). Coupled with the known location of the 1940 terminus, this constrains the possible glacier-length variability in the preceding couple of centuries, and requires that the industrial-era retreat is larger than any of those fluctuations.

Similar findings have been presented for glaciers worldwide. Zemp et al. (2015) provide a global assessment of glacier-front variations over the past five centuries. In contrast to the assertions in L22, there is a globally coherent (Hock et al., 2019), comprehensive, and pervasive picture of industrial-era retreat that is unprecedented in prior centuries (Zemp et al., 2015).

1.4. L22 select less relevant data; more relevant data supports S21

L22 shows a proxy-based summertime temperature reconstruction from Neukom et al. (2011) for southern South America (south of 20°S, whereas Palcaraju glacier is located at 9°S). But L22 omits to show or mention the reconstruction for the subtropical portion of the domain (Fig. 4 in Neukom et al., 2011), which is obviously of greater relevance for the Palcaraju glacier. This subtropical reconstruction shows substantially smaller temperature variability, with peak-to-peak fluctuations a factor of two to four smaller than in the three extra-tropical regions (North and South Patagonia and the Chile coast) and does not conform to L22's narrative of a sudden cooling around 1400. Again, L22 does not communicate to the readers their reasons for the omission of this clearly relevant information and instead selects one of the less relevant extra-tropical series to show, although they do not specify which one, and without providing any justification. As Neukom et al. notes, the errors associated with these proxy-based temperature reconstructions are large, but for what it is worth, the standard deviation of the interannual temperature variability (reported in the Table S4 of the supplementary material of Neukom et al.) is comparable to what we used to generate natural glacier fluctuations in our study.

In our view, selecting the less-relevant extratropical time series instead of the more-relevant tropical record creates a misleading representation of Neukom et al.'s work on the relevant subtropical climate variability for Palcaraju glacier.

1.5. Anthropogenic contribution to global glacier mass loss larger than suggested by L22

L22 cites Marzeion et al. (2014) for an assessment of anthropogenic contribution to glacier mass loss. This study has been superseded by Roe et al. (2021), which concludes that the central estimate of anthropogenic contribution to industrial-era mass loss is essentially 100%.

2. Concluding remarks

L22 presents a selection of late-Holocene environmental indicators from the literature. As enumerated above, in our view there are several omissions and misrepresentations of data that are highly relevant to the magnitude of glacier-length and climatic fluctuations and, in one instance, it is our view that data has been altered in a way that greatly distorts the original information (which in fact contradicts L22). The omissions and errors are misleading, and serve to obscure the widely established fact that industrial-era glacier retreat substantially exceeds the fluctuations of prior centuries. It is inaccurate for L22 to conclude that the preindustrial length fluctuations simulated by S21 are challenged by other palaeoclimatic evidence from the region.

As we noted in S21, our estimate of natural glacier-length variability for Palcaraju (a standard deviation of 230 m) is conservative in the sense that it is the largest that is consistent with the known length fluctuations over the past 350 years. Therefore, it is an upper bound on the degree to which natural variability might be contributing to the industrial-era retreat. We note that our calculations also included the impact of interannual climatic persistence indicated by instrumental temperature records.

These issues notwithstanding, nothing whatsoever in L22 addresses the ~1 °C of industrial-era warming at Palcaraju; our attribution of that warming to anthropogenic forcing (following methods consistent with a broad literature and assessed by the IPCC); the impact of that warming on raising the equilibrium-line altitude (ELA); the effect of the ELA increase on ablation; and the subsequent impact of that mass loss on glacier geometry. The conclusions of L22 are not supported by the data cited by the authors, which is in fact firmly in line with the findings of S21.

Data availability

Data used to produce the comparison plot in Fig. 2c are available as Supplementary Data files.

Code availability

No code was used in this study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsames.2023.104692.

References

Emmer, A., 2017. Geomorphologically effective floods from moraine-dammed lakes in the Cordillera Blanca, Peru. Quat. Sci. Rev. 177, 220–234. https://doi.org/10.1016/j.quascirev.2017.10.028.

Hock, R., et al., 2019. High Mountain areas. In: Pörtner, H.-O., et al. (Eds.), IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, pp. 131–202.

Lüning, S., et al., 2019. The medieval climate anomaly in South America. Quat. Int. 508 (September 2018), 70–87. https://doi.org/10.1016/j.quaint.2018.10.041.

Lüning, S., et al., 2022. Attribution of modern Andean glacier mass loss requires successful hindcast of pre-industrial glacier changes. J. S. Am. Earth Sci. 119, 104024 https://doi.org/10.1016/j.jsames.2022.104024.

Marzeion, B., et al., 2014. Attribution of global glacier mass loss to anthropogenic and natural causes. Science 345 (6199), 919–921. https://doi.org/10.1126/science.1254702.

Neukom, R., et al., 2011. Multiproxy summer and winter surface air temperature field reconstructions for southern South America covering the past centuries. Clim. Dynam. 37 (1–2), 35–51. https://doi.org/10.1007/s00382-010-0793-3.

Rabatel, A., et al., 2013. Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. Cryosphere 7 (1), 81–102. https://doi.org/10.5194/tc-7-81-2013.

Roe, G.H., Baker, M.B., Herla, F., 2017. Centennial glacier retreat as categorical evidence of regional climate change. Nat. Geosci. 10 (2), 95–99. https://doi.org/10.1038/ngeo2863.

Roe, G.H., Christian, J.E., Marzeion, B., 2021. On the attribution of industrial-era glacier mass loss to anthropogenic climate change. Cryosphere 15 (4), 1889–1905. https://doi.org/10.5194/tc-15-1889-2021.

Strelin, J., et al., 2008. Holocene glaciations in the Ema Glacier valley, Monte Sarmiento Massif, Tierra del Fuego. Palaeogeogr. Palaeoclimatol. Palaeoecol. 260 (3–4), 299–314. https://doi.org/10.1016/j.palaeo.2007.12.002.

Stroup, J.S., et al., 2014. Late Holocene fluctuations of Qori Kalis outlet glacier, Quelccaya ice cap, Peruvian Andes. Geology 42 (4), 347–350. https://doi.org/10.1130/G35245.1.

Stuart-Smith, R.F., et al., 2021. Increased outburst flood hazard from Lake Palcacocha due to human-induced glacier retreat. Nat. Geosci. 14 (2), 85–90. https://doi.org/10.1038/s41561-021-00686-4.

Zemp, M., et al., 2015. Historically unprecedented global glacier decline in the early 21st century. J. Glaciol. 61 (228), 745–762. https://doi.org/10.3189/2015JoG15J017.