Climate of the Past Discussions

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Reply on RC1

Irene Schimmelpfennig et al.

Author comment on "Glacier response to Holocene warmth inferred from in situ ^{10}Be and ^{14}C bedrock analyses in Steingletscher's forefield (central Swiss Alps)" by Irene Schimmelpfennig et al., Clim. Past Discuss., https://doi.org/10.5194/cp-2021-110-AC3, 2021

We thank Yarrow Axford for her positive and constructive comments. We agree with all her comments and suggestions and revised the manuscript according, which clearly strengthens the manuscript. Our answers are given below in bold.

Minor comments (those most substantive are **ed):

The Abstract could use some tweaks to be more precise and impactful. Specifically:

Instead of "we apply a new approach" would it be more clear to describe this as an emerging or increasingly popular approach? Current wording made me think this study was the first such use of its 10Be-14C approach.

We agree with this comment and have changed the wording accordingly: "we apply an emerging approach"

Please clarify what is meant by "the predominant occurrence of glacier advances until the end of the Little Ice Age"

We agree that this needs clarification. The text now reads "At ~3 ka, Steingletscher advanced to an extent slightly outside the maximum Little Ice Age (LIA) position, and experienced sizes until the 19th century that were mainly confined between the LIA and 2000 CE extents."

The statement that "This implies that at least the summer climate of the HTM was warmer than that of the end of the 20th century for several millennia" requires that these glaciers have been roughly in equilibrium with climate of the late 20th Century rather than lagging far behind. I doubt this issue would have a big enough effect to nullify the quoted statement, but suggest discussing the assumptions of this conclusion more fully somewhere in the paper text to better support this somewhat provocative statement in the abstract.

The reviewer is right that glaciers are currently not in equilibrium and that this needs to be discussed. We changed the text in the abstract as follows: "Although glaciers in the Alps are currently far from equilibrium with the accelerating anthropogenic warming, thus hindering a simple comparison of summer temperatures associated with glacier sizes, our findings imply that the summer

temperatures during most of the Holocene, including the HTM, were similar to those at the end of the 20th century."

In Discussion section 5.3 we also added in lines 549-557: "The fact that alpine glaciers are currently out of equilibrium with the accelerating anthropogenic warming, lagging behind by up to several decades, complicates a direct comparison of summer temperatures associated with glacier positions of the Holocene and the Anthropocene. Glaciers in similar settings and of similar size as Steingletscher have response times on the order of a few to ~50 years (e.g. Oerlemans, 2012; Zekollari and Huybrechts, 2015), indicating that the summer temperatures responsible for Steingletscher's 2000 CE extent may have occurred in the middle or end of the 20th century, thus being 0.5-1°C less than in 2000 CE, according to the instrumental temperature record in the Alps (http://www.zamg.ac.at/histalp/; Auer et al., 2007). Our data therefore imply that summer climate during the HTM was similarly warm as or warmer than during the second part of the 20th century. No further inferences can be drawn on the amplitude of warming."

Line 130 the word "century" is missing

This is now corrected.

Line 212 could be clarified, instead of "inboard of any of the Holocene glacier advances," how about "inboard of all Holocene moraines"? since evidence of some Holocene advances inboard of the moraines has been erased/covered.

We agree and changed the text to "inboard of all Holocene moraines".

**The conceptual model laid out in lines 220-233 is central to the paper, and well explained here – but things get complicated and hard to visualize when we get to section 3.5 and Figure 5b. An added conceptual figure illustrating the various relevant, hypothetical trajectories of the two isotopes would be very helpful in making this paper more meaningful for non-cosmo readers.

We agree and have added a conceptual figure, now Fig. 5, that facilitates the understanding of the principles of the approach and of the hypothetical trajectories of the two isotopes.

Section 3.6. May be worth mentioning the typical size of change from the recalibration? I assume recalibration was undertaken to be thoroughly accurate but made only a small difference that doesn't affect conclusions.

Yes, this is correct. Section 3.6 now reads: "The radiocarbon ages previously published in King (1974) and Hormes et al. (2006) and discussed in this study were calibrated with the online program OxCal 4.4 (Bronk Ramsey, 2009), using its standard options and the IntCal20 calibration curve (Reimer et al., 2020) and are reported relative to the year 1950 CE. This changes the 2σ age intervals by at most 6% compared to the calibration with the earlier OxCal 3.9 version presented in Hormes et al. (2006). The radiocarbon ages published in King (1974) were uncalibrated and can therefore not be compared to the ages calibrated in our study. Note that with regard to the original studies, the general interpretations of all radiocarbon ages discussed here remain unaffected from the (re)calibration."

Lines ~465-469: Isn't it very likely that in the Joerin study some periods of retracted ice are simply not represented by discovered 14C-dateable deposits? That possibility is

acknowledged in line 472 ("might also be…. lacking organic material from unknown retreat periods at the radiocarbon-dated sites") but it's not made to sound particularly likely, thus the need for the explanation about relative glacier size in lines 468-469. An "absence of evidence is not evidence of absence" scenario seems likely – but I don't know the Joerin study and may very well be missing something. Just clarify in the text.

Yes, the reviewer is correct. We clarified the text in lines 529-535: "However, we acknowledge that this interpretation is tentative and will need to be verified, as the observed differences in the cumulative retreat durations might also be inherent to uncertainties in the dating approaches. In particular, it is likely that some periods of retracted glaciers are still unknown because the associated radiocarbon-dateable material has not yet been discovered. Another source for differing results from the two methods could also derive from unaccounted-for in situ ^{14}C production through thin ice (see Sect. 3.3). We also note that the existing data on Holocene glacier retreat does not allow verifying whether or not the glaciers completely vanished at some point during the Holocene."

Line 474: do not capitalize chironomid

This is now corrected.

Line 491: clarify "steady ANNUAL warming". Interesting point about the Greenland N/Ar annual temp reconstruction contrasting with models showing annual warming through the Holocene.

"Annual" has been added.

Line 495: Cool point about widespread glacier advances ~3 ka but a lack of independent proxy evidence for temporary cooling to drive those advances. This seems like an interesting question/issue for glacial geologists and paleoclimatologists focused on the Holocene to ponder some more. Very very tenuously there may be hints of a corresponding climate event in the midge record in figure 6d?

We agree and added in lines 566-567:" Hints of a LIA-like cooling at 4-3 ka are only noticeable in the pollen-based summer temperature record at Rutor Glacier (Fig. 7d). "

**Line 500: "glaciers across the Alps were smaller than their modern extents for most of the Holocene" I think the take-home from this sentence would be even stronger if you put a timeframe on it. eg We find that Steingletscher was smaller than its present size for x-x kyrs in total throughout the Holocene, and given its expanded size throughout much of the past 3000 years, first shrank smaller than present no later than x ka. Likewise, line 503 could be more precise than "for several millennia of the HTM." (how many millennia and which ones?)

Ok, we agree and have added the following text at the beginning of the conclusions: "We find that Steingletscher responded highly sensitively to natural climate changes throughout the Holocene. It was as small as or smaller than its 2000 CE extent for a total of ~7.4 kyr throughout the Holocene. No later than ~10 ka, it shrank to its 2000 CE extent (or beyond) and advanced again to a LIA-like size at ~3 ka, followed by expanded extents throughout much the past 3000 years until the rapid general retreat that started in the 19th century. "