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## Reply on RC2

Irene Schimmelpfennig et al.

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Author comment on "Glacier response to Holocene warmth inferred from in situ  $^{10}\text{Be}$  and  $^{14}\text{C}$  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-AC4>, 2021

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**We are grateful to Kurt Nicolussi for his positive and helpful feedback that further improve the manuscript. We have thoroughly addressed all raised points, as detailed below in bold.**

Specific and minor points

Lines 336-338: It remains unclear why the two samples 16-10 and 16-12, analysed for both  $^{10}\text{Be}$  and  $^{14}\text{C}$  content, should have had the same exposure history and why the results were - therefore - averaged, as they come from clearly different positions in terms of sampling elevation. One site may have been covered by ice during glacier advances in the early to mid-Holocene, but the other may not have been reached, which could be one explanation for the different results. The inferred longer exposure time of sample 16-12, which was taken at a more elevated position, also points to such a scenario. A more complex consideration seems to make more sense here.

**We agree that it is likely that the two sample locations experienced a slightly different exposure history, because they are situated  $\sim 160$  m in distance and  $\sim 34$  m in elevation from each other. Unfortunately, based on our data, we cannot decide with certainty if the longer exposure duration inferred for sample 16-12 is due to a longer ice free duration or to the uncertainties inherent to the method (e.g. a thinner ice cover than above sample 16-10, see your later comment on the possible production of  $^{14}\text{C}$  through ice). In section 4 (results), we conservatively present the average exposure duration and standard deviation of  $7.4 \pm 0.8$  kyr that can be deduced from the results of STEI-16-12 and STEI-16-10, following the simplified assumption that samples on a transect parallel to the ice flow experienced the same exposure history on millennial time scales (Goehring et al., 2011). Distinct exposure histories of the two sample locations are further explored in the discussion section 5.1. We changed the text according in lines 382-388: "Following the assumption that samples on a transect parallel to the ice flow experienced the same exposure history on millennial time scales (Goehring et al., 2011), an average ice-free duration and standard deviation of  $7.4 \pm 0.8$  kyr can be deduced from the results of STEI-16-12 and STEI-16-10. Given that STEI-16-12 lies  $\sim 160$  m further outboard and 34 m higher in elevation than STEI-16-10, the longer exposure duration derived for STEI-16-12 could also either be due to shorter ice cover, or be an artifact of a thinner ice cover above this sample, the latter potentially leading to**

**small muogenic  $^{14}\text{C}$  production in the subglacial surface of the sample (see Sect. 3.3). Distinct exposure histories of the two sample locations are explored in section 5.1"**

Line 385 It not clear to me why the find of a wood fragment points to a warmer climate. If it is about the inferred position of the tree line, which in turn is interpreted climatically, this would make sense.

**We agree that this needs clarification. The wood fragment was found at the base of a peat profile on a fluvio-glacial deposit near the LIA limits (King, 1974). It is rather the succession of the fluvio-glacial deposit and the peat that indicate that the glacier retreated from a large extent at the timing given by the radiocarbon date of the wood ( $\sim 2.5-1.9$  cal ka). We changed the text in lines 435-437 to "The bracketing radiocarbon age of a wood fragment of  $\sim 2.5-1.9$  cal ka at the base of a  $\sim 1.10$  m deep peat profile on fluvio-glacial deposits near the LIA glacier limit points to glacier retreat (King, 1974)."**

Lines 394-417 These lines discuss the time span in which the Steingletscher was smaller than its 2000 CE extent, i.e. that the Chüebriegel was not ice-covered. ("... indicate that the glacier was smaller than its 2000 CE extent for a total of  $\sim 7.4$  kyr during the Holocene"). Wouldn't it be also possible that - since a certain ice thickness ( $>70$  m, lines 231-233) is required in each case to prevent  $^{14}\text{C}$  production - there were also less intense advances, that resulted in only minor ice overburden, but which clearly exceeded the 2000 CE extent? This would better explain the long exposure duration determined for sample 16-12 against the background of the state of knowledge on Holocene glacier evolution.

**We agree that the text was not clear enough regarding the potential effect of ice cover on  $^{14}\text{C}$  production in a subglacial rock surface. We now clarified in lines 245-250: "Shielding by  $>70$  m of ice is required to reduce  $^{14}\text{C}$  production to 1% of its surface production, and under a thin ice cover of  $\sim 13$  m  $^{14}\text{C}$  is produced at 10% compared to an ice-free surface, while  $^{10}\text{Be}$  is produced at only 1% (Hippe, 2017). The photograph in Fig. 4 allowed us to estimate that during the glacier extent in 1982, ice cover was on the order of  $\sim 20$  m to 50 m above the sample locations, suggesting that  $^{14}\text{C}$  production in the subglacial rock surfaces during episodes of ice cover should be small enough to not significantly affect the interpretation of our data."**

Line 476: The statement "HTM might have been  $\sim 1-3^\circ\text{C}$  warmer than modern times" is quite strong, however, it needs a more specific temporal reference than "modern times" because of the currently fast changing climate conditions.

**We agree that the modern reference periods for the temperatures need to be specified, due to their rapid evolution. We changed the text to " Alpine summer temperature reconstructions based on chironomid and pollen assemblages are consistent with the Holocene glacier behavior in the Alps, showing a prolonged period of high temperatures during the early and mid-Holocene that might have been periodically and locally up to  $\sim 1-3^\circ\text{C}$  warmer than in 1981-2010 CE (e.g. Heiri et al., 2015; Badino et al., 2018; Fig. 7c, d)."**

Lines 495-496 I agree that there is a lot of evidence for glacier advances and LIA-like extents between ca. 3.6 and 2.6 ka, but on the other hand, there is evidence for the glaciers Mer de Glace and Aletsch that they had a maximum extent as around 2000 CE at ca. 3 ka (see, e.g., Le Roy et al. 2015) - this should be added into this discussion.

**Ok, we agree. We changed the text in lines 567-570: "This inconsistency will also need to be further investigated, because several other moraines of similar age**

are preserved across the Alps (Schimmelfennig et al., 2012; Le Roy et al., 2017; Moran et al., 2017), while other Alpine records indicate glacier extents at ~3 ka that are as short as in ~2000 CE (Holzhauser et al., 2005; Le Roy et al., 2015; Fig. 7g, h)."