Dear Reviewer,

thank you for your comments. Please find our responses below.

The manuscript by Lazslo Palcsu and colleagues presents tritium, radiocarbon and water stable isotope data from Triglav and Skuta glaciers in Slovenia, with the aim of reconstructing the dynamics of these glaciers over the past century. The authors drilled several cores in the two glaciers, collected samples for tritium, oxygen and hydrogen stable isotope analyses, as well as one radiocarbon analysis on a sample from Triglav glacier. They combined the data to present a reconstruction of the ice dynamics for the two glaciers. While any study of quickly melting glaciers is worth pursuing, the one presented here suffers from several methodological failures, strongly questioning the results and their interpretation. Below is a presentation of the main issues.

1. Both glaciers are located at low elevations (Triglav at ~2500 m and Skuta at ~2000 m above sea level). At these altitudes and latitudes, precipitation in the Alps occurs in liquid form during the warm season. Realistically, it cannot be expected that none of this water will infiltrate inside the snow mass.

   Authors' response: Yes, that is true. Although the manuscript handles these questions, we provide further explanations here. In the case of Triglav glacier, the ice layer at the depth of 1 m prevents meltwater intrusion deeper than 1 m. This is confirmed by the low tritium values below 0.1 TU under the depth of 1 m. Skuta is different. The whole core seems to be soaked with meltwater. This is plausible because the tritium jumps down to 3 TU from 6 TU below 0.8 m. However, the stable isotope, for example 18O change is even larger than at Triglav. So, it seems, as percolation water affects tritium, it must affect stable isotopes as well. However the extent of the change might be small, as the pattern remains, as seen in Figure 2. Moreover, tritium at Skuta decreases significantly at 0.8 m, while 18O (with 2H) have large shifts both at 0.8 m and 3.6 m.
   See these articles:
   Pohjola, V. A., Moore, J. C., Isaksson, E., Jauhiainen, T., Van de Wal, R. S. W., Martma, T., ... & Vaikmäe, R. (2002). Effect of periodic melting on geochemical and isotopic signals in an ice core from Lomonosovfonna, Svalbard. Journal of Geophysical Research: Atmospheres, 107(D4), ACL-1.
   Van Der Wel, L. G., Streurman, H. J., Isaksson, E., Helsen, M. M., Van De Wal, R. S. W., Martma, T., ... & Meijer, H. A. J. (2011). Using high-resolution tritium profiles to quantify the effects of melt on two Spitsbergen ice cores. Journal of Glaciology, 57(206), 1087-1097.

   Supplemental figure 1 show that both glaciers consist of snow and firn and the low density of these would promote infiltration of water. As a result, it is expected that the glaciers themselves do not consist of ice (firn/) formed from winter precipitation, only, but also of refrozen summer liquid rain. Positive air temperatures during the melt season would also promote melting of snow/ice and downward infiltration of water, a phenomenon observed by the authors, as well (page 3, line 8): "increased meltwater circulation along the whole ice sequence, as observed during coring".

   Authors' response: that sentence that the Reviewer refers to concerns only Skuta.

Two consequences emerge: the glaciers are not formed from snow diagenesis, only – hence the various comparisons with winter air temperature and precipitation tritium concentration are wrong – and second, the same downwards percolating water would have drastically altered the original stratigraphy, the tritium content and the stable isotope composition of the ice.

Authors' response: Winter temperature has not been compared to precipitation tritium. We argued that accumulated snow fell in winter, so tritium of winter precipitation was considered. Percolation water is different (see above). In case of Triglav very low tritium values below 1 m pointed out that percolating water can be neglected below. Argument for Skuta can be seen above.

It these conditions, it is difficult to rule out that one organic samples was not also moved from its original depositional site.

Authors' response: We disagree. It is hard to imagine, that a plant stem of 5 cm embedded in a stony ice layer can be moved away.

Next, it is surprising that the authors did not encounter (or did not described) summer melt layers, a common occurrence in the upper parts of glaciers with surface melt.

Authors' response: We explained that in case of Triglav the upper 0.1 m represents the last winter snow, hence mostly lost, while the upper 1 m represents the last 70 years.

Because of this issue of water freely moving inside the ice, it is very difficult to ignore the fact that all analytical results could be unreliable to a certain and varying degree.

Authors' response: Percolation water below 1 m at Triglav was excluded. Percolation water is indeed an issue at Skuta, but was explained in the text and above.

2. The authors use d18O measured along the ice cores as a proxy of air temperature.

Authors' response: No, time series have been compared and aligned. We did not use 18O as a absolute temperature proxy, just a tracer of temperature change.

Somehow, they seem to be oblivious to the clear potential alteration of the original signal in ice by the melt water that circulates through it.

Authors' response: The effect of percolating melt water has not been excluded in the evaluation. See above.

They do however exclude data from ice at the base of Triglav glacier which "was likely affected by the subglacial water fluxes", but did not consider this to be a problem for Skuta Glacier.

Authors' response: Subglacial meltwater flux seems to affect only the bottommost samples at Triglav glacier. See Figure 2, and that specific sample does not modify the evaluations.

Water at the base of a glacier is a problem for stable isotope analyses if it mixes with the ice above, but then this would also happen when water circulate through the ice mass itself. The relatively homogenous d18O values in Skuta are a clear indicator of this process happening. Further, because of this mixing, it is not clear what the d180 signal would represent.

Authors' response: d18O at Skuta is not relatively homogenous. It has a larger variation than at Triglav, whereas no percolation water is expected below 1 m at Triglav. We emphasize this effect has not been neglected in the manuscript, but it might be emphasized more significantly. Therefore, we have expanded the spectral analysis of the records and incorporated these changes into the updated Supplementary Figure S6 (see below).

3. In order to reconstruct the age of the glacier, the authors combine tritium, radiocarbon and d18O data. They tune their d18O records to a reconstruction of air temperature at a nearby lake, Jezero v Ledvici. There are two problems here. First, the cited "reconstruction" is not a reconstruction, but an extrapolation of lowland gridded air temperatures from several sites across Europe to the location of the lake, using multiple regression analysis and subsequent corrections for latitude and latitude (Agusti-Panareda et al., 2002, Brancelj et al., 2002). The lake is located several hundreds of meters (almost 1000 m below Triglav) and the authors did not make any effort to further correct the data to account for these altitudinal differences.

   Authors' response: Brancelj et al., 2002 should have been cited. It was added. The d18O values have not been corrected for the altitude difference, because that was not the purpose, but to compare and align it to the temperature time series of Jezero v Ledvici. Furthermore, we have compared the Jezero v Ledvici time series with instrumental data from nearby stations available in the CRU 4.09 product (Harris et al., 2020) (See new Supplementary Figure S7 below). We can see an overall agreement between the records, making the use of the Jezero v Ledvici feasible.

   While instrumental times series similar in length to the data of Batarbee et al (2002) do not exist in Slovenia, reconstructions, do and these could have been better for comparisons. However, the fact that the stable isotope composition of ice was affected by downward percolation of water (and likely freezing) inside the ice, the measured d18O is not a meaningful indicator of air temperature (it is worth mentioning that the authors consider the ice as being formed from winter snow, only and yet they compare the d18O with an annual signal).

   Authors' response: We have addressed this above.

4. One additional problem related to the generation of the age depth model is the lack of consideration for the length of missing ice. The fact that no peak bomb was found indicate extensive melting, and yet this is not considered by the authors.

   Authors' response: As argued in the manuscript a clear, obvious bomb peak was not found, rather some remaining ice from the last 70 years. As written in the manuscript (5.1 Estimation of the age of the ice from radioisotopes), we argue that the upper 1 m

accumulated in the late 1950s, so during the recent decades (after 1960) the net accumulation was negative, i.e. extensive melting.

The thickness of missing ice could be of any length (and hence age); hiatuses inside any sedimentary deposit are difficult to constrain in the absence of precise age determination below and above it. Considering the entire snow deposit as continuous for age modeling is thus difficult to understand.

Authors' response: We argued that the upper 10 cm is fresh, the upper 0.1-1.0 m is late 1950, the plant stem is from 1955, below 1 m the ice is OLDER than 70 years. The alignment to the lake sediment time series further constrains the age beyond 100 years.

Combining the issues above, it results that the reconstructed age depth models and inferred accumulations rates are problematic, to say the least. The circulating water through the ice makes any d18O signal problematic to interpret…;

Authors' response: the shape and trend have been compared to the temperature time series, not the absolute values. In addition, as indicated in the Supplementary Figure 6, despite the potential presence of red noise in the spectrum of both records due to postdepositional processes, there is an overall signal that have been preserved and is less disturbed in the Triglav record. Additional spectral analysis using the depth and the proposed age-depth model as independent variables avoiding interpolation to add extra "red noise" to the spectrum (e.g., Lomb-Scargle , Weighted Z transform "WWZ", Evolutionary Spectral Analysis) give us similar results (not included in the manuscript). Indeed, they indicate that the spectral correlation of the Triglav and Skuta records is unevenly distributed, with some sections showing higher coherence (0-100 cm) than others (>300 cm). Overall, we do not dismiss the potential loss of the signal but rather focus on what has been preserved, which is an overall isotopic imprint smoothed/altered in some sections but still regionally comparable.

…presence of hiatuses of unknown age lead to a wide range of possible ages for the ice, the reconstructed air temperature used to tune the d18O record is not relevant for the study area.

Authors' response: We consider the net accumulation rate was positive until about 1960, but afterwards negative.

There are numerous minor issues with the manuscript, but considering the major ones above, it is not relevant to point them out here. One final comment, on the conclusions: these are not derived from the paper itself, e.g., lines 183 and 184 on the causes of the melt. The authors cite a change in the solar radiation between May and August in recent decades. It is not clear what they really understand by "solar radiation". Solar radiation (or solar irradiance) changes on multi-decadal to multi-millennial time scales and it definitely did not change during the summer of the past decades.

Authors' response: Solar irradiance, of course. Nonetheless, we modified that part as shown here:

Line 61: The reasons for the decline of glaciers can be mainly attributed to the lower average snow depth in the last 30 years compared to the 130-year period before, the increase in summer air temperatures ~~and duration of solar radiation from May to August~~ over the last decades.

Line 183: Their retreat is largely linked to reduced average snow depth over the past 30 years compared with the previous 130-year period, along with rising summer air temperatures ~~and longer durations of solar radiation between May and August~~ in recent decades.

Also, the conclusions do not respond to the issues raised by the authors in the introduction on water availability and ecosystems. Both these questions and the conclusions are just general statements.

Authors' response: In the Introduction we emphasize the importance of such results from remains of glacier in the Alps for the assessment of the effects on water availability and freshwater ecosystems, however the evaluation of such effects are beyond the scope of this study.

Agustí-Panareda, A. & R. Thompson, 2002. Reconstructing air temperature at eleven remote alpine and arctic lakes in Europe from 1781 to 1997 AD. J. Paleolim. 28: 7–23.

Brancelj, A., M. Šiško, G. Muri, P. G. Appleby, A. Lami, E. Shilland, N. L. Rose, C. Kamenik, S. J. Brooks & J. A. Dearing, 2002. Lake Jezero v Ledvici (N.W. Slovenia) – changes in sediment records over the last two centuries. J. Paleolim. 28: 47–58.

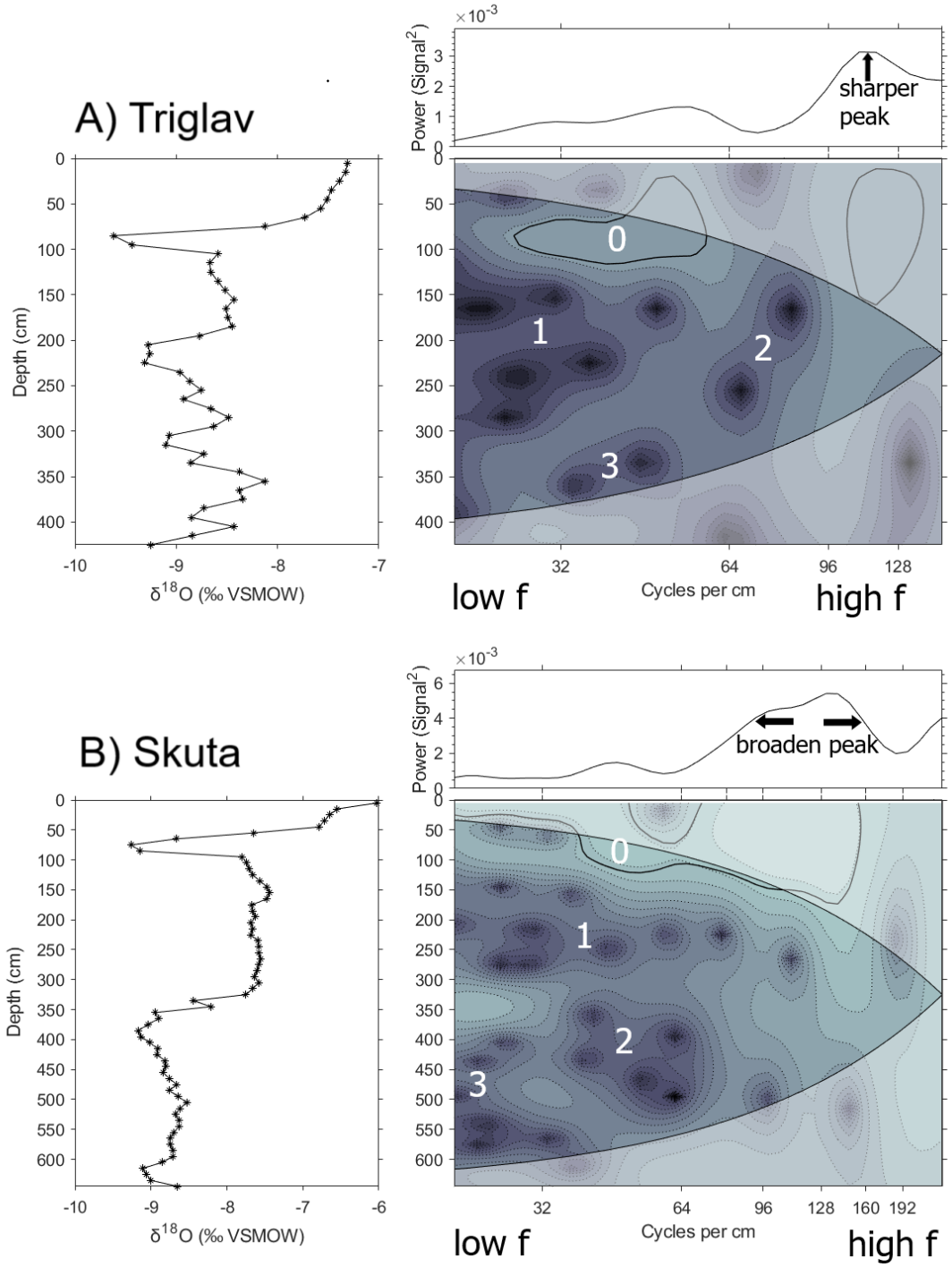


Figure S6. Spectral comparison of the Triglav and Skuta $\delta^{18}O$ records as a function of depth (cm). Both $\delta^{18}O$ profiles indicate similar $\delta^{18}O$ vertical profile, though smoothed for Skuta. The local wavelet spectrum (bottom-right panel) marks the most intense periodicities (brightern shade) at specific depth bands. Black contour lines indicate significant coherence. Conversely, the global wavelet power spectrum (top panel) indicates the frequencies with stronger presence across all depths in the ice cores. The significance level is p=0.05 within the cone of influence in all cases. In general, the figure shows that the Triglav and Skuta $\delta^{18}O$ records have a distinctive local power spectrum at specific depths, owing to their different location (~50 km) and intrinsic accumulation and compaction rates but an overall similar global spectrum. At the first 100 cm, both glaciers seem to capture the periodicity of 32-64 (#0) cycles per cm. After that, each glacier present different signal with local noise. Indeed, the Triglav glacier shows localized areas of 0-32 (#1) cycles per cm at 150-200 cm and 250-300 cm with a separated

periodicity of 64-96 (#2) cycles per cm (higher frequency) from 100 to 300 cm. In contrast, the Skuta record presents a broader and continuous periodicity from 0-64 (#1) cycles per cm between 150 to 250 cm, suggesting a combination of low to high frequency signal. A more localized periodicity ~64 (#2) cycles per cm lies at deeper 400-500 cm layers. Finally, the bottom of the cores for both glaciers is also different, with the Triglav being embedded between the 32-64 (#3) cycles per cm whereas the Skuta record lies at 0-32 (#3) cycles per cm. Altogether, we can conclude that the Skuta record is more prone to suffer from red noise issues (spectral power is concentrated at lower frequencies) than the Triglav record which seems to retain a sort of high frequency (blue noise). This last statement is clearly illustrated by the peak-shape in the power spectrum, being broader for Skuta but narrower for Triglav. According to Fisher et al. (1985), the presence of red noise background is an indicator of diffusion effects particularly seen in the $\delta^{18}O$ signal which are more pronounced in the Skuta record. Nevertheless, despite the potential acquired noisy signal, there is a global coherence in the Triglav and Skuta $\delta^{18}O$ spectral signals suggesting a global dominant climatic control (>64 cycles) ultimately dependent and tuned by local depositional processes at specific depths and frequencies (<64 cycles).

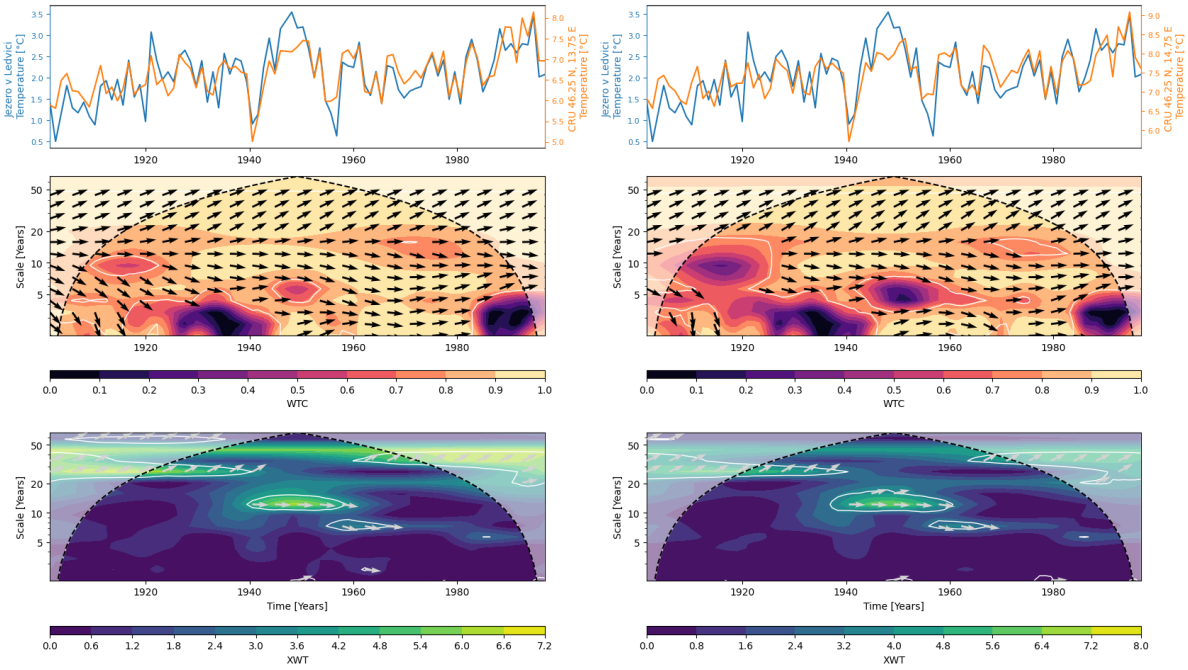


Figure S7. Cross Wavelet analysis between the Jezero v Ledvici Temperature (°C; blue line) record and the CRU 4.09 gridded Temperature product derived from nearby instrumental stations (°C; orange line) (Harris et al., 2020) extracted for the Triglav and Skuta glacier locations. Wavelet coherence (WTC) and Cross Wavelet Transform (XWT) correspond to the middle and bottom plots. There is a high correlation and in-phase (right arrows) between the records from lower to higher periods. Individually, the time-series show spectral power particulary at decadal scale.

References

Fisher, D.A., Reeh, N., Clausen, H.B., 1985. Stratigraphic Noise in Time Series Derived from Ice Cores. Ann. Glaciol. 7, 76–83. https://doi.org/DOI: 10.3189/S0260305500005942

Harris, I., Osborn, T.J., Jones, P., Lister, D., 2020. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Sci. Data 7, 109. https://doi.org/10.1038/s41597-020-0453-3