Reply to Referee #1 Mauri Pelto

Referee #1 Festi et al (2020) provide a detailed review of the dating and accumulation record revealed from an ice core in the former accumulation zone of the Adamello Glacier. The change from a net accumulation rate of ~0.9 ma-1 to no preservation of accumulation is as important as the dating of the core. More attention needs to be given to other dated temperate glacier cores, in particular in the Alps. There are regional mass balance records that extend over at least part of the ice core period and the period when no accumulation has been preserved that can highlight the pattern identified here. Further records from this same glacier, also referred to as Mandrone Glacier, which are more recent should be noted (Ranzi et al. 2010; Grossi et al. 2012) (1995-2009). The greater context will strengthen the findings of this paper.
Authors: We thank referee #1, Mauri Pelto, for the useful suggestions to improve our manuscript and we here address his recommendations.

Referee #1 14: Reword: “Dating glaciers is an arduous yet essential task in ice core studies, which becomes more challenging when the glacier is experiencing mass loss in the accumulation zone as result of climate warming leading to an older ice surface of an unknown age.”
Authors: Done.

Referee #1 22: You have a short abstract and could add what is equally important to the ability to date this core, something like “The change in mass balance at the coring site, in the former accumulation zone, but which no longer retains accumulation, is in the range of ~1 ma-1”.
Authors: Sentences now reads: “For the period of 1995-2016 the mass balance at the drilling site (former accumulation zone) decreased on average of about 1 m w.e. a-1 compared to the period 1963-1986.”

Referee #1 32: “.. even in what had formerly been the accumulation zone.”
Authors: Done.

Referee #1 36: “... making annual layer counting impossible when the seasonality in the signal is lost”
Authors: Done.

Referee #1 37: Reference for the percolation issue for annual signal retention would be good.
Authors: Reference has been added.

Referee #1 39: Reword, “To date relatively few ice cores from temperate high elevation glaciers have been successfully be dated (von Gunten et al., 1982; Kang et al., 2015; Pavlova et al., 2015; Kaspari et al., 2020; Gäggeler et al., 2020).” This avoids having to be accurate in citing every dated ice core from an alpine glacier.
Authors: Changed accordingly.

Referee #1 Other examples I have had a chance to review from temperate glacier settings in North America alone include Naftz et al. (1996), Neff et al. (2017) and Yalcin et al. (2006).
Authors: We included Naftz et al. (1996), Neff et al. (2012, this is the correct date) but not Yalcin et al (2006) because it does not mention the fact that it’s a temperate glacier.

Referee #1 In the Alps you should refer to specific locations where this has been accomplished in addition to Silvretta Glacier. Should mention the Colle Gnifetti core from Monte Rosa (Schwikowski et al. 1999), and Col du Dom on Mont Blanc (De Angelis and Gaudichet, 1991).
Authors: These references refer to cold glaciers, not temperate, and have therefore not been included.

Referee #1 47: State elevation for comparison to Ortles Glacier.
Authors: Added.

Referee #1 67: Reword "Adamello Glacier is located at a relative low elevation of 2500-3400 m a.s.l. (Figure 1) and currently affected by considerable mass loss (Maragno et al., 2009) with recent negative mass balance observed even in the accumulation zone above?" This likely indicates the glacier does not have a persistent accumulation zone. What has been the ELA in recent years?
Authors: To avoid the repetition of "Adamello" at the beginning of two consecutive sentences we changes into" The Adamello is the largest glacier in Italy with an extension of 16,3 km^2 (Smiraglia and Diolaiuti, 2015) and being located at a relative low elevation of 2500-3400 m a.s.l. (Figure 1) it is currently affected by considerable area loss…". Yes, the glacier does not have a persistent accumulation zone. This consideration has now been added. Direct information about the ELA are lacking for the site but according to Žebre et al (2021) the Adamello coring site is likely located below the current ELA. We added this information in the site description, in the "Age of surface" and conclusion paragraph.

Referee #1 85: Figure 1 is not satisfactory. Figure 1 the left panel for Adamello Glacier is not sufficiently clear to be useful. The field area maps need to include elevation contours, longitude-latitude and scale, since these can easily be found in GLIMS or Grossi et al. (2012).

Authors: Figure 1 has been modified**:**

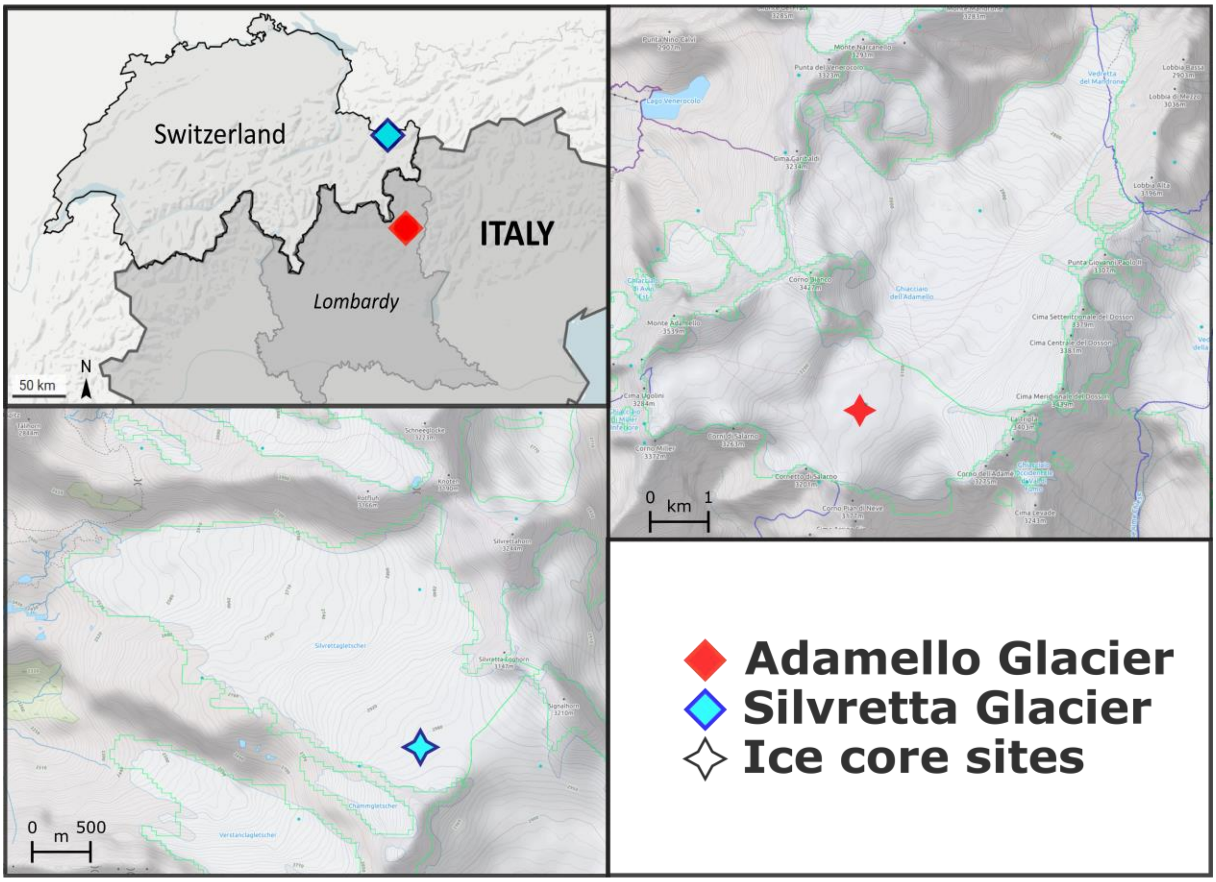

Figure 1. Map showing the locations of the Adamello (red diamond) and Silvretta (light-blue diamond) Glaciers) and respective zoom-in maps on ice core drilling sites: Adamello (red star); Silvretta (blue star) . All maps are north-up oriented.

Referee #1 155: What is the timing of the potential multi-year pollen signal and does that coincide with years of high snowlines when snowcover was lost at glaciers with mass balance records? Review Huss et al (2015) and Carturan et al (2013), the latter in Table 3 also lists annual ELA.
Authors: the timing is 1977-79 and 1989-91. There is no striking coincidence between these years and particularly negative mass balance years in the records suggested. This might be due to regional and local variability.

Referee #1 188: Any insight on why the usual decrease in activity with depth was not observed?

Authors: Possible reasons could be related to changes in the seasonal distribution of annual precipitation/deposition rates, or to changes in the main source origin of recorded air masses (lower ^{210}Pb activity concentration over the oceans compared to coastal or continental sites). For more details, see Gäggeler et al., 2020. Because we can currently only speculate, these potential explanations were not included in the manuscript. However, we now added further information explaining what requirements need to be fulfilled in order to observe the typical exponential decrease in 210Pb concentration activity with depth.

Referee #1 200: Can you quantify very close agreement?
Authors: Within a few years. As can be seen in Figure 5 the dating by the two approaches in the period 1963-86 is lying on top of each other. That this is particularly the case for the period 1963-86 and "within a few years" was now added to the text now also including a reference to Fig. 5.

Referee #1 205: The year 1998 also marks the beginning of a periods of substantially more negative mass balance in the region Huss et al. (2015) and Carturan et al. (2013). Relate to mass balance observations on Adamello (Mandrone) Glacier for part of the period where a record is not retained Ranzi et al. (2010) and Grossi et al. (2012).
Authors: We now added this considerations in the paragraph "Final Adamello chronology" relating to the age of surface.

Referee #1 222: It is worth quantifying the size of the pollen grains to the ice crystals. Does the lack of pollen migration suggest the pollen is incorporated in ice crystals, or that meltwater percolation rates are too low to mobilize? You may not have insight on this, but if you do it will be interesting.
Authors: Unfortunately, we don't have a clear insight on this topic and therefore every hypothesis would be speculative. Clearly, we agree that this is an issue worth investigating.

Referee #1 229: Reword, because it more accurate to say no accumulation has been retained. "Based on the good agreement and our confidence in the dating we can conclude that for at least two decades no net accumulation has been preserved at the drill site."
Authors: Changed accordingly, except we prefer to keep "20 years" instead of "two decades".

Referee #1 239: The annual accumulation that had existed 1963-1986 indicates that mass balance in this area of the accumulation since 1998 when accumulation is not preserved has declined by more than 1 m on average. This is as important a finding as the dating and should be emphasized more.
Authors: We agree and thank the reviewer for this input. We now stress this finding more and added/reworded the related section in the conclusion: "For the period 1963-86 an average annual net accumulation rate of 0.9 ± 0.03 m w.e. a^{-1} could be determined. On the other hand, no accumulation was preserved for about the last 20 years at the Adamello 2016 drilling site on Pian di Neve (Italian Alps) as indicated by all approaches used to estimate the age of the surface, yielding an age older than the drilling date of 2016."

Referee #1 255: Explain why this model is a good choice and how it has worked in a similar environment. How does this compare to methods used at Colle Gnifffeti by Lüthi and Funk (2000).
Authors: The Dansgaard-Johnson model is a standard 1D ice-flow model, in the past being widely applied both on polar ice sheets and alpine glaciers. It is a slightly more sophisticated version of the maybe more famous Nye model, considering a non-uniform vertical strain rate, i.e. a horizontal shear zone layer in the bottom part. Based on borehole deformation measurements performed on a variety of alpine glaciers, this certainly yields a more realistic numerical representation of reality. In case of basal sliding, the horizontal shear stress decreases with the sliding velocity. This can be taken into account in this model (our estimate is based on a glacier frozen to bedrock, i.e. no sliding assumed based on the findings by Picotti et al., 2017 of an absence of melt water at the base). While the Dansgaard-Johnson model used here is a 1D model, the modelling approach used/developed by Lüthi and Funk (2000) is based on much more complex 2D and 3D models (also including improvements in modelling the firn part which is irrelevant here because no firn layer exists and more), requiring extensive additional observational data (e.g. digital elevation maps of the surface and the bedrock, radio-echo soundings of the ice thickness, firn density and the englacial temperature fields either prescribed or calculated in coupled models, measured surface velocities, density profiles, the ages of chemically dated layers in ice cores and borehole closure measurements). Obviously, the approach by Luthi and Funk (or comparable 3D approaches) is much more costly in terms of time,

measurements and computation. If the purpose is solely about estimating the age of ice at a certain depth at an ice core drill site (typically in the accumulation zone, selected specifically in an area of least complicated ice flow), then for the rather small alpine glaciers with complex glacier/bedrock geometries, even the most complex models will yield high uncertainties in their age-depth estimates. Also, they may still not yield results in (close) agreement with observations, i.e. the age of absolutely dated horizons (e.g. Licciulli et al., 2020). This is true, unless they can be constrained by actual dated horizons available throughout the core. If not, any such model can only provide a best guess associated with rather large uncertainties particularly for the bottom few meters above bedrock (certainly true also for 2D and 3D in the absence of constraint from borehole measurements, such as temperature and deformation like in our case).

In the revised version we now better and more carefully explain the limitations of age modelling, remaining cautious in how to portray our interpretation of results and with a clear main message in which we have high confidence in its robustness even if considering all uncertainties. See also related comments and answers to the other referees. The section now reads:

"For an estimation of the potential age range accessible by the Adamello ice archive, the one-dimensional Dansgaard-Johnsen ice-flow model was applied (Dansgaard and Johnsen, 1969). For the resulting age-depth relationship estimate shown in Figure 6, model parameters were as follows. Based on the bedrock depth determined by Picotti et al. (2017) using seismic measurements, the value for glacier thickness at the drill site was 265 ± 5 m (238 ± 4.5 m w.e.). The bottom shear zone thickness was assumed to be 15 % of the glacier thickness. This is slightly lower than the ~20 % typically observed for cold and polythermal high-elevation glaciers (e.g. Jenk et al., 2009; Uglietti et al., 2016; Gabrielli et al., 2016; Licciulli et al., 2020) but likely more reasonable for a temperate glacier (e.g. Kaspari et al., 2020). In any case, because constraining information from dated age horizons is lacking for the bottom part, a relatively large uncertainty of ±10 % was assigned. With these parameter settings, the value for the annual accumulation rate was found by tuning for a best model-fit to the dated 1986 and 1963 ^{137}Cs horizons (least squares approach). The dating uncertainty and the uncertainties associated with the pre-set model parameters described above were employed to derive upper and lower bound estimates (to transfer the contribution form uncertainty in ice thickness to uncertainty in age, relative depths were used).

The model - nicely matching the determined bottom age for the ADA16 core and accounting for layer thinning (vertical strain) – provides us a best estimate of the mean annual accumulation rate at the ADA16 drill site for the period ~1946 to 1986 of 0.9 ± 0.03 m w.e. a^{-1}. However, the assumption of steady-state conditions and the complexity of bedrock geometry and glacial flow in the deepest part of high-alpine glaciers strongly limits a realistic modelling of strain rates (and thus age) for the deeper parts, even using the most complex glaciological 3D ice-flow models. In our case, the lack of data for additional constraint in the deeper/older part, the assumption of steady-state conditions in annual accumulation rates (equal to an average value for the entire period contained in the archive) which are further based on a relatively short time range covered by the 46 m core only, the derived model-based age-depth relationship can only yield a current best estimate. Anyhow, this is at least sufficient to reveal the potential of the site. The Adamello ice archive is very likely to cover the last 1000 years. Being contained in the major part of the total ice thickness (about the upper 240 m of ice; ~220 m w.e.), a millennial-long record should thus be accessible in high resolution. Also, there is reasonable likelihood for a few thousand more years contained in the remaining ~10 % of ice below."

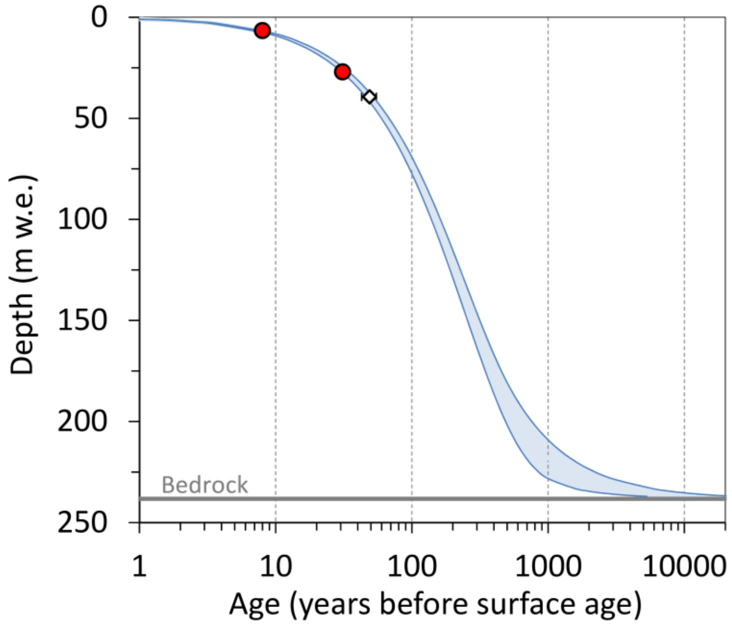

Figure 6. Model based estimate of the age-depth relationship down to bedrock for the ADA16 drill site. Red dots show the 1986 and 1963 ^{137}Cs horizons used to fit the model. The estimated age for the bottom of the 46 m long ADA16 ice core is shown in addition (open diamond, not used for model tuning). The shaded area indicates the range of estimates as confined by the upper and lower uncertainty bounds (thin blue lines).

Referee #1 274: "..indicating no accumulation preserved during the last 20 years." The lack of retained accumulation across an accumulation zone also indicates a glacier that cannot survive (Pelto, 2010).
Authors: We rephrased and added the suggested consideration and citation.

References not included in the manuscript

Žebre, M., Colucci, R. R., Giorgi, F., Glasser, N. F., Racoviteanu, A. E., & Del Gobbo, C.: 200 years of equilibrium-line altitude variability across the European Alps (1901−2100). *Climate Dynamics*, *56*(3–4), 1183–1201. https://doi.org/10.1007/s00382-020-05525-7, 2021.