Review of “Multimillennial synchronization of low and polar latitude ice cores by matching a time constrained Alpine record with an accurate Arctic chronology” by Paolo Gabrielli , Theo M. Jenk , Michele Bertó , Giuliano Dreossi , Daniela Festi , Werner Kofler ,Mai Winstrup , Klaus Oeggl , Margit Schwikowski , Barbara Stenni and Carlo Barbante

The manuscript of Gabrielli et al., presents a revised dating of three non-polar ice cores drilled in a distance of a few meters in 2011 at the glacier Alto dell’Ortles (3859 masl, Eastern Alps, Italy), and for which a first dating was published in 2016 (Gabrielli et al., 2016, denoted as TC2016 in the following)). To achieve a refined common chronology of the three cores, the depth scale matching of the tree cores is revisited on the basis of the 18O records of all three cores, and by adding additional depth match markers by using the Pb concentration profile from two of the three cores.

The absolute timescale of the common depth scale is then obtained by:
a) using the already existing chronology of 2016 which was based on 210Pb, tritium, beta activity and 14C determinations,
b) using additional time markers originating from:
- one 14C dating of an organic fragment giving a time marker at 232 ± 126 BCE,
- the synchronization of the excess (non-crustal) Pb flux record to the one of a well-dated Arctic ice core record (McConnell et al., 2018) from ~1900 CE to ~200 BCE,
- automated and visual counting of annual layers based on pollen and d18O and dust records from 2011 to 1900.
c) applying the obtained time markers in a continuous timescale on which the depth-age Monte Carlo based model COPRA (developed by Breitenbach et al., 2012).
Finally a 1D flow model (Dansgaard et al., 1969) was used to test the revised depth age relation and to test the hypothesis of steady-state conditions of the glacier side with a 1D flow model.

This study addresses the for ice-core archives very important scientific question of the ice core depth age relation, which is in the scope of CP. The study presents new data and the manuscript is structured adequately with respect to the aim of the manuscript. In my opinion the manuscript may be suitable for publication after major revisions were made.

One of the major concerns I have, is the use of the 14C data within the revised dating attempt, since at least two recent dating studies of high alpine ice cores showed that it cannot be necessarily assumed that the depth-age chronology of small scaled alpine ice cores is free of any discontinuities or age reversals (see e.g. Hoffmann et al., 2017, Preunkert et al. 2019).

Having that in mind, a critical look on the 14C raw date published within the first dating attempt (TC2016), one becomes aware that the Ortles chronologies are not free of doubt of

a discontinuity in the depth-age scale, although glaciological investigations did not show any hints on such an occurrence (see TC2016). Note that this was neither the case in the study of Hoffman et al. 2017 at Colle Gnifetti (4450 m asl Swiss Alps) neither within the study of Preunkert et al., 2019) at Col du Dome (4250 m asl French Alps). Therefore, a potential occurrence of such a feature should be addressed in the revised dating attempt.
I took the liberty to draw a graph (see Figure 1 below) in which the available non averaged 14C results from TC2016 Table 2 (see also below) and the 14C result of this manuscript are reported over the depth of core 3. To do so the depth scale of core 1 between 68 and 72 m depth was roughly matched core 3 by applying: depth core3 = depth core1 - 1m.
As could be seen there are in core 1 as well as in core 3 independent signs of a depth-age disturbance around 71m depth (equivalent of core 3).
Within the TC2016 dating attempt the age reversal in section 102 of core 1 was eliminated using the mean age of the three subsamples of section 102, the subsection 103 sample of core 1 was not used since it would have represented a chronological inversion, and it had a increased risk of contamination during sample preparation.

As mentioned above since the time of the publication of the first dating attempt in 2016, it became obvious that one can not expect a continuous undisturbed depth-age relation at non alpine glacier sites. Therefore, either additional 14C analysis should be undertaken at the depth between 70 and 72m (depth equivalent of core 3) to confirm or exclude a depth age disturbance, or address this point in this manuscript and discuss the consequences of a potential disturbance of the continuity in the depth age profile around 71 m depth (equivalent of core 3) in detail throughout the manuscript (i.e. within the comparison of the non-crustal Pb Ortles data with the Arctic Pb ice core data (section 3.2), and within the application of the COPRA model (section 4) and the Dansgaard-Johnsen model (section 5).

Table 2 from TC2016:

**Table 2.** $^{14}C$ analyses of the particle organic fraction (WIOC) obtained from the four sections (tubes) of the Mt. Ortles ice cores no. 1 and no. 3. Except for Sect. 103b, the samples were analysed in three subsamples (top, middle, bottom). $^{14}C$ determination in Sect. 105b (core no. 1) refers to a larch leaf that was found in the ice. Samples reported in bold are those also included in Table 3. Note the notation used for calibrated ages in yrs b2012.

| Core no. | Tube no. | Measure | Top depth (m) | Bottom depth (m) | WIOC (μg) | $F^{14}C$ | $^{14}C$ age (yrs BP) | Cal age (yrs cal BP) | μcal age (yrs cal BP) | μcal age (yrs b2012) | σ (years) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 98b | WIOC | 68.26 | 68.49 | 17.11 | 0.971 ± 0.024 | 236 ± 199 | (−4–461) | 279 | 341 | 167 |
| 1 | 98b | WIOC | 68.49 | 68.73 | 17.86 | 0.911 ± 0.021 | 749 ± 185 | (550–902) | 732 | 794 | 163 |
| 1 | 98b | WIOC | 68.73 | 68.96 | 15.06 | 0.900 ± 0.024 | 846 ± 214 | (562–974) | 824 | 886 | 192 |
| | 98b | WIOC[b] | 68.26 | 68.96 | | **0.927 ± 0.025** | **609 ± 217** | **(331–790)** | **595** | **657** | **205** |
| 3 | 102 | WIOC | 70.87 | 71.14 | 7.98 | 0.784 ± 0.043 | 1955 ± 451 | (1395–2431) | 2011 | 2073 | 517 |
| 3 | 102 | WIOC | 71.14 | 71.35 | 7.15 | 0.867 ± 0.065 | 1146 ± 602 | (537–1720) | 1253 | 1315 | 620 |
| 3 | 102 | WIOC | 71.35 | 71.57 | 13.28 | 0.818 ± 0.032 | 1614 ± 314 | (1187–1921) | 1590 | 1652 | 347 |
| | **102** | **WIOC[b]** | 70.87 | 71.57 | | **0.823 ± 0.027** | **1565 ± 264** | **(1262–1818)** | **1521** | **1583** | **286** |
| 1 | 103b | WIOC | 71.8 | 72.48 | 10.37 | 0.932 ± 0.037 | 569 ± 320 | (156–903) | 517 | 579 | 291 |
| 1 | **105b** | **Larch leaf** | **73.25** | **73.25** | **68[a]** | **0.728 ± 0.006** | **2550 ± 65** | **(2500–2752)** | **2612** | **2674** | **101** |
| 3 | **106** | **WIOC** | **73.73** | **74.02** | **10.91** | **0.628 ± 0.031** | **3737 ± 397** | **(3593–4787)** | **4173** | **4235** | **523** |
| 3 | **106** | **WIOC** | **74.02** | **74.24** | **11.50** | **0.568 ± 0.030** | **4544 ± 424** | **(4623–5715)** | **5178** | **5240** | **530** |
| 3 | **106** | **WIOC** | **74.24** | **74.47** | **18.47** | **0.481 ± 0.020** | **5879 ± 334** | **(6354–7156)** | **6742** | **6804** | **365** |

[a] Pure C extracted after combustion.
[b] Combined values from the three subsamples of tubes 98b and 102.

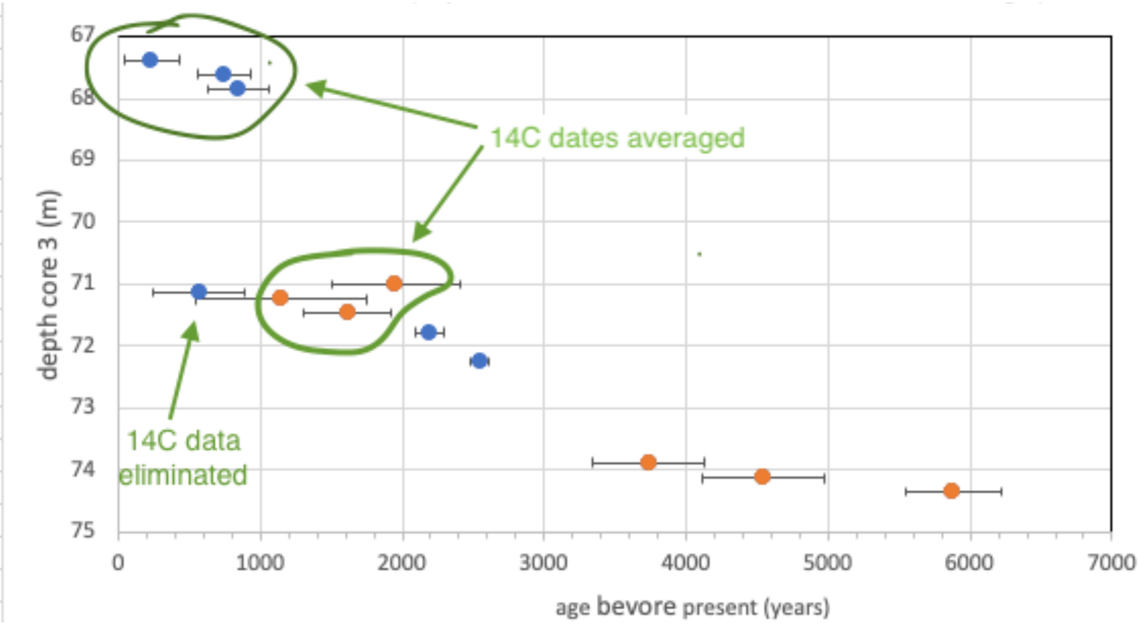


Figure 1: Non averaged 14C results from TC2016 Table 2 (see above) and the 14C sample of this manuscript over the depth of core 3. Blue points correspond to 14C samples from core 1 which are reported on the depth of core 3. To do so the depth scale of core 1 between 68 and 72 m depth was roughly matched to the one of core 3 by applying: depth core3 = depth core1 - 1m as read from Figure 2 of the manuscript.

Another major concern I have is the traceability of the proceeding of depth and time scale matching using d18O and Pb profiles, i.e. for the depth scale matching of the three cores and dating of the common Ortles depth scale between 1907 CE and ~200 BCE by matching the non-crustal Pb Ortles profile with the Pb data of a well dated Arctic ice core.
Although the authors describe their proceeding very detailed, it is not easy to follow their proceeding and arguments.
To improve that:
1. A table or a scheme should be added in section 2, which gives an overview on: which parameters are available in which parts of which of the three cores, and their respective use in view of the dating procedure. Since different reference depth scales are used in the Figures (Fig 1. reference depth from core 2, Fig 2 reference depth of core 3, Fig 5 reference depth of core 1) that will be an important guidance for the reader throughout the different sections of the manuscript. In addition, a SI table would be very helpful which reports the used tie point depths of the three cores in absolute and water equivalent depths for each core.

2. Figure 1 is as it stands not useful for the reader since the matching of d18O profiles is not traceable. It would be better to use an illustration type as used in Fig. 2 means keep the individual depth scales and highlight tie point and their connections between the cores. Hereby prescind the principal tie points used to anchor the depth scale matching and their connections between the cores, vice versa the refinement tie points set afterwards. In addition, the y axis should be extended, in order that the variations of the d18O profiles become more obvious, especially in the lowest part of the cores.

3. Figures 2, 4, S2, S3, S4 should be changed. As it stands, the reliability of the depth scale matching via the comparison of the non-crustal Pb profile cannot be assessed by the reader since in the above-mentioned illustrations the non-crustal Pb data were logarithmized or logarithmic axes are used to present the Pb data. In addition the Pb and the non-crustal Pb data are not made available for the reader (at least I did not find them). Therefore, to make the reasoning of the Pb profile matchings of the three cores and between Ortles and the Arctic core traceable for the reader, no logarithmic data and y axis scales should be used in Fig4, Fig S2, S3, S4.
Among other things, this would allow:

- to see clearer at which point the two Ortles Pb records agree or differ between core 1 and core 3. Differences seem to be up to half a log scale and over up to one m depth which makes up several hundred years at this depth (e.g. around 65, 68 and 70 m depth of core 3). Since for the moment, only one of the profiles is chosen for the age matching with the Arctic ice core, this is an important point to be discussed.
- to give the reader the opportunity to see the quality and reliability of the matching between the Ortles and the Arctic (and the CG) non-crustal Pb profiles. E.g. the authors state in line 1 of page 10 "In general, the match between Alto dell'Ortles and SZ is excellent, except during 1650-1900 CE …" however Fig 4, Fig.S2, Fig. S3 and suggest that the matching is rather arbitrary especially after ~ 600 CE the course over time of the Ortles non-crustal Pb and Arctic Pb differs significantly. As it stands (logarithmic scale) I am not convinced that the Pb matching with the Arctic core is reliable enough to shift the age of the 14C data to the limit of their 68% probability, and to neglect the 14C sample at 1361 ± 204 CE in section 4. It will be also very important to see, whether the assumption of a depth age disturbance would improve the Pb matching agreement of Ortles and the Arctic ice core or not.

An alternative to showing the Pb and non-crustal Pb data on non-logarithmic scales and making them public within this manuscript, might be to join the refined dating addressed here to the aimed environmental discussion of the Pb data in a common manuscript.

Other comments:
The application of the Dansgaard-Johnsen 1D model (see Dansgaard et al., 1996) on the revised depth-age relationship at the end of the manuscript (section 5) should be shortened. Only synthesized essential information of the model, the different input parameter, the outcome and the discussion of the results stay in the manuscript. Model description, input parameter determination of glaciological observations should be put in the SI.

For the comparison of non-crustal Pb Ti is used at CG and Rb at Ortles (Figures S2, S3, S4). Why Ti was not used as well at Ortles for consistency? Please report in the text the crustal values used for the Figures. Also discuss and provide errors in calculating non-crustal Pb. How large are the changes of Rb with age in the Ortles ice (please report the Rb profile in the Supplementary material).
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References which are not cited in the manuscript but which should:

Hoffmann, H., Preunkert, S., Legrand, M., Leinfelder, D., Bohleber, P., Friedrich, R., & Wagenbach, D. (2018). A new sample preparation system for micro-14C dating of glacier ice with a first application to a high alpine ice core from Colle Gnifetti (Switzerland). Radiocarbon, 60(02), 517–533. https://doi.org/10.1017/rdc.2017.99.

Preunkert, S., J.R. McConnell, H. Hoffmann, M. Legrand, A. Wilson, S. Eckhardt, A. Stohl, N. Chellman, M. Arienzo, & R. Friedrich (2019) Lead and antimony in basal ice from Col du Dome (French Alps) dated with radiocarbon: A record of pollution during antiquity, Geophys Res Lett, doi:10.1029/2019GL082641.