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The Cryosphere Discussions

Interactive comment on "First investigations of an ice core from Eisriesenwelt cave (Austria)" *by* B. May et al.

B. May et al.

Barbara.May@iup.uni-heidelberg.de

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Reply to Referee 1

We thank referee 1 for his constructive comments.

A) Specific comments:

Referee 1:

"The maximum age of the ice body is assumed to be related to the onset of its formation. Is there no melting at the bottom and no corresponding mass turnover? Do you consider the ice body stagnant, losing mass only by melting and sublimation at the surface?"

Authors response:

We agree with the reviewer's concern and extend the description of the drilling site settings in Section 2.2 in view of bottom melting and ice flow pattern, which, later on, is taken into account in the discussion of the maximum age.

Basically, we cannot exclude basal melting episodes. Obleitner et al. (this issue) report rock temperatures of about –1.5°C in winter. In detail, the measurements show rock temperatures close to 0°C in summer and between about –1.5°C and –0.7°C at 20 cm and 125 cm distance to the cave surface in winter. The englacial temperature measurements at 6 m depth of the drilling site reaches a maximum of –0.2°C during summer and -0.6°C in winter. At this stage, we assume no mass loss from basal melting, at least, for the present situation. Evidently, bottom melting is crucial in assessing the characteristic live time of the (stagnant) ice body. We feel, however, that any warming of the ice/bedrock interface to initiate melt is driven by an increase in the cave air temperature. This signal needs years to diffuse into the bedrock; meanwhile a considerable ice fraction is ablated at the surface. Thus, bottom melting is only required to maintain a steady state geometry while the mass balance is persistently positive.

Regarding ice flow we indeed refer to a stagnant ice body (see comment in the reply to Referee 2 below).

Referee 1:

"The radiocarbon dating chapter is hard to follow and (probably therefore) inconclusive. A table with the data would help. Out off the four samples analyzed, three ranged between 65 and 76 pmC, whereas one was super modern and was considered as contaminated. The correction for the blank contribution just on the basis of the lower C mass is speculative. With this questionable quality of the radiocarbon data, giving an age and annual layer thickness estimate is not really justified."

Authors response:

We did not intend to report an age estimate based on the scattered radiocarbon data but simply offered a scenario on a possible age constrain (here even a realistic uncertainty range would be hard to state). According to the referee's objection we change the wording as to make this clearer especially the hypothesis on the mean annual layer thickness. We have meanwhile obtained three additional 14C measurements. One sample again fell into the blank category. The other two, although carrying the same blank contribution problem, support the previous "one point age estimation". We report now the radiocarbon data in table form (see attachment) including the new data and change the wording to emphasize that we only wish to give an idea about the age by using a very crude scenario.

Furthermore, we decided to change the notation of the 14C ratios from pmC (percent modern Carbon) to fraction modern carbon F14C (as defined by Reimer et al., 2004). The two notations are essentially the same: F14C = pmC [in%]/100. For the sake of direct comparison with the manuscript submitted to TCD , the attached table still reports pmC. It will be consistently changed in the revised paper.

Referee 1:

"Why does melting and refreezing result in elongated, vertical bubbles?"

Authors response:

See our reply on the same query raised by referee 2.

B) Technical corrections:

Referee 1: "Figure 1: Increase font"

=> done

Referee 1: "Figure 6 and 7: Red and pink is difficult to discern."

=> We changed pink to yellow.

Referee 1: "Figure 8: Blue and black lines are difficult to discern."

=> We changed black to bright blue (cyan)

Reply to Anders Svensson (Referee 2)

We would like to thank Anders Svensson for his comments and particularly for his detailed proposal for extending the discussion of the isotope profile towards climate scenarios (at our own discretion).

A) General comments:

Referee 2:

"...it appears to be an assumption throughout the paper that the ice is not flowing, or at least ice flow is not really taken into consideration. Without ever having put my foot in the cave, I would assume that the ice is actively flowing. This is temperate ice almost at the melting point, which is very soft and deforms easily. If indeed, ablation and sublimation only plays a minor role for the mass balance (as you suggest?) the ice flow will be driven by the ice source, e.g. the inflow of ice through the ice column or from other areas in the cave, and ablation/melting at the edges/bedrock. If the ice is actively flowing the age of the ice at the drill site will depend not only of the depth of an ice layer but merely on the distance to the ice source. You would need estimates of the inflow of ice and a simple ice flow model to determine this. To investigate if the ice is indeed flowing one could survey the movement of marks/sticks at the surface over time, one could measure the deformation of a borehole that is kept open, or at least follow the position of the existing borehole. The non-horizontal ice floor supports the idea of active ice flow."

Authors response:

We continue adhering to the statement that the investigated ice body is stagnant throughout. There is no driving stress since the surface is essentially horizontal, whereas the ice body is entirely confined by the cave walls (see Fig. 2b). Moreover, there is also no mass balance gradient needed to be compensated by ice flow and also in view of the maximum ice depth of 7m the yield shear stress would hardly be exceeded even assuming a sloping surface. As shown by numerous poles drilled through the ice and fixed at the bedrock to support the touristic path in ERW even very steep ice appears to be essentially stagnant (A. Rettenbacher, show cave management, personal communication). Regarding the drilling site, we are thus dealing with a kind of dead ice (seen also in less distinct depressions of glacier bedrocks). This view is corroborated by some scattered fabric analyses done on ice core samples showing no indication of ice deformation (J. Kipfstuhl, personal communication).

Referee 2:

"There are air bubbles in the ice! To me this comes as somewhat of a surprise as the formation of air bubbles in the polar ice caps are formed in the snow-to-ice transformation in the firn. Having no snow and no firn layer in the cave it is a little of a mystery to me where those bubbles originate from. In the manuscript it is stated that elongated bubbles 'are most likely formed through melting and refreezing of the surface ice'. To me this appears as a rather unlikely scenario. Indeed, in the polar regions melt layers or refrozen water is exactly characterized by containing NO bubbles (when the ice melts the air escapes and it is not reincorporated by refreezing). To me it seems much more likely that the bubbles are introduced at an earlier stage, e.g. from the ice column."

Authors response:

One should not confuse melt layers in sedimentary glacier ice with the congelation type cave ice we encounter at the ERW drilling site, which is formed by freezing of drip water. Depending on the freezing rate air components initially dissolved in the liquid water are rejected from the developing ice front. Moreover, CO2 bubbles may evolve during calcite precipitation. Following the famous work of Carte (1961), under these settings bubbles tend to be smaller at high freezing rates. They may become elongated perpendicularly to the freezing front (Hubbard, 1991). We agree that our

statement "bubbles are most likely formed through melting and refreezing" is somewhat misleading (implying bubbles formed from drip water saturated with air or surface melt getting saturated before freezing again). We change the wording accordingly.

Referee 2:

"Air bubbles are elongated in the upper 4 m of the ice and round in the lower parts. To me elongated air bubbles strongly suggest an active ice flow whereas round bubbles suggest ice that is 'stuck' for some reason, such as the structure of the bedrock (maybe the GPR can tell something about this?) In Greenland ice we have elongated air bubbles on the ice ridge caused by the ice deformation. In ice that 'gets stuck' round ice bubbles are likely to reform after some time due to energy minimization. Based alone on the shape of the ice bubbles in your core, I would therefore suggest that your ice drill has penetrated two distinct sections of ice: an upper actively flowing section of 'recent' ice and a lower 'stuck' section of older ice. It would be most useful to look at some thin sections of ice to see if the ice crystals in the upper section are also elongated along with the air bubbles (which is the case in Greenland)."

Authors response:

As we neglected ice deformation by the above reasoning there can be no bubble geometry changes driven by ice flow dynamics. Note also that bubble elongation is in the direction of the core axis, which is rarely seen in glacier ice cores.

Referee 2:

"...there is a significant change of about 10 permil in dD at the 4 m transition zone from 'warmer' to 'colder' values, which is associated with the change in the impurity content of the ice and the change in the air bubble shape. I find it likely that the water isotopes primarily reflects climate, and thus changes in precipitation and seepage water. Just as it is the case for the oxygen isotopes of stalagmite records in the Alps, such as the Kleegruben stalagmites. Lower isotopic values correspond to colder climate and vice versa. The Holocene Climatic Optimum would be a candidate for a warmer and wetter climatic period that could be the origin of the 'warmer' isotopes. The water isotopic shift in the ERW core appears to be of the same order of magnitude as that between glacial interstadial and stadial values in the Kleegruben stalagmite oxygen isotopes."

Authors response:

There is no shortage in the ice cave literature of over-interpreted findings. We intended therefore to restrain from hypothesizing what kind of climate signal might be preserved in the core, unless, at least, the order-of-magnitude age scale is fixed. We admit that the referee's scenario would be intriguing, but we note that the isotope shifts may be easily produced by only a small change in the seasonality of accumulated drip water. This would be somehow associated with climate but not in the direct sense of a climatologic shift in the isotope signature of the precipitation (i.e. air temperature change). Note also, that a comparison of δ18O changes seen in stalagmites of Kleegruben Cave (over relatively large temporal episodes) with that of the ERW cave ice is far from being straightforward. This is first of all due to the fact that carbonate isotope data integrate temperature and precipitation changes associated with a different isotope/temperature sensitivity (Vollweiler et al., 2006) compared to our isotope data of ERW drip water. On the other hand, kinetic isotope effects associated with incremental freezing of complicates the interpretation of ice isotopes in these settings. Nevertheless, we will add a sentence in the outlook that we cannot exclude an external climatic forcing to account for the dichotomy in the ice core with respect to stable isotope physical and chemical properties.

B) A few specific comments:

Referee 2:

"Could you please provide a table summarizing the results of the four C-14 samples and analyses? It is difficult to extract the results from the main text. What was for example the result of the upper most sample, what exact depths were they taken, etc."

=> See response to referee 1 regarding the radiocarbon dating chapter.

Referee 2:

"Figure captions Figure 6+7: 'by filling the missing sections. . .' -> gaps are linearly interpolated."

=> done

References

Reimer, P. J., Brown, T. A., and Reimer, R. W. (2004). Discussion: reporting and calibration of post-bomb 14C data. Radiocarbon, 46-3:1299–1304

A. E. Carte: Air bubbles in ice, Proceedings of the Physical Society, Vol. 77, p. 757-768, 1961

B. Hubbard, Freezing-rate effects on the physical characteristics of basal ice formed by net adfreezing, Journal of Glaciology, Vol. 37, No. 127, 1991

Vollweiler et al.: A precisely dated climate record for the last 9 kyr from three high alpine stalagmites, Spannagel Cave, Austria, GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L20703, doi:10.1029/2006GL027662, 2006

Attachment: new Table 2

14C is still reported as pmC in agreement with the manuscript submitted to TCD. The notation will be changed in the revised paper to F14C = pmC [in %]/100.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/4/C1277/2010/tcd-4-C1277-2010-supplement.pdf

Interactive comment on The Cryosphere Discuss., 4, 1525, 2010.