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The Cryosphere
Discussions

Interactive comment on "Isotope hydrological studies on the perennial ice deposit of Saarhalle, Mammuthöhle, Dachstein Mts, Austria" *by* Z. Kern et al.

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Response to Referee1

First of all we would like to say thanks to our Refrees for their valuable comments and critics on the manuscript. Below we are to respond to the general and specific comments of Referee1.

Referee1's General comments Considering the up till now very sparse investigations of the glaciological characteristics of cave ice and its potential relevance as climate archive, the manuscript provides novel and useful data to help understanding cave ice formation. Also, the main questions primary asked of any climate archive - 1) the age

(structure) of the ice and 2) what information (e.g. in form of delO-18) is recorded within the ice matrix - are discussed This paper has the potential to be a significant contribution to cave ice and climate research studies. However, the current presentation of the overall well-conducted study must be substantially improved on several accounts. The manuscript would gain in understanding by an altogether more cautious and critical approach. The complexity of ice caves and their problems as climate archive are not sufficiently displayed. Especially lacking are more background information on the Mammut cave system and its weather conditions itself. This missing information makes it difficult to determine, how the findings of this Ms can be extrapolated or compared to other cave systems. The presentation of the data is incomplete (a plot of isotope vs depth should be included) and its interpretation seems at times patchy and incoherent. Below, I elaborate on the abovementioned aspects and several other details that need to be addressed during revisions.

Authors' response: The original brief paragraph with some information about the site have been completed with all the demanded details and have been collected into a new section. We hope these expanded section will give sufficient information to support the further discussion. The recommended delta vs depth plot has been included as a part of the new Fig.3. In addition the discussion has been restructured and, especially the section "Stable water isotopes", has been rewritten taking advice from both Reviewers. A two-component open-system freezing model adequately explained the found isotopic peculiarities of the Saarhalle cave ice.

Referee1's p.1450, l.1 to p. 1451, l.2: The introduction gives the impression that cave ice provides a well structured, low accumulation climate archive directly comparable to cold, mountain glaciers and has been neglected for unknown reasons up till now. The introduction should contain more information about the potential and problems of cave ice investigations in terms of gaining insight into past climate changes.

Authors' response: We accept the critics. A new paragraph has been added to indicate the fundamental problems: "However this latter could have very complex origin. The water supply could be snow, freezing karstwater or freezing out of water vapour from cooled moisture air. The dominance of these sources can vary from cave to cave so no uniform model could be expected to interpret environmental proxies (like accumulation rate, or isotope hydrological fluctuation) derived from cave ice deposits. For instance, cave ice have been found significantly enriched in the stable isotope composition compared to local mean annual precipitation from many ice caves (e.g. Lauriol and Clark, 1993, Fórizs et al., 2004; Claussen et al., 2007; Perşoiu et al., 2007; May et al., 2010) however it is not a general rule because cave ice sometimes comparable or more depleted than the local precipitation (e.g. Yonge and MacDonald, 2006; Luetscher et al., 2007; Kern et al., 2009a). Detailed studies are recommended for each individual ice cave to understand its unique system (Yonge and MacDonald, 2006; Turri et al., 2009)."

Referee1: p. 1451, l.3-14: In order to get a better picture of the location some additional information on describing the cave system are necessary.

Authors: The brief paragraph with information about the site has been completed with all the demanded details and has been collected into a new section.

Referee1: Also, information about the water sources and sinks responsible for the ice formation are needed, even if only speculated or simply observed over time. Examples for missing information on the setting are: l.3-8: At which altitude are the entrances and exits?

Authors: Twenty-one entrances are currently known. The altitudes of some of the most relevant ones are given in the new section.

Referee1: How much rock covers the cave system? Especially above the drilling position Saarhalle? Authors: Overburden above Saarhalle is estimated to 60 m

Referee1: l.9-14: Where in the system is the Saarhalle located? How far removed from an entrance/exit?

Authors: Some sentences have been included into the new site description section. In

addition the cave map has been attached to the paper as an Electronic Supplement. The distance of Saarhalle from the Western Entrance (through cave passages) is ∼350 meters, directly (through the rock) is ∼60 meters.

Referee1: What is the average temperature and humidity in the Saarhalle?

Authors: The mean annual air temperature ranged between -0.1°C and -0.46°C in the Saarhalle in the 1996-2000 period, the long-term average was -0.30°C. The relative humidity has never been monitored during wintertime. During the summertime the humidity is always quite close to (or at) saturation but we feel that it makes no sense to include these data as most instruments are not really reliable close to the saturation point.

Referee1: What geometry does the ice block have (e.g. reference picture in Hausmann and Behm, same issue)?

Authors: Some sentence has been added.

Referee1: Is there any sign of ice sliding or flowing? Why (not)?

Authors: This feature has never been monitored however there is no any sign of ice sliding or flowing. Two main points can be mentioned that tend to give more probability to the absence of any ice dynamics. Firstly, Saarhalle ice block sits in a bowl shaped basin (Behm and Hausmann 2007, 2008; Hausmann and Behm 2010). Secondly, sliding or flowing has not been observed in the case of Feenpalast, the better monitored ice body of Mammuthöhle.

Referee1: Are there visible calcite layers?

Authors: There are some visible layers, probably cryocalcite, in the sidewall and there were frequently observed white and yellowish microplates and fluffy aggregates in the molten ice. Learning from a similar study (May et al. this issue) we reckon that these can be cryogenic calcite particles.

Referee1: Is there evidence of drip water infiltration into the Saarhalle? What feeds the ice formation: drip water or water vapour?

Authors: The main source of ice formation was/could be an open question before our study. We think that one of our main results is that we can exclude the potential origin of freezing out water vapour. Dripping water is observed very scarcely in Saarhalle in recent times. However, we think that in this aspect recent conditions might be irrelevant to the ice forming conditions in the past.

Referee1: What diminishes the ice? Melting or sublimation?

Authors: On the basis of temperature monitoring data we speculated that melting might probably be a more important factor of ice erosion compared to sublimation.

Referee1: p.1451, l.16-18: The first "main scope" should be removed as it certainly is not a main point in the paper and is dismissed later on with one sentence. The attempt to link GPR signals with calcite layers should be discussed, but not at this point.

Authors: Done as suggested.

Referee1: p. 1454, l.1-8: It should be explained, why the respective station was used for data comparison. For example why choose Golling and Feuerkogel for comparison with the stable isotope composition? And why are tritium data from Salzburg necessary? Furthermore there are inconsistencies: Salzburg is mentioned also for stable isotope comparison, but entirely left out of the discussion later on. At the same time tritium data from Salzburg are used (Fig. 2) but not mentioned here

Authors: Owing to the availability of the updated version of ANIP is was possible to clarify this part in the revised manuscript. Feuerkogel dataset is used as local precipitation reference. The reason is that this is the closest ($\sim$30km) station situated at a comparable elevation (1598 m asl). Salzburg and Golling data are left out from the revised version.

Referee1: p.1454 f.: I would reconstruct the Tritium chapter: => ice with less than 8.5

TU can only origin either before 1960 or after 1980 (based on data from Vienna and Feuerkogel) => considering the observed loss of ice in the last 10 years, two scenarios are envisioned: 1) low ice accumulation 1 cm/yr => earliest date 1905. 2) high accumulation of minimum 15 cm/yr required for all tritium samples to be not older than 1981. => Conclusion: while the first assumption is much more likely, the second can not be dismissed? Or are there any information about ice grow rates in the Saarhalle?

Authors: This part is reconstructed following the suggestions.

Referee1: 3.2 Stable water isotopes The conclusion drawn from the stable water isotope data is not convincing. It is a priori clear that the source of the frozen water is eventually precipitation water. The almost identical parameters in the delD delO-18 regression found for the ice and for a certain precipitation site (Golling) appears to be somewhat by chance. The result suggests indeed that local kinetic effects are not important, but this finding would not indicate (as claimed by the author) that the ice has preserved or would preserve climate signals associated with precipitation. In any case the isotope depth profile needs to be displayed giving a feeling on the overall variability or any major features.

Authors: The isotope depth profile has been inserted as a part of new Fig. 3. A mixed-component open-system freezing model is addressed in the revised discussion to explain the stable isotope properties of Saarhalle cave ice.

Referee1: p. 1455, l.15-27: When comparing the delD delO-18 regression Golling seems to be chosen simply because it is close and matches with the findings from the ice core. However, Golling lies significantly lower and it is therefore questionable, if the station is really suitable for comparison with the cave ice, since the precipitation infiltrating the cave origins significantly higher up. I strongly suggest here a comparison with more than one source. What about Feuerkogel or Patscherkofel? Also Springwater signals could be considered here (e.g. Scheidleder et al., 2001 (http://www.umweltbundesamt.at/fileadmin/site/publikationen/M108.pdf)?

Authors: Feuerkogel has been used as the reference for the local precipitation and the three nearest springs were also considered in the rewritten discussion. The ice core water isotopes are co-plotted with the local karstwater (3 springs) and Feuerkogel water lines. In addition we would like to remark that dD values were not presented in Humer et al. 1995 for Feuerkogel and the closest station where both d18O and dD were available was Golling. So water line was possible to determine only for Golling and that was the reason why it was used in the earlier version.

Referee1: p. 1456, l.1-20: Discussing the overall mean values of the delO-18, again references are only made for one other source (which is now curiously Feuerkogel and not Golling). Also only the mean values are given, whereas there is no mention of a standard deviation or a span. A table containing major statistical data (mean, standard deviation, max, min) would help to easily compare the ice core and reference data. However, it is quite apparent from Fig. 3, that the isotope composition in the ice core is clearly less variable than for the Golling (or the Feuerkogel) station. Compared to both stations the heavier and lighter values are not found in the ice. This observation of course correlates with the shift in the mean values. Comparing summer and winter values from the reference stations with the ice data indicate a selection of summer precipitation, thus solidifying the assumption of a biased seasonality. Of course an attempt at explaining such a selection should be given. What would be an alternative explanation for the heavier values? What about fractionation during freezing?

Authors: The requested table presenting the basic statistics is done and will be inserted. We have also discussed the potential (expected) fractionation during freezing. A mixed-component open-system freezing model was found to be adequately describe the isotopic peculiarities (enriched composition, lower d-excess values, water line with a slope 8) of the Saarhalle cave ice.

Referee1: p. 1456, l.12-20: Point 1.: I can not follow the authors claim that water evaporates under saturated conditions from the karstic fissures. Point 2: Why should the melting snow run off and not be infiltrated into the cave?

Authors: We have rewritten this discussion. A mixed-component open-system freezing model is addressed in the revised discussion to explain the stable isotope properties of Saarhalle cave ice.

Referee1: p.1457, l.1-14: I can not follow the argumentation of linking the EC signal with drip-water and/or meltwater. What is the difference between drip water and melt water? Water infiltration into the cave is always in the form of drip water. Or is there any evidence, that water infiltrates the cave by any other way? I assume, that the authors mean to distinguish between slow infiltration, where the water is long retained in the stone overburden (later the term karstwater is used) and fast infiltration, where a strong addition of water (through heavy rain or snow melting) reduces the time in the stone. In this case, I find the term melt-water confusing. The term surface water used in the conclusions seems more appropriate. In this context, the study of precipitation and spring water in the Dachstein area by Scheidleder et al., 2001 should be included/referenced as another example of EC in surface water. Is the explanation of contribution from different sources the only one? What about salt-exclusion during freezing (as described by May et al.)? Are there no calcite layers at all in the ice block, or only not in the core? Is there any co-variation with the isotope signal?

Authors: We have left the term 'meltwater' and used 'karstwater' or 'surface wazter'. In addition, the three nearest springs were selected from the dataset of Scheidleder et al. 2001. These are Koppenbrüllerquellen, Meisenbachquelle and Hirschbrunn. Their stable isotope and conductivity data were used in an improved/revised interpretation. Conductivity values of these three springs ranged from 9 μS/cm to 200 μS/cm. The minimum seems to be an outlier as the rest of the values are distributed in the 120 – 200 μS/cm range. This latter range was adopted in the new discussion as the fluctuation range of the "local karstwater". We have found some insoluble particles in the ice. The two most abundant types were a, white or yellowish microplates and aggregates, and b, ochre mud. We think that the 'a' type might be equivalent to the 'white crystals' (cryocalcite) and the 'b' type might be equivalent with 'ochre silt' described by May et al. 2010. The isotope signal does not show covariance, instead a weak anticorrelation with fluctuation ($r= -0.18$ for d18O vs EC, $p=0.01$) with the fluctuation EC.

Referee1: p. 1457, l.15-19: The Eisriesenwelt ice core shows several distinct layers and spots of cryo-calcite, which was not observed in the Mammut cave. This supports the assumption by May et al. that strong salt exclusions during freezing is the reason for the low EC values in the ERW core rather than a change in the water source.

Authors: May et al. differentiated two main sections in their EC profile measured from Eisriesenwelt ice core. The upper section was characterized by very low EC values and the EC peaks were perfectly matched cryocalcites layers. In their lower section EC was characterized by higher values and such covariance cannot be observed. Their assumption that salt exclusions during freezing is the reason for low EC relies and, I think, is valid for the upper section of the ERW ice core. We would like to emphasize the big difference of the EC fluctuation range in the Saarhalle ice core ($\sim$100-200 μS/cm) and the ERW core ($\sim$10-50 μS/cm). We think that this discrepancy indicate some substantial difference between the two cores and if any part of the ERW could be comparable to Saarhalle ice core is the lower section of ERW where the covariance between cryocalcites and EC cannot be observed. In addition, in the Saarhalle ice core we have observed white microplates and aggregates (suspected to be equivalent with 'white crystals' described by May et al.) in samples with any EC values. The correlation coefficient calculated between abundance classes of 'white/ yellowish microplates and aggregates' was -0.12 while for the abundance classes of 'ochre mud' it was 0.7. This also indicate that in the Saarhalle ice core the main trigger of EC is not linked to cryo-calcite however the EC variability is associated with changes of the ion content in the water source.

Referee1: 4 Conculsion The conclusions should be reevaluated following the revisions.

Authors: The 'Conclusions' section is rewritten in line with changes in the discussion.

Referee1: Minor and technical comments p. 1452, l.19-21: What is meant by the

characteristic reflector zone? Explain or reference! Insert here the discussion about linking GPR to calcite layers (= first "main scope").

Authors: Done as suggested.

Fig. 2: Is the Salzburg data really needed?

Authors: Salzburg will be not used in the revised version.

Fig. 3: What resolution have the reference values for Golling: annual or monthly? Why not plotting only the ice core data and including the water lines for the reference data (Golling, Feuerkogel, Springwater) in the same plot?

Authors: This will be Fig.4 in the revised manuscript. We will follow the recommended modifications.

* Include a delO-18 vs depth plot!

Authors: This new figure will be added. The delta vs depth will be included into a new fig. 3.

* Include a table for the statistical data (mean, standard deviation, min-max) of the ice core and any reference stations! distinguish between summer and winter.

Authors: The requested table presenting the basic statistics will be inserted.

Referee1: There are several mistakes in wording and spelling (not all are mentioned below), e.g. exchange electrical conductivity with electrolytic conductivity p. 1451, l.19: . . . of the water forming the Saarhalle. . . p. 1452, l.12: . . . collected in an insulated box. . . p. 1452, l.16: . . . was transferred to the Institute for Nuclear Research HAS for tritium concentration and electrolytic conductivity measurements. p. 1452, l. 19: . . . characteristic reflector zone but no major clay. . . p. 1454, l.16: . . . _ -7cm yr-1 rate (Mais and Pavuza, 2000), this fact not only. . .

Authors: Listed mistakes are corrected.

Interactive comment on The Cryosphere Discuss., 4, 1449, 2010.

Table 1. Basic statistics of the $\delta^{18}O$ and the d-excess data of the ice core compared with the regional atmospheric precipitation (Feuerkogel, ANIP, 2010) and the three nearest karst springs (Scheidleder et al., 2001).

	$\delta^{18}O$ ‰			d-excess			s[a]
	Mean	SD[b]	Min/max	Mean	SD	Min/max	
Full	-10.88	0.70	-12.95/-9.51	9.2	1.5	6.2/12.7	8.13
Low EC	-10.68	0.62	-11.72/-9.84	8.8	0.9	7.6/10.0	8.5
normal EC	-10.90	0.71	-12.95/-9.516	9.2	1.5	6.2/12.7	8.07
Feuerkogel[c]	-12.79	0.74	-14.46/-11.75	13.2	1	10.7/15.2	8.25
summer[c]	-9.92	0.89	-11.65/-8.08	13.3	0.9	11.7/15.4	8.02
winter[c]	-14.05	1.64	-17.23/-10.77	11.4	1.5	9.3/15.1	8.03
Karstsprings	-12.16	1.27	-15.01/-9.41	10.9	0.9	9.4/13	7.85

a: slope of the $\delta^{18}O$ vs δD regression

b: standard deviation

c: amount weighted annual/seasonal mean values

Fig. 1. Table1

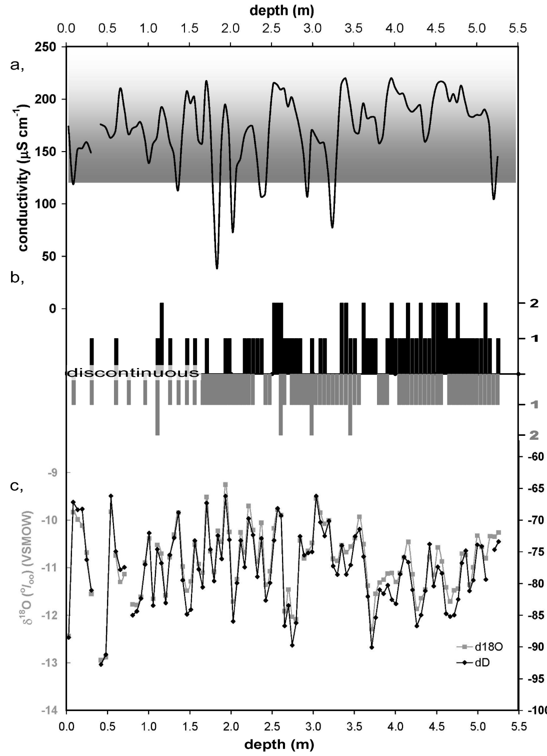

Fig. 2. Figure 3. Multi-plot summarizing the analytical results of the 5.28 m long cave ice core a, Electrolytic conductivity profile of the ice core (black line). (See full caption in the revised manuscript)

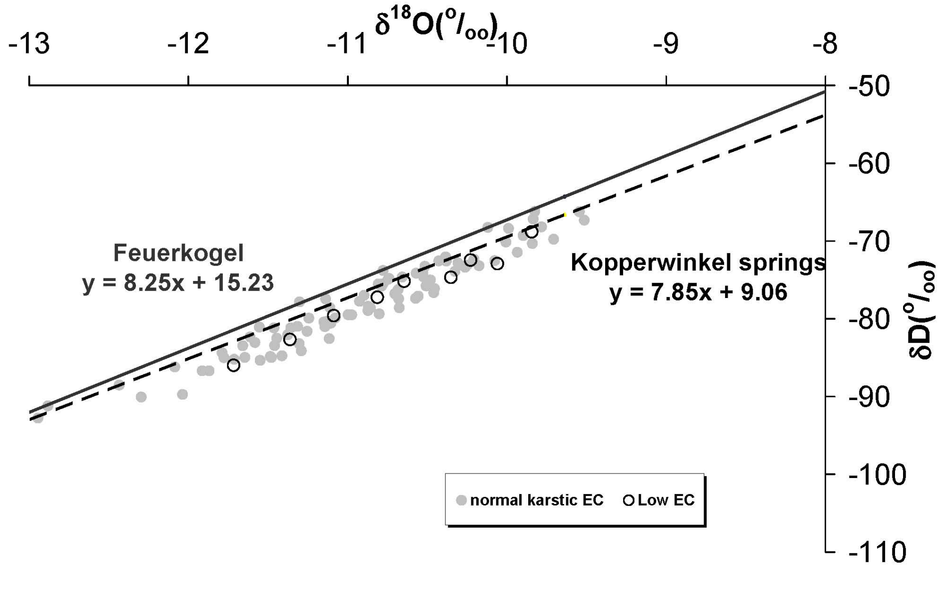

Fig. 3. Figure 4. Stable isotopic characteristics of the Saarhalle ice core and the potential sources. (See full caption in the revised manuscript)