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The Cryosphere Discussions

Interactive comment on "The mass and energy balance of ice within the Eisriesenwelt cave, Austria" *by* F. Obleitner and Ch. Spötl

F. Obleitner and Ch. Spötl

friedrich.obleitner@uibk.ac.at

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Interactive comment on "The mass and energy balance of ice within the Eisriesenwelt cave, Austria" by F. Obleitner and Ch. Spötl S. Suter (Referee)

General Comments - the paper is well structured and scientifically sound Comment: I'm impressed about how accurate you could determine your energy balance components in view of the quite difficult conditions in the cave (dust, humidity) and the small gradients in temperature and humidity involved. Consequently, your term dE/dt, which is calculated from the energy balance if I well understood, also includes the measuring errors from the other energy balance components. You should mention this, although this error might be small in your case Response: thanks for appreciating our effort. You are right that dE/dt, or better each component determining it, is affected by the inherent

uncertainties. This concerns not only inaccuracy due to input data but, as we apply a numerical model, it also includes effects due to e.g. limited accuracy of the employed solution procedure or parameterizations. We performed the sensitivity studies to quantify at least some major effects. In response to your suggestion, please note the added sentence: "These terms also include the inherent uncertainties (input and numerical) which will be quantified by sensitivity studies."

Comment: How could you prevent condensation and rime accretion on the infrared radiometers under the very humid cave conditions? Where they ventilated? Heated? If not, can you quantify the error on the longwave radiation measurement? Response: It was not possible to ventilate or heat the radiation sensors due to limited power supply. We put extra drying substance into the sensors, which certainly helped to prevent problems inside but not at the outer surface of the filter. This certainly is one of the largest uncertainties, which particularly hurts because radiation is the most significant energy-balance component. At the time of the multiple visits to the instruments, the down-facing sensor was hardly affected. We observed drops from time to time hanging at the shield but not at the sensor itself. The up-facing sensor was certainly prone to condensation which was observed several times. We never observed rime, but we were there only once during winter, when rime formation might have been more prominent. We regularly cleaned the sensor and originally thought that we could see a corresponding change in the signal (dry vs. wet). However, we did not see a clear signal. We think that this signal may have been hidden by other disturbances during maintenance (levelling sensors, replacing drying substance, serving other sensors). The manufacturer did not provide any useful information about the magnitude of potential errors or corrections. We are also unaware of a corresponding study in the literature. Thus, no correction was applied and we consider the surface-emitted component (surface temperature) more reliable in this respect. It is also clear that these kinds of problems are not crucial during winter when the air is not at saturation and natural ventilation is more effective. We do not have any information about the effect of dust accretion, which was not directly observed and tentatively may be more pronounced during winter. As to the question regarding our quantification of the error (+/-0.5Wm-2) we referred to an investigation of the accuracy of the same radiometers used at Vatnajökull glacier in Iceland (Obleitner and de Wolde, 1999). This was a quite humid environment, too. Effective field accuracy was estimated by comparison of measurements at known surface temperature (melting glacier). However, there was ongoing natural ventilation and therefore this estimate is probably an optimistic one. Unfortunately, and as documented in Table 2, the according uncertainty remains a crucial one and future cave experiments should try to assess this more reliably.

Comment: Point out more clearly the motivation for and significance of the present paper: should it mainly be a process study, a contribution to climate change detection and monitoring or should it also document the touristic impact on the ice cave? Response: The manuscript is mainly thought as a process study that provides a basis for touching the other issues as well. We revised the introduction correspondingly to point out this more clearly. Specifically: "This paper deals with the processes related to the energy balance and the ice devolepment at the distal end. . ."

Comment: Give topographic heights as m a.s.l. Response: corrected

Comment: Does permafrost occur in the surrounding bedrock? This could have a major influence on the amount and the temporal occurrence of seepage water -> discuss Response: we were interested in this question as well and installed thermistors in the rock, as mentioned in the manuscript. The data came too late to be directly used for the simulations, but their evaluation is currently in progress. Please note the attached figure (below) showing a preliminary analysis of a seasonal cycle of measurements in a horizontally drilled hole at EP, ca. 50 cm above the ice surface (4, 22, 58 and 125 cm depth). Thus referring to your question, we may conclude that overall there is a permafrost environment. But it is discontinuous as the near surface rock layers (<10 cm) experience slightly positive temperatures during summer. This conforms to our observations regarding dripping water and the development of an ice column at EP. The latter is addressed in the manuscript as an important factor for the observed

interannual variability of ice changes. Our current view is that the many vertical shafts in the cave play an important role there, because they are normally closed by ice plugs (related to permafrost), which occasionally open and then effectively provide water to the deeper layers which can refreeze.

Comment: Section 9. Summary: why don't you call this section 'conclusions and perspectives' what it actually is? A short summary is normally given in the abstract. This section 9 is far too long and repeats too many obvious points. Concentrate on the really essential findings of the paper. Response: the revised summary was changed as suggested

Comment: The usefulness of cave ice (thickness) as a climate signal or for climate monitoring sounds a bit doubtful to me. The availability of seepage water at the right time seems to be crucial for the mass balance and by far dominates the air temperature signal in the cave. The influence of the local meteorological/synoptic and (hydro) geological conditions on both seepage water and cave air temperature should be better investigated Response: we basically agree. However, our study did not focus at this topic, thus lacking relevant data (no measurement of seepage water) and the measurement period is certainly too short in this context. At least, however, we could provide some basics indicating future directions. No doubt this requires the involvement of other research directions. Some more specific issues are stated in our summary, too.

Specific Comments

Comment: p. 1741, l. 4: 'feature', use 'reflect' Response: corrected to "show"

Comment: p. 1741, l. 6: 'determined' not 'predetermined' Response: corrected

Comment: p. 1741, l. 14: 'These results' -> what results? Explain Reponse: see sentence below

Comment: p. 1741, l. 15: What reliability do the sensitivity studies prove? Response: "Sensitivity studies prove reliability of the calculated energy balance regarding diverse measurement uncertainties . . ."

Comment: p. 1742, l. 27: I guess you want to say '. . . occurs 700 m behind or after the lower entrance. . .' Response: "Perennial ice only occurs within the first 700 m behind the lower entrance;"

Comment: Section 3. Measurements, did you control the position of the weather station (levelling) to avoid possible tilting of the instruments with time? Response: Yes. The instruments were maintained nine times during the measurement period (June 2007 until October 2009). The basic service comprised photographic documentation, manual observations (stakes, surface conditions, riming, intercomparison measurements with extra instruments), changing batteries, exchanging drying substance (radiometer), control of sensor adjustment, and downloading data. Tilt of the mast was never an issue, because the tripod was put on insulating wood pieces and fixes with ice screws. Notably the ice surface was very stable and smooth compared to a typical glacier environment. The levelling of radiometers was checked and only small corrections were necessary. But this was more due to inevitable disturbances during maintenance of other sensors. Therefore these level adjustments were done at the very end of the procedure.

Comment: Pity, that only 2 ice temperature sensors were installed. If one sensor fails your gradient is gone. . . was the broken sensor replaced? If not, how did you derive the gradients? Response: To monitor ice temperatures we initially installed 3 sensors in the ice plus radiometric surface temperature measurements. Unfortunately, one thermistor died out for unknown reasons right in the beginning of the measurement period (installed 1m below the surface). The sensor could not be recovered (frozen in) thus it could not be replaced without serious disturbance of the remaining devices. Thus our analysis of temperature (gradients) is based on the surface temperature measurements and sensors at 0.5m and 3m (i.e. at about the base of the ice at this point in the EP). This data is documented in Fig. 4, 5 and 6 and mainly served to verify the simulation results. Due to this concept the failure of one sensor was not that critical.

Comment Fig. 6a: how is the absolute scale in m you use here defined? You mentioned that the ice thickness is 3.3 m at the investigation site. This does not correspond to your scale here Reponse: You probably refer to Fig 8a. There, the depth scale does not cover the whole model domain. This is for the sake of better demonstration of the important features that happen in the upper parts of the domain (quasi constant temperatures in the deeper ice parts). For similar reason Fig.8b shows an even smaller part of the domain. Regarding this figure please note that the legend in the abscissa (date) is updated in order to correct for a bug in the visualisation program (Feb was missing). However, this was just a matter of improper labelling and the results were correctly displayed and interpreted already. The comment revealed a typing error, which has been corrected. Measured ice thickness is actually 3.03 m.

Comment: p. 1750, l. 26: what type of 'thermometers' did you use? NTC thermistors, PT100? Response: NTC resistors were used indeed.

Comment: p. 1751, ld. 8: as your paper actually deals with an energy balance over cold ice you could mention: Suter, S., Hoelzle, M. and Ohmura, A. (2004): Energy balance at a cold Alpine firn saddle, Seserjoch, Monte Rosa. International Journal of Climatology 24, 1423-1442. Response: thanks for the hint on this relevant source; we include it now in Section 5.3

Comment: p. 1751, l. 18: what are 'these fluxes'? Explain Response: please note the accordingly changed text: "The annual net balance of the fluxes at the upper and lower boundaries leaves energy to warm and melt the ice, which is corroborated by the observed decrease in ice thickness."

Comment: Fig. 7: mention that 'total energy balance' equals dE/dt Response: changed as suggested

Comment: p. 1752, l. 7: what is 'the atmospheric at the surface'? Explain Response: "forcings" was missing and is corrected.

Comment: p. 1753, l. 5-6: shouldn't Ohata's NR be larger than 0.22 as you speak of a stronger radiation input afterwards? Response: There was some error there (see also review 1). Please note the correspondingly corrected paragraph: "The authors followed a similar approach as Ohata et al. (1994a), thus considering the energy balance of the whole cave system and data for a year with a negative mass balance (−10 cm during 2002/2003). Converting the given data to Wm-2 yields NR+GHF = 1.0, SHF = -0.3, LHF = -0.2Wm-2. We are not aware of documented energy balance data from another ice cave. However, it is remarkable that at least for these three ice caves (Fuji, Monlesi and ERW) the order of magnitude and the sign of the calculated fluxes is remarkably consistent."

Comment p. 1753, l. 20: is it 1.1 or 1.0 W/m2 as in Table 2? Response: thanks for this note, the actual value is 1.0 Wm-2, but this value is no more mentioned in the text.

Comment: Table 2: give the units in the left column Response: changed as suggested

Comment: p. 1756, l. 1 and 5: what should I see in Fig. 3? Explain Response: Fig.3 (upper left) shows that the minimum monthly air temperature is about -1.5°C (March). Thus, if the annual air temperature would increase by 1.5°C negative temperatures could not occur in the cave any more, corresponding to the reasoning of this sensitivity study. This also applies to the maximum temperature.

Comment: p. 1756, l. 6: here you give 2 cm/yr; in table 2 it is only 1 cm/yr. . . Response: thanks for the hint on this typing error, 1 cm/yr is the correct figure.

Comment: Table 2l: indicate the amount of seepage water of 0.05 mm/h in the table too Response: changed as suggested (legend)

Comment: Fig. 9: shouldn't it be: 'The effect on the mass balance is calculated in terms of monthly changes in ice thickness compared to the reference run'? Reponse: This phrase is better and your suggestion is adopted in the figure legend.

Comment: p. 1757, l. 21: why anthropogenic? How? Explain Reponse: As noted we

do not know the reason for this observation (small increase in ice thickness in November) which according to our sensitivity study could be a natural phenomenon. On the other hand, Schöner et al . (2011) noted some disturbances due to cleaning of the cave in late autumn. As long as we do not know more about the actual activities and in view of the small potential effect (increase in ice thickness during November) we prefer to skip the misleading sentences. The paragraph is modified to: "Cave management may also involve changes of local water supply, which is not documented regarding the EP investigation site itself. However, Schöner et al. (2011) indicate that water management may well affect the ice development in outer parts of ERW (cleaning in autumn).

Comment: p. 1759, l.16: better 'The meteorological data reflect the basic. . .' Response: changed as suggested

Comment: p. 1760, l. 19: should be '. . .which progress beyond the ice-rock interface. . .' Response: changed as suggested

Comment: p. 1761, l. 10: point out more clearly: how would the air flow influence the cave ice chemistry? Or what would ice chemistry analysis tell about the airflow? Response: For instance, consider refreezing of seepage water depending on air temperature in the cave and the cold content of the ice. In a dynamic cave the latter both depend on the strength of cold air advection during winter, which contributes to isotopic signals. Similar regards the formation of rime or sublimation processes. The deposited layers may preserve atmospheric signals at the time of their formation. Air flow may also deposit dust or organic material at the ice surface influencing the chemical composition of ice layers . We skipped this sentence.

Interactive comment on The Cryosphere Discuss., 4, 1741, 2010.

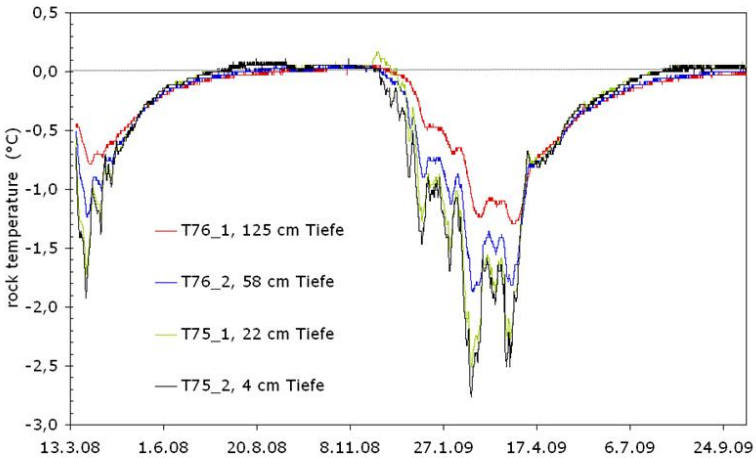

Fig. 1. Evolution of rock temperatures at EP