Dear colleague,

Thank you for this comment.

You find my responses below.

Sincerely yours,

Anatoly Legchenko

The authors present time-lapse 3-D-SNMR imaging of a small polythermal glacier in the French Alps, over the period 2009 – 2012 during which subglacial cavities were drained by pumping each fall, and subsequently re-fill naturally. They suggest that their results show both changes in cavern volume (caused by creep processes) as well as estimates of cavern re-filling rates by natural recharge. The field data and modelling work are of high quality, and represents a useful addition to the paper of Vincent et al (2012), Journal of Glaciology, Vol. 58, No. 211, 2012 doi: 10.3189/2012JoG11J179; further SNMR datasets are presented, and SNMR data interpreted as 'time-lapse' images showing changes in water volumes, which are then corroborated by comparison with pumped water volumes. However, the current manuscript is difficult to follow for readers unfamiliar with the abovementioned 2012 paper – this reviewer found that the 2012 paper gave a much greater insight into the nature of the glacier, the measurements taken, and the problems and issues that arise when interpreting SNMR data for glacial water content. I therefore recommend that the introduction of the submitted manuscript be rewritten, to provide a clearer picture of the previous work, and the additional contribution made here.

We do agree that some remind part would be useful in the paper for allowing it to be read along without some other reading. From the other side, we think that we should not go too far in repeating already published stuff and it is why we reduced this part.

As the reviewer suggests, we will present a short review about this glacier in the introduction.

The specific issues mentioned below concerning the interpretation of the results presented, should also be addressed.

Specific issues a) How can the use of forward modelling solve the non-uniqueness problem with SNMR interpretation (P 2124 last para, and p2126 first para)? Forward modelling in itself cannot reduce the number of potential fits.

Yes of course the reviewer is right. We cannot overcome the equivalence problem using the forward modeling. In our interpretation we use two steps:

1) we do 3-D inversion with regularization that provides quasi-unique solution, but smoothed. As it was presented before (Legchenko et al, 2011) the resolution of the inversion is not sufficient for located water better than +/- 20m. But inside the SNMR loop the sensitivity is varying. Consequently water located within the resolution may produce SNMR signal that vary up to 4 folds. Modeling results show that the smooth inversion overestimate the volume about twice.

For estimating water volume we use the forward modeling carried out so that: 1) experimental data are fitted within experimental error (noise); 2) we select the min number of blocks necessary for that; 3) placing blocks with water at the positions with min and max sensitivity of the loop we obtain the min and max estimated volumes.

So SNMR estimate of the water volume should be understood as: if we assume a compact model composed of the min necessary number of blocks necessary for fitting field data then the volume will be estimates as .....

This approach showed good results at least for Tête Rousse glacier where the cavern is rather compact and apparently our assumption was correct.

b) Authors state that the average water content of the cavern '... is 40% rather than the 100% expected for the bulk cavern,' and explain this lower value represents averaging of liquid water and ice [P2126 last para] . The figure of 40% must depend on the volume over which averaging is conducted, and is therefore arbitrary/not meaningful?

Yes, for quantifying distribution of the water volume it is arbitrary, but for locating cavern it was rather useful. We used these images for guiding drilling program (it was much better to have an uncertainty of +/- 20 m than to investigate with borehole the entire glacier). It was also useful for time-lapse analysis because the average water content obtained with the same inversion procedure provided a good idea about glacier evolution in relative images.

c) Some water content remains locked within temperate ice and cannot be pumped out [p2128 line 20] – however this 'locked-in' water should still contribute to the SNMR signal for the dataset collected after pumping, and should therefore be correctly accounted for by the water budgeting conducted (Tables 1 and 2). It's presence therefore cannot explain the discrepancies between pumped and SNMR estimated water volumes (Table 2).

Yes, if we would compare only SNMR images trapped water rest always the same. But trapped water does not contribute to pumping results. So, the discrepancy is there. We have seen that the major portion of water was not trapped and for this reason we think that our results are in larger part related to the cavern and in smaller part to other water in the glacier.

d) The SNMR technique detects only liquid water, so it cannot distinguish air (i.e. empty cavern) from ice. So, how can we tell that the cavern is larger is 2009-2011 than 2012, rather than simply containing more water [p2129 line 12], as indeed authors state later [p2132 line 16]? Can increased amounts of trapped air after sequential cavern

drainage actually explain the water volume reductions proposed (65% in one year and

73% in two years, p2129, last para), rather than cavern closure by ice deformation?

Yes, it is also possible. However, sonar measurements and radar measurements confirmed that the geometry of the cavern changed since the first pumping.

We will precise this section taking into account this comment.

e) '...significant deformation of the glacier surface became visible only in July 2012' [p2132 line 14]. This comment deserves more explanation. How do we know this, how

much deformation and where was it, in relation to the caverns?

The glacier surface was under observation and small movements were continuously observed. But this sentence was stating that a large crevasse appeared and some ice deformation over the cavern location became visible on the surface.

Monitoring of the glacier surface is the subject of an another paper in preparation.

f) Creep deformation as the mechanism for cavern closure is mentioned [p2133 line

15]. Assuming we can believe that the caverns do reduce in size (see point d) above),

are such volume reductions not more likely to arise from re-freezing processes?

In fact, we do not know exactly the mechanisms of the ice deformation in this glacier. We just mentioned some generally existing mechanisms.

For freezing water in cavern, cavern should be filled with water, but it was empty. Surrounding temperature was about 0°C before (for years) and after drainage, why freezing did not happened before? We discussed this possibility and we do not think that it is the dominating mechanism.