Comments on "Monitoring water accumulation in a glacier using magnetic resonance imaging", by Legchenko *et al.*

I think this could be a nice and informative paper that demonstrates the applicability of a promising geophysical technique in glaciology. I agree with the authors that it's among the first places that I have seen glaciological 3D-NMR imaging – but glaciological NMR papers do exist (e.g., http://geoinfo.amu.edu.pl/sgp/LA/LA21/LA21_057-074.pdf), and this group did publish a multi-disciplinary study of this site, which included some of the SNMR results presented here, together with its theory in an appendix (Vincent *et al.*, 2012, Journal of Glaciology, v58, 211, doi: 10.3189/2012JoG11J179). This leads me to question the value that this paper adds, but I will return to this issue later in the review.

General Comments

While I am not an expert in SNMR techniques, and there are admittedly few glaciological precedents to compare this work with, I would appreciate more information about constraints on the interpretation that has been made. While there is some discussion of the limitations and resolution of the SNMR technique, these do not seem to be acknowledged in later discussions about cavity size and water content, which leads me to the following concerns. These should at least be acknowledged, and preferably explained and quantified, in a resubmission of the paper.

a) On Page 2124, the authors state that "SNMR cannot resolve small targets, and provides only results averaged over a volume larger than the target-volume." However, the cavern does not appear small with respect to the survey loops (see Figure 2) therefore what is the real influence of the cavern size? At what dimension does this condition become a concern? There is also discussion of quantifying uncertainties and sensitivities (Page 2125); these concepts are then not developed in the paper.

b) I appreciate that the water content from the SNMR is a volume-averaged quantity, but at what fractional water content is the 'edge' of the cavern defined? There is some use of the term "3D-SNMR estimates of the water volume" but elsewhere, the reader is led to believe that the geometry imaged in the SNMR survey *is* the geometry of the cavern. It must be explicitly stated that (e.g.), the SNMR-implied volume is the maximum possible extent of the real cavern. Indeed, SNMR over-estimated the water content by 3100m^3 (Page 2127, also Figure 4); how much of this is an artefact of the resolution of the technique, vs. the glaciological processes (e.g., hydraulically connected channels, interstitial water) that are quoted?

c) The follow-on from this is: if the quantity measured is a volume average, then there must be some amount of lateral smearing taking place and the true cavern must be smaller than the size that is implied in the data. How much smaller is it? The error +/- 20 m is stipulated (Page 2126), but I don't see how the size of the cavern could be larger than the non-zero cell volume implied by the SNMR. Equally, the water content implied is given error bounds of

+/- 20%... Is this total water content, or the water content for any one cell? If it's the latter, what does this imply when the water content of a cell is 5%, as was the maximum measured in 2012 (Figure 11)?

d) Can you also be sure that the cavern is entirely water-filled during the SNMR survey?

e) You also mention that the temperate glacier may contain 2% water content, so how do you resolve this background from the cavern wall? Essentially, what water content marks the transition from wet ice into an open cavern? – many of the cells in the 2012 dataset, for example, could be interpreted as just showing interstitial water.

I know that sonar and radar measurements exist for Tête Rousse, and I find it surprising that these have not been incorporated into this work (e.g., as this group did in their Journal of Glaciology paper). It seems that it would be possible to reduce uncertainties in the volume averaging if certain constraints (e.g., the depth to the cavern roof from GPR/sonar? The cavern thickness from sonar?) were applied.

This brings me on to my over-riding concern with the paper. All this said, the data do convince me that SNMR detects an evolving cavern within Tête Rousse glacier and I think that this is a neat time-lapse experiment; furthermore, it is glaciological significant as an extension to 2012 of the work published in Vincent *et al.* (2012). My major concern is, though, without evidence from those other data sources, could these results have been interpreted from SNMR alone, with all of its apparent ambiguities?

If not, to say that results in this paper are derived from SNMR without acknowledging the other data sources, is somewhat misleading. There is no significant acknowledgment that much of the foundation work in this research was established in the Vincent *et al.* (2012) publication, and a reader may be led to believe that these observations were derived from SNMR alone. This is not by any means to suggest that SNMR is a flawed technique, but that it suffers from uncertainties and limitations just like any other geophysical method. Therefore, the best way to use it is in conjunction with other techniques – and the paper should acknowledge this too.

<u>Specific Comments</u>

Page 2128, Line 4: How did you estimate the temperate ice water volume as 2%?

Page 2129, Line 12: You say that the larger cavern is associated with better correlation given a complex geometry thereafter; is it not possible that the water in the larger cavern represents a greater proportion of a volume average, and can therefore be measured more accurately?

Page 2131, Line 11: "SNMR is cost-effective and reliable", but in comparison to what? Do you expect that you could have placed initial constraints on (e.g.) temperate ice water content without other techniques? I think it would be better to suggest that SNMR is highly complementary to established glaciological techniques; clearly the best results will come where multiple methods are combined (i.e., in Vincent et al., 2012).

Page 2132, Line 2: Define 'large'. Is it not possible that water could flow between the two reservoirs through a conduit that is not resolvable with SNMR (i.e., 'small')?

Page 2132, Line 22: "Despite of" should just be "Despite".

Page 2133, First paragraph: This reads like a new concept in this paper, and is therefore not suited to conclusions. Better-placed in the discussion.

Page 2133, Line 10: Unless I'm mistaken, there were only two storage areas observed in the 2012 acquisition (Figure 11). Given that you have three SNMR snapshots, it would seem that having one cavern is the 'norm', and imaging two is an anomaly.

Page 2133, Line 14: You did not explicitly invoke creep closure as 'the' method of reducing the cavity volume in the discussion, and nor was the viability of this thoroughly discussed. My gut feeling is that it seems like a large volume to close up, but I'm not a modeller… nonetheless, it seems like some basic quantification of this would be required to back up the SNMR observations.

Figure 2: Is it significant that certain areas that are marked as cavity abut against the acquisition grid? (i.e., the north and south boundaries?) Does this not suggest that there is an inherent acquisition effect in play, in the estimation of cavern volume?

Figures 5,6, and 11: What are the grey meshes around the cavern volume? As impressive as they appear, these figures do not serve any useful comparative purpose because they are in different orientations; they do give some indication of the shape of the cavern, but not as a means of comparing its changing volume. To be useful to this end, they must be viewed from the same angle and preferably with the same colour bar. Even then, I question their value and it seems to me that a simple plan-view map and a cross-section would serve the desired purpose.